EVALUATION OF METHODS FOR RECOMMENDING INSTREAM FLOWS TO SUPPORT SPAWNING BY SALMON

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By

CHRISTOPHER C. ESTES

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

WASHINGTON STATE UNIVERSITY
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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of CHRISTOPHER C. ESTES find it satisfactory and recommend that it be accepted.

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INTRODUCTION

This thesis evaluates the feasibility of applying four methods to collect and analyze instream flow* data for estimating the availability of spawning habitat for pink (*Oncorhynchus gorbuscha*) and chinook (*O. tshawytscha*) salmon as a function of flow variation in Willow Creek (Figure 1). These methods are: the Instream Flow Incremental Methodology (IFIM)** approach of the U.S. Fish and Wildlife Service (USFWS) Instream Flow Group (IFG 1979), the Montana (Tennant 1975) percentage of average annual flow, and Orsborn (1982) basin, flow and channel characteristics/spawning flows and bankfull characteristics/spawning area methods. This thesis is an extension of the Susitna River Basin studies (Estes and Lehner-Welch 1980; Estes et al. 1981) undertaken by the Alaska Department of Fish and Game (ADF&G).

Funding for this study was provided by the U.S. Department of Agriculture Soil Conservation Service through the Interagency Cooperative Susitna River Basin Study, the ADF&G, a Title III grant from the U.S. Water Resources Council administered by the Division of Land and Water Management of the Alaska Department of Natural Resources, the U. S. Geological Survey (USGS), and Washington State University.

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*An instream flow is the quantity of flow occurring within a natural stream channel at a specified location during a given period of time.

**The IFIM "can be thought of as a collection of computer models and analytical procedures designed to predict changes in fish habitat due to increments of flow change" (Bovee 1982).

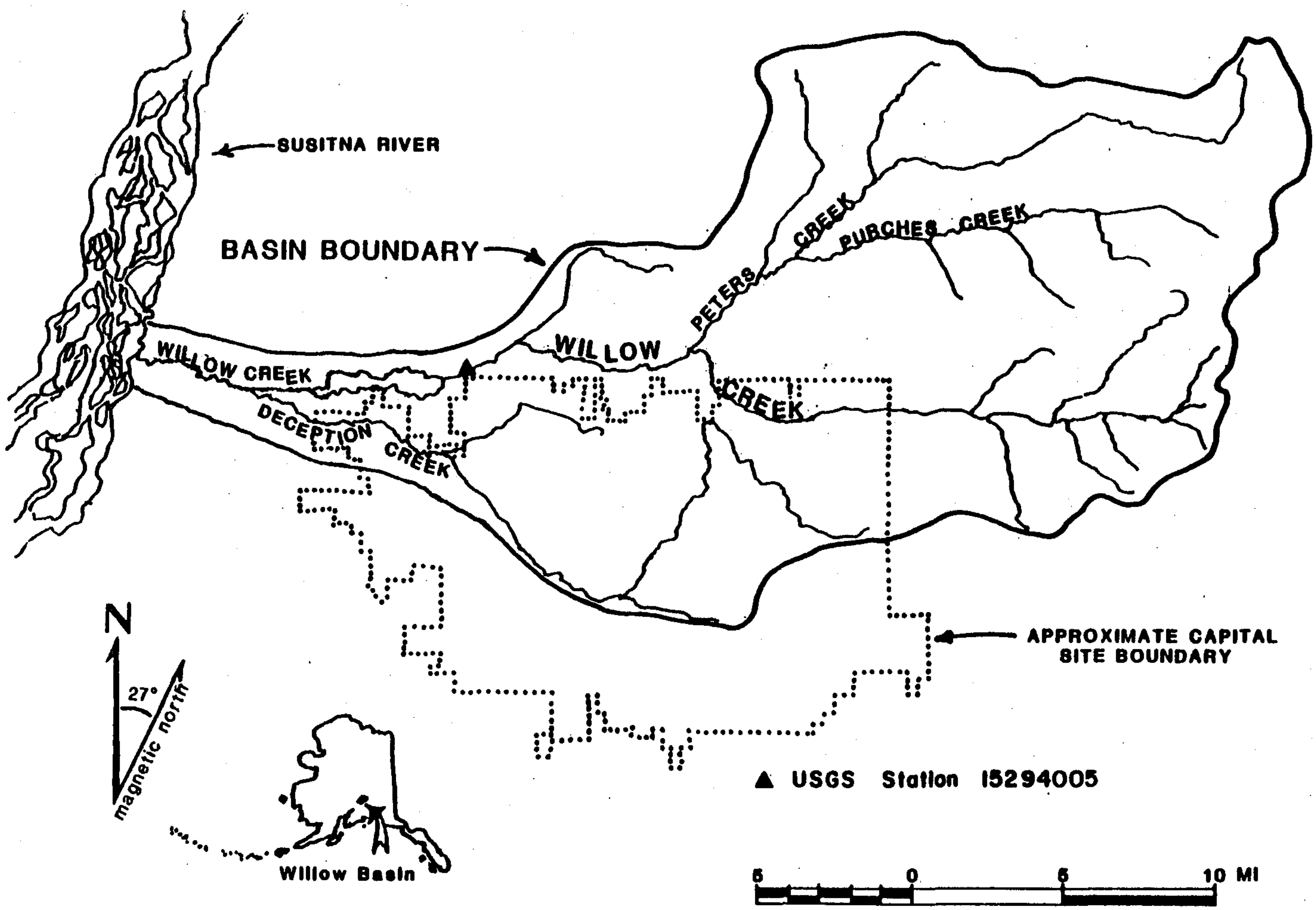

Figure 1. Study area.

The objectives of this thesis and general descriptions of the four instream flow evaluation techniques are summarized in this chapter. The next chapter provides a historical overview of instream flow evaluations. Following it, is a chapter describing the study area, fishery resources and the four instream analyses. A chapter comparing the results of the four analyses follows the individual analyses. The final chapter contains conclusions and recommendations.

Objectives

Four objectives were established for this report:

1. Provide a basic description of four instream flow methods representing a variety of data, analysis, and resource requirements;

2. Estimate spawning habitat area and/or flows with the four methods;

3. Define limitations of this study and recommendations for future studies; and

4. Develop suggestions for selecting these methods.

Background

Instream flow evaluations of fish habitat define the availability (area) or quality of a stream for supporting spawning, incubation, rearing, and passage of fish as a function of flow variation. Instream flow analyses are based on the theory that changes in riverine habitat conditions can be estimated from a field, or synthetic data base. Collectively, instream flow methods are based on three principal components:

1. Physical Projections - the collection and assessment of geomorphic and/or hydraulic data to forecast or summarize a range of hydraulic and related conditions (e.g., channel shape, water depth and velocity, channel width, wetted perimeter, substrate composition, cover, and upwelling) as a function of flow;

2. Fish Habitat Criteria Analysis - the determination of the behavioral responses of fish to channel, geomorphic or flow related variables (e.g., channel shape, water depth and velocity, substrate composition, and upwelling); and

3. Spawning Habitat Projections - the combination of the first two components to project the availability

(area) or quality of habitat for salmon spawning within study sites as a function of flow.

Accordingly, these techniques are intended for use in those situations where the flow regime and channel structure are the major factors influencing riverine habitat conditions. Furthermore, the physical and biological aspects of field conditions must be compatible with the underlying theories and assumptions of the techniques applied. Water chemistry, temperature, light, and other variables known to influence habitat quality (Krueger 1981; Hale 1981) are assumed not to change significantly in the analyses presented in this thesis. If it were determined that these variables would vary significantly with flow, then approaches supplemental to those discussed in this thesis would have to be considered.

Instream flow methods are commonly grouped as "office" or "field/office" methods (Wesche and Rechard 1980). These classifications are based on the level of field effort required by the methodology as opposed to whether field data are actually required. Often the level of field effort will be determined by the requirements of the methodology, existing data bases, and the availability of resources. Most methods, regardless of whether they are classified as office or field, were originally derived from extensive data bases and analyses.

Although some methods may not require field data, Wesche and Rechard (1980) state that courtroom testimony based upon observations and measurements at a site should have more credibility than testimony based on office evaluations alone.

Four instream flow evaluation techniques (one field and three office), requiring different levels of effort, were selected for this evaluation. Results of these four methods are evaluated individually and collectively.

The first method, the Physical Habitat Simulation (PHABSIM) modelling approach of the IFIM (IFG 1979; Bovee 1982), is a collection of computer programs which are combined to translate flow variations into the availability of physical habitat (weighted usable area). PHABSIM models require extensive hydraulic data collection and analyses to simulate available physical (hydraulic) conditions (a physical model). Fish habitat criteria are required to develop fish utilization criteria files. The fish habitat criteria files are used to determine the percentage of total wetted surface area at a given flow which provides habitat for spawning based on physical characteristics simulated by the physical model. The resulting product is designated as weighted usable area (WUA). WUA is an index of the capacity of a site to support the species and life stage being considered. It is expressed as square (ft^2) or percentage (%) of wetted surface habitat area estimated to be available per 1000 linear feet of stream reach at a given flow. It is <u>not</u> a measure of the number of fish at a site. PHABSIM processes are summarized in Figure 2.

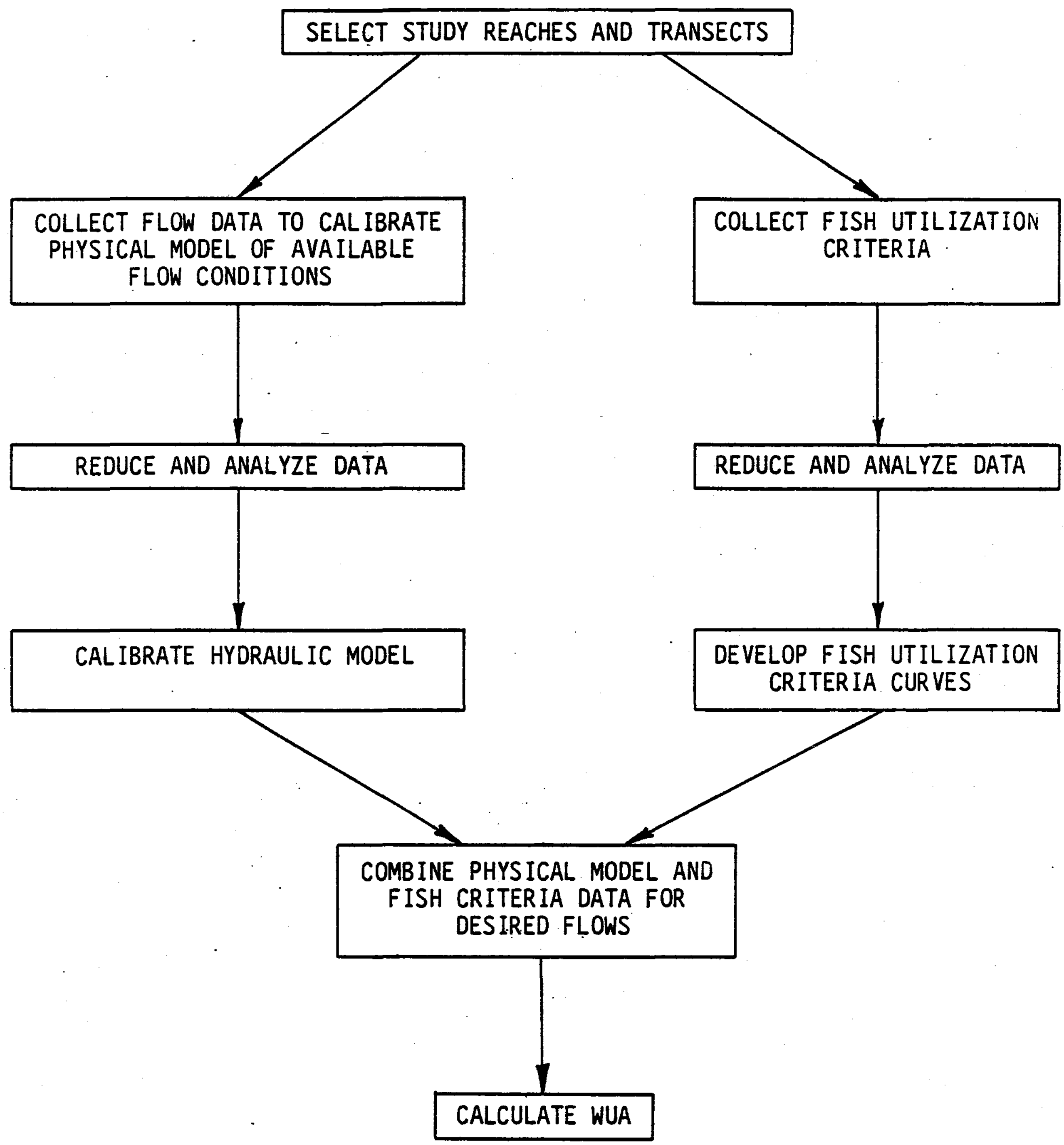

Figure 2. Summary of Instream Flow Incremental Methodology Processes.

The second method, the "Montana Method" (Tennant 1972, 1975, 1976 a,b), requires that an average annual flow (QAA) be calculated from an existing or synthesized data base and that the study site be inspected periodically. Percentages of the QAA, established by Tennant, are used as a basis for recommending a flow regime to support fish populations.

The third method, developed by Orsborn (1982), is based on estimating the discharge at which maximum spawning area (QMSA) occurs as a function of velocity and depth criteria as determined from existing information on basin and streamflow characteristics.

The fourth method, also by Orsborn (1982), provides for the estimation of maximum spawning area (MSA) as a function of bankfull discharge and requires one field trip to obtain measurements of channel geometry.

The next chapter is a historical overview of instream flow evaluations.

EVOLUTION OF INSTREAM FLOW CONCEPTS

This chapter summarizes instream flow concepts, and the history of the development of instream flow techniques.

Instream flows represent the discharges that occur in natural channels. These flows are interrelated with the physical, chemical, and biological components of aquatic, riparian, and terrestrial ecosystems. For example, seasonal instream flows are essential determinants of channel morphology, riparian and aquatic flora and fauna, water quality, estuarine inflow, and streamload transport (Stalnaker and Arnette 1976; Orsborn and Deane 1976; Orsborn and Watts 1980; Hynes 1970). As a result, maintenance of natural seasonal instream flow patterns is essential for the protection of these valued ecosystems.

The complexity of streamflow interactions and effects is heightened by the dynamic nature of natural flows (Linder 1976; Fraser 1975). Under natural conditions, instream flows are continually fluctuating. Seasonal high flows move bedloads, flush sediments, and maintain channel morphology (Linder 1976). Flows during average and low-flow conditions establish base levels of biological productivity (Hynes 1970; Elser 1972; Tennant 1975). The organisms that inhabit or utilize lotic and riparian environments are characterized by physiological, physical, and behavioral traits which adapt them to these dynamic systems (Hynes 1970; Fraser 1972, 1975; Reiser and Bjornn 1979). Instream flow variations (acute and/or chronic) induced by human activities may exceed the ability of organisms to adjust, and thus lead to their reduction or elimination (Giger 1973; Fraser 1975; Stalnaker and Arnette 1976; Reiser and Bjornn 1979; Reiser and White 1981; Becker et al. 1982).

A variety of beneficial human uses can be derived from instream flows and the associated aquatic, riparian, and terrestrial flora and fauna. Uses of instream flow-related environments include fishing, navigation, hydroelectric generation, hunting, boating, swimming, aesthetic enjoyment, and scientific and educational study. Instream flows required for population growth, conveyance for mineral and fuel resource development, industrialization, hydroelectric projects or similar activities can compete with instream flows required for navigation, recreation, and aquatic, riparian and terrestrial organisms as illustrated in Figure 3. Therefore, the influence of varying seasonal flow regimes on essential flow-dependent biotic and abiotic values, and other beneficial human uses, must be evaluated when developing instream flow recommendations.

During the past 15 years, an assortment of methods have been developed and applied for quantifying the relationship of flow to fish habitat suitability for various life functions (passage, spawning, incubation and rearing) and to other instream flow uses. The majority of these methods are described in Chambers et al. (1955), Rantz (1964), Ziemer (1973), Hunter (1973), Collings (1974), Platts (1974), Fraser (1975), White (1975), Orsborn and Deane (1976), Stalnaker and Arnette (1976), Ott and Tarbox (1977), Swanston et al. (1977), Cuplin et al. (1979), Wesche and Rechard (1980), Newcombe (1981), Orsborn (1982), Baldridge

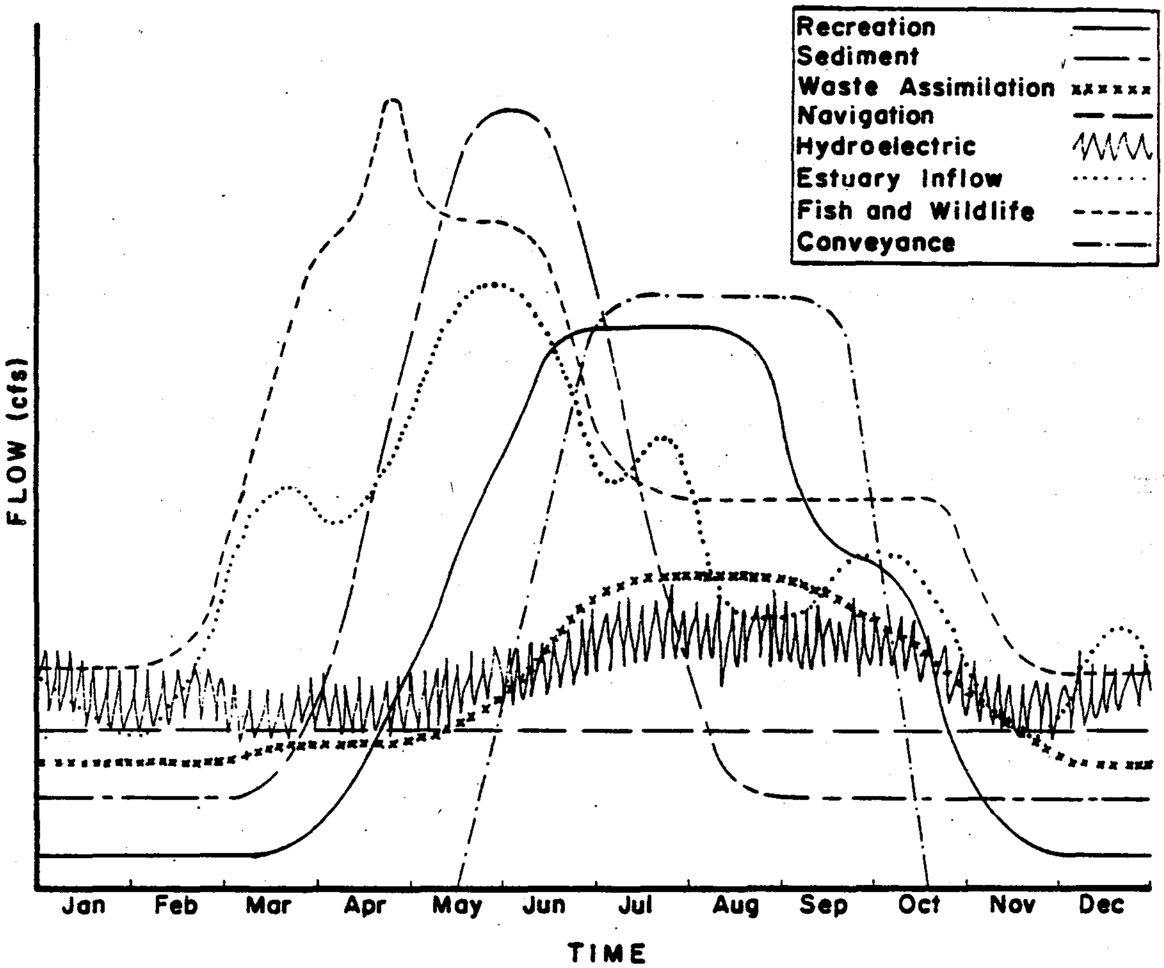

Figure 3. Hypothetical array of instream flow requirements for several uses (adapted from Wassenberg et al. 1979).

and Amos (1982); Bovee (1982), ADF&G (1983), and Estes and Vincent-Lang (1984).

Workshops and symposia have been held and a federal agency was formed to track the evolution and application of these methodologies. The first two principal workshops were held in September 1975 in Logan, Utah (Stalnaker and Arnette 1976) and in 1976 in Boise, Idaho (Orsborn and Allman 1976). The former was sponsored by the USFWS to evaluate a draft publication which compiled methodologies practiced by agencies, institutions and individuals. The editors of the 1975 proceedings indicate that "some of the sections are relatively complete or provide the basis for additional development"; whereas other sections "do not describe all appropriate or available methodologies, but emphasize fundamental concepts or particular approaches." The 1976 workshop was jointly sponsored by the Western Division of the American Fisheries Society and the Power* Division of the American Society of Civil Engineers. It was held to provide a forum for resource specialists from throughout the nation to share their approaches to problems associated with the technical, legal and social aspects of quantifying and reserving instream flows for fish and wildlife (Orsborn and Allman 1976).

Following the Boise conference, the USFWS established the Instream Flow Group (IFG) in Ft. Collins, Colorado in July 1976. The IFG (1979) was created to:

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*Presently called the Energy Division.

1. develop improved methods for assessing and predicting instream flow requirements for fish, wildlife and other aquatic organisms, recreation and aesthetics;

2. develop improved guidelines for implementing instream flow recommendations; and

3. establish an effective communication network for disseminating instream flow information.

The IFG has become the focus of instream flow related information dissemination over the past 8 years. It has developed the Instream Flow Incremental Methodology (IFIM), which is an overall systematic approach for interactively defining instream flow requirements based on area of habitat suitable for fish and wildlife as a function of flow. Central to the IFIM is the Physical Habitat Simulation (PHABSIM) system, a collection of computer models used to predict the availability of hydraulic and related conditions which are suitable for fish spawning, incubation, rearing, and passage as a function of flow variations (Trihey 1979; Bovee 1982).

In 1978, a workshop was sponsored by the IFG in Ft. Collins to evaluate the progress made following the 1975 and 1976 workshops (Smith 1979). Resource specialists from throughout the nation, familiar with various instream flow techniques, participated in the conference. A critique of the activities of the IFG was provided by the participants.

It was stressed that the IFIM was being misrepresented as a simplistic "cookbook" technique and the sole approach for solving instream flow problems. It was recommended that efforts should be made to inform potential users otherwise. Participants suggested that reference to other evaluation techniques should be made by the IFG and guidelines developed for selecting the IFIM or other approaches. Suggestions for remedying some of these shortcomings are included in the proceedings (Smith 1979).

As a result of the 1978 workshop and the interests of researchers, studies have been conducted to compare differences between instream flow techniques by Prewitt and Carlson (1977), Glover (1980), Glover and Ford (1983), Nelson (1980), Orth and Maughan (1981), and Annear and Conder (1983a,b). Wesche and Rechard (1980) authored a report which identifies a process for selecting an instream flow method. The publication includes a brief description of principal instream flow methodologies, basic resource requirements, and recommendations and limitations for their application. It does not, however, provide a complete basis for comparing the spectrum of advantages and/or disadvantages of selecting one approach over another, or fully explain the significance of varying results derived by each method. Bovee (1982) describes the IFIM as a universal approach for defining instream flow requirements.

The publications and studies summarized above are steps in the right direction and should be integrated, expanded, and continually updated. The American Fisheries Society (Peters 1982) recognizes the need for these activities:

> "Much of the present confusion, misunderstanding, and operational inefficiency with respect to present instream flow methods is caused by the lack of a single, recognized reference containing available, accurate descriptions and evaluations of instream flow methodologies for aquatic resources and guidelines for selecting the most appropriate method for a given situation."

Accordingly, this thesis contributes to the efforts of researchers to develop an overall guide to, and critique of, instream flow methods.

The next chapter describes the general characteristics of the Willow Creek study area and the four instream flow analyses.

INSTREAM FLOW EVALUATIONS

This chapter is divided into five sections. The first section provides a description of the general study area, fishery resources and previous studies from which this thesis evolved. The next four sections represent the four instream flow techniques evaluated for the study area, and are each further subdivided into parts containing methods, results, and a discussion.

Study Area

Willow Creek is 70 miles by road to the north of Anchorage, the major population center of Alaska. It is 30 miles in length and located within the 166-square mile Willow Creek drainage (Figure 1) in the southwestern foothills of the Talkeetna Mountains. Elevations in this area range from approximately 5,500 feet mean sea level (MSL) in the upper portion of the watershed to 100 feet MSL at the confluence of Willow Creek with the Susitna River.

Approximately 25 percent of the study area is part of a 100-square mile site selected by Alaskan voters as the location for a new state capital. The remainder of the study area adjoins Willow Creek both upstream and downstream of its confluence with Deception Creek. The portion of the study area that is contained within the proposed Capital site is owned almost entirely by the State of Alaska and is virtually undeveloped. Lands adjacent to Willow Creek, however, are in private or

Borough ownership and have been developed to a limited extend.

In recent years, the Willow Creek drainage has become a focal point for increasing recreational activities (e.g., fishing, hunting, boating, hiking, cross-country skiing, and snowmobiling) primarily because of the aesthetic qualities of the area and its proximity to Anchorage. The high productivity and variety of species make it one of the most important sport fisheries in the lower Susitna River basin (Mills 1981). Willow Creek also serves as an access corridor to other fishing and hunting areas within the Susitna River drainage and is used extensively by boaters for this purpose.

This increased recreational use, along with speculation on land in the proximity of the capital site, have led to tremendous increases in the rate of development, especially of recreational lots in the Willow Creek area. It is therefore essential that land-use activities associated with this development are planned and implemented with minimal degradation to the fish and wildlife resources.

Fishery Resources*

Four of the five species of Pacific salmon (chinook, pink, coho, and chum, *O. keta*) are known to utilize Willow Creek (Figure 26). In

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*Additional Willow Creek fishery data are presented in the ADF&G publication: *New capital city environmental assessment program - phase I* (Watsjold and Engel 1978).

addition, adult sockeye salmon (_O. nerka_) are known to mill at the mouth of Willow Creek. Resident fish species include Dolly Varden (_Salvelinus malma_), rainbow trout (_Salmo gairdneri_), Arctic grayling (_Thymallus arcticus_) and burbot (_Lota lota_). Timing of life phase activities of these species in Willow Creek is illustrated in Figures 4 and 5.

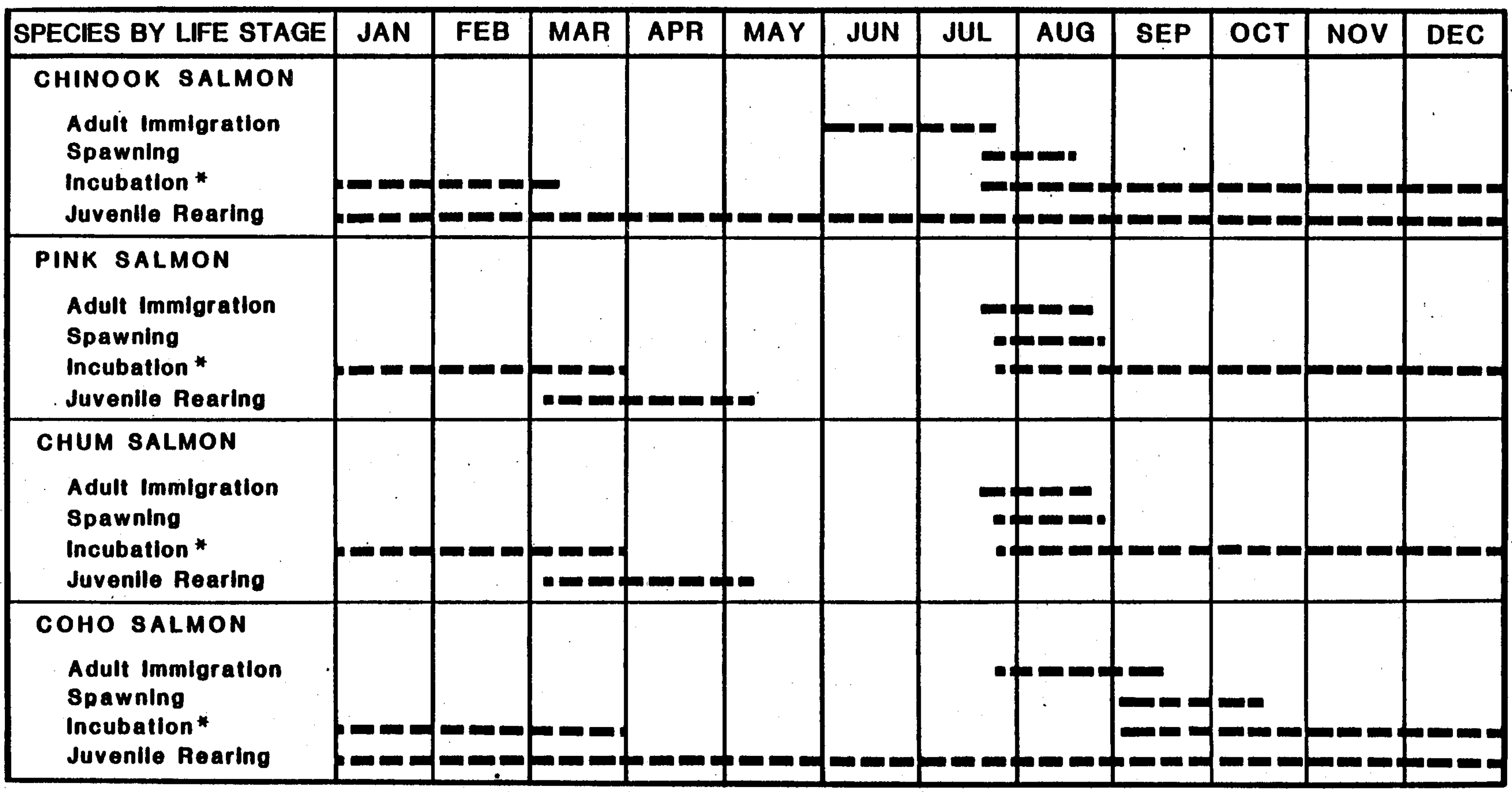
Pink salmon are the most abundant salmon found in Willow Creek, with the largest runs occurring during even years. In 1978 and 1980, Willow Creek had the highest pink salmon sport fishing harvest (19,000 and 24,000, respectively) in Alaska (Mills 1980; 1984). With the opening of a limited chinook sport fishery in 1979 (chinook fishing had been prohibited since 1972), Willow Creek now provides one of the four roadside fisheries for this species in the Susitna Basin.

Spawning for these two species in Willow Creek occurs during mid-July through August (Figure 4). Accordingly, the relationship of July and August flows to the spawning phase of these two important species was the focus of this investigation. Resources were not available to study other species and life phases.

General Life History

Chinook and pink salmon are anadromous. That is, they spawn in freshwater and spend a portion of their life cycle in the ocean until they mature and return to their natal stream to spawn and die. Timing of the upstream migration varies by geographic location, species, and

SPECIES PERIODICITY CHART FOR WILLOW CREEK



*Includes period from egg deposition to fry emergence.

Figure 4. Anadromous fish species periodicity chart.

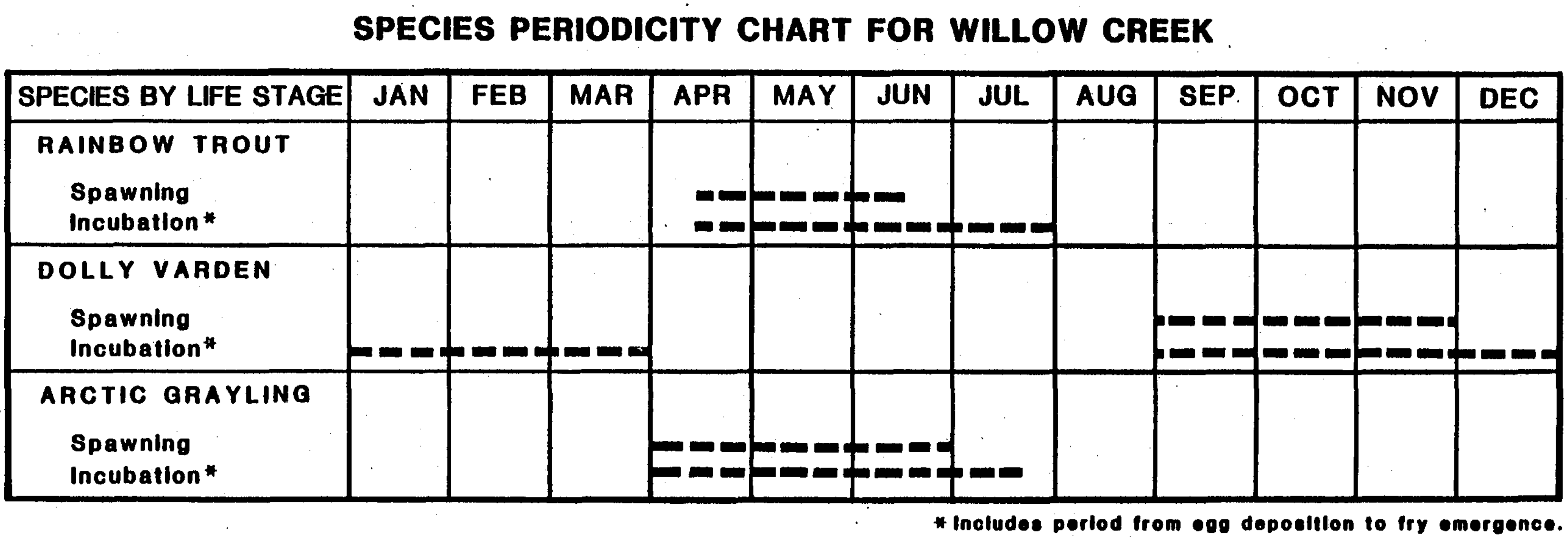


Figure 5. Resident fish species (burbot data unavailable) periodicity chart.

stock (Hart 1973; Scott and Crossman 1973; Morrow 1980).

Chinook and pink salmon in Willow Creek are considered Susitna River stocks. Adult chinook salmon begin to enter the Susitna River in late May (Morrow 1980) with the peak of their run occurring in July. The migration of adult pink salmon into the Susitna River begins and peaks in July (Estes et al. 1983b).

The majority of spawning by chinook salmon in Willow Creek occurs between mid-July and mid-August. Spawning by pink salmon occurs from late-July through late-August. Both species usually die within a week or more after spawning.

The incubation life phase (including emergence) for chinook and pink salmon lasts approximately thirty weeks. The actual length of incubation is temperature dependent and can vary. Chinook alevins remain in the gravel three weeks after hatching, then work their way up through the gravel until they become free swimming. Pink salmon alevins remain in the gravel several weeks longer than do chinook salmon.

Chinook salmon fry rear in the freshwater one to two years prior to outmigrating to the sea. Pink salmon fry begin their outmigration to the sea almost immediately upon emerging from the gravel.

Chinook salmon spend three to five years at sea and pink salmon one year, prior to returning to their natal habitat in Willow Creek to spawn and die.

Prior Studies

Studies of Willow Creek in 1978 by the ADF&G (Watsjold and Engel 1978) provided preliminary information on fish species composition, areas of fish spawning and rearing, aquatic habitat characteristics, and recreational angling. They did not, however, address instream flow requirements of the fishery resources in this system.*

The quantity and quality of chinook and pink salmon spawning habitat are dependent upon flow related** factors such as velocity, depth, upwelling, cover, and substrate composition (Chambers et al. 1955; Westgate 1958; McNeil 1964; McNeil and Ahnell 1964; Rantz 1964; Fraser 1972, 1975; Hunter 1973; Krueger 1981; Swift 1966). The response of these variables to naturally occurring changes in streamflow cannot be evaluated cost-effectively by monitoring a natural system on a continual basis. Therefore, four methods are compared in this chapter for estimating the effects of unobserved seasonal streamflow patterns on spawning habitat availability in Willow Creek.

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*Further discussion of the importance of instream flows to fish and wildlife resources is presented in Estes and Lehner-Welch (1980)and ADF&G (1980).

**Water quality conditions which vary with flow are not evaluated in this report.

Instream Flow Incremental Methodology

The PHABSIM system of the IFIM is comprised of three components. These include a physical model, fish habitat criteria, and spawning habitat projections (Figure 2):

1. Physical Modelling - the development and use of hydraulic availability models to forecast a range of available physical conditions (i.e., depth, velocity, substrate composition; presence of upwelling, etc.) as a function of flow variation;

2. Fish Habitat Criteria Analysis - the determination of the behavioral responses of fish to discharge related variables (i.e., depth velocity, substrata, and upwelling) and development of weighted behavioral response criteria curves (e.g., utilization curves); and

3. Spawning Habitat Projections - the combination of the first two components to project the weighted usable area (WUA) of spawning habitat for salmon within study sites as a function of flow.

Methods*

Analytical approaches, and methods for their application to this study follow.

Site Selection

Analytical Approach

Two basic approaches exist for IFIM study site selection: the "critical" and "representative" reach concepts (Bovee and Milhous 1978; Trihey 1979; Bovee 1982). Application of the critical reach concept requires knowledge of the hydrology, water chemistry, and channel geometry of a stream in addition to rather extensive knowledge of fish distribution, relative abundance, and species-specific life history requirements. The representative reach concept is most appropriate when only limited biological data and life history requirements are available, or critical habitat conditions cannot be identified with any degree of certainty.

Using the critical reach concept, a study reach is selected because some physical characteristic of the aquatic habitat is of critical

*The Methods part of this section of the chapter is subdivided into the site selection process and the above three IFIM components.

importance to the fish. In essence, a recognizable physical characteristic of the watershed hydrology or instream hydraulics in a reach is known to control species distribution or relative abundance within the study area, thus causing the reach to be designated as "critical".

The representative reach concept reflects recognition of the importance of physical habitat variables throughout the entire stream in sustaining fish populations. Thus, under the representative reach approach, study reaches are selected for the purpose of quantifying relationships between streamflow and physical habitat conditions at several locations that collectively exemplify the general habitat characteristics of the entire river segment inhabited by the species of interest. Adaptations of these two site selection concepts were applied to this study.

Application of Analytical Approach

A number of factors were considered in choosing reaches including: presence of spawning activity; accessibility; permission from landowners; physical difficulties that could be encountered when surveying and/or obtaining acceptable flow measurements (based on the hydraulic characteristics and physical setting of the site); the proximity of USGS gaging stations; and the availability of personnel, equipment, and time. As a result, reaches which were selected during this study do not exactly match the definitions (Bovee and Milhous 1978; Trihey 1979; Bovee 1982) for "critical" or "representative" reaches. Thus, they should <u>not</u> be used to represent other reaches within Willow Creek without evaluating whether the comparison is valid. Transects were selected within each reach according to the procedures outlined in Bovee and Milhous (1978).

Three reaches in Willow Creek (Figure 6) were selected for the collection of water quantity, and supporting biological data (Estes et al. 1981). A description of each study reach follows:

1. The lower Willow Creek reach was located downstream and upstream of the Parks Highway Bridge. Six transects were established within this reach which was channelized in 1963 to permit construction of the Parks Highway Bridge (Figures 7, 8*). Major pink salmon spawning areas are located throughout this reach.

2. The middle reach was located 3.5 road miles upstream from the junction of the Parks Highway and Hatcher Pass Road Bridge. Four transects were established

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*A representative transect for each reach is included in the body of the thesis. All transects are presented in Appendix A.

WILLOW CREEK
INSTREAM FLOW INCREMENTAL METHODOLOGY STUDY REACHES

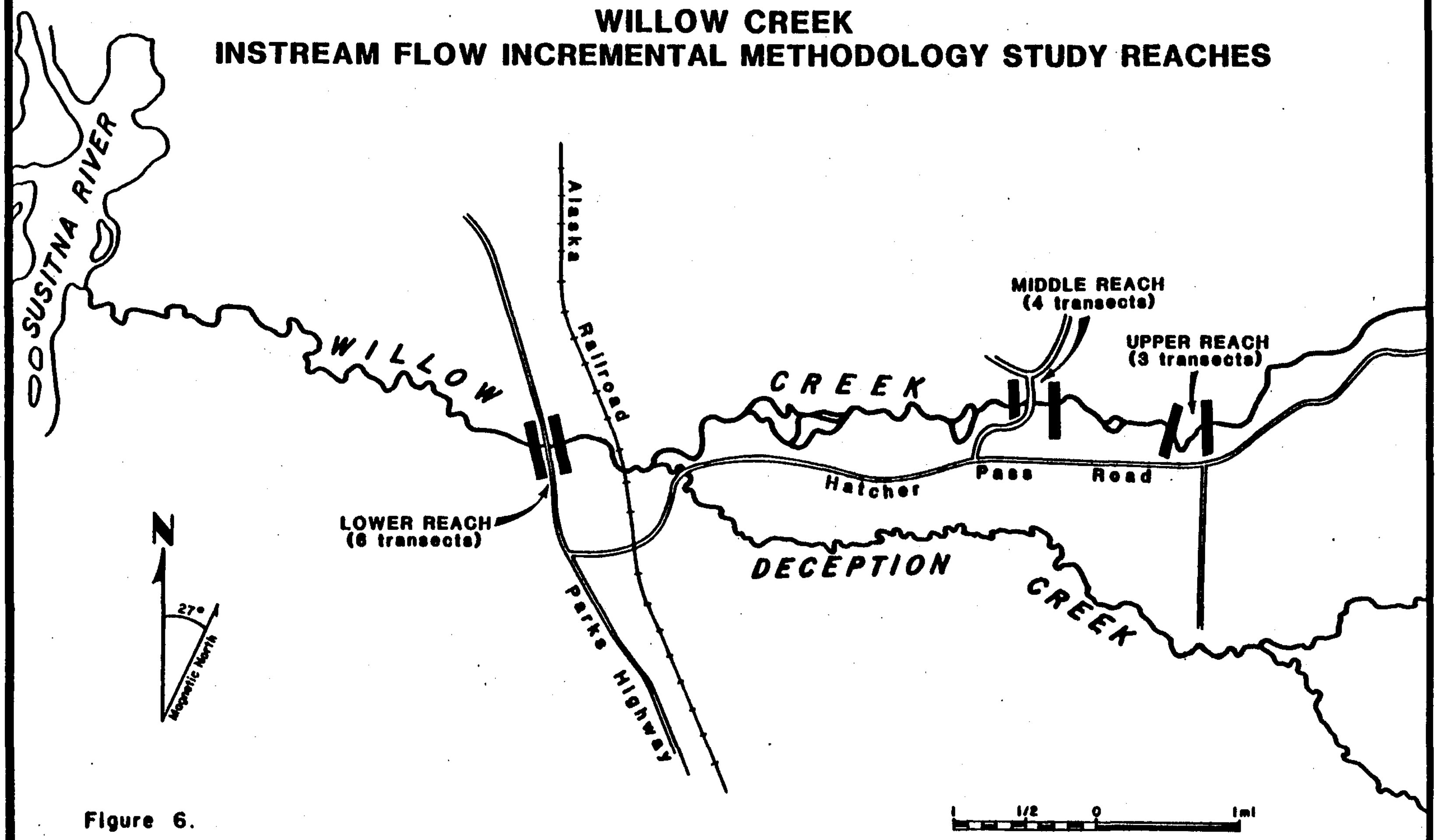
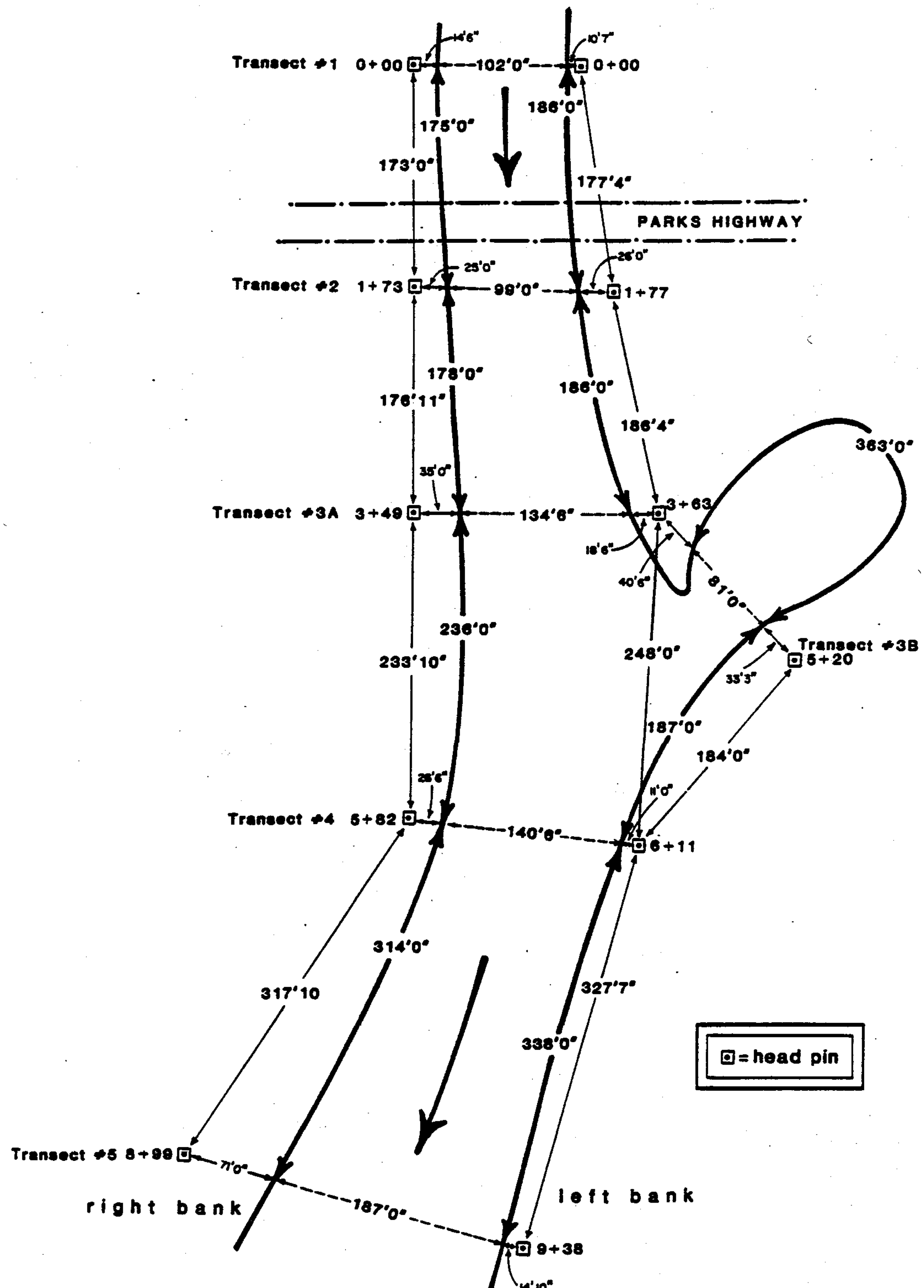


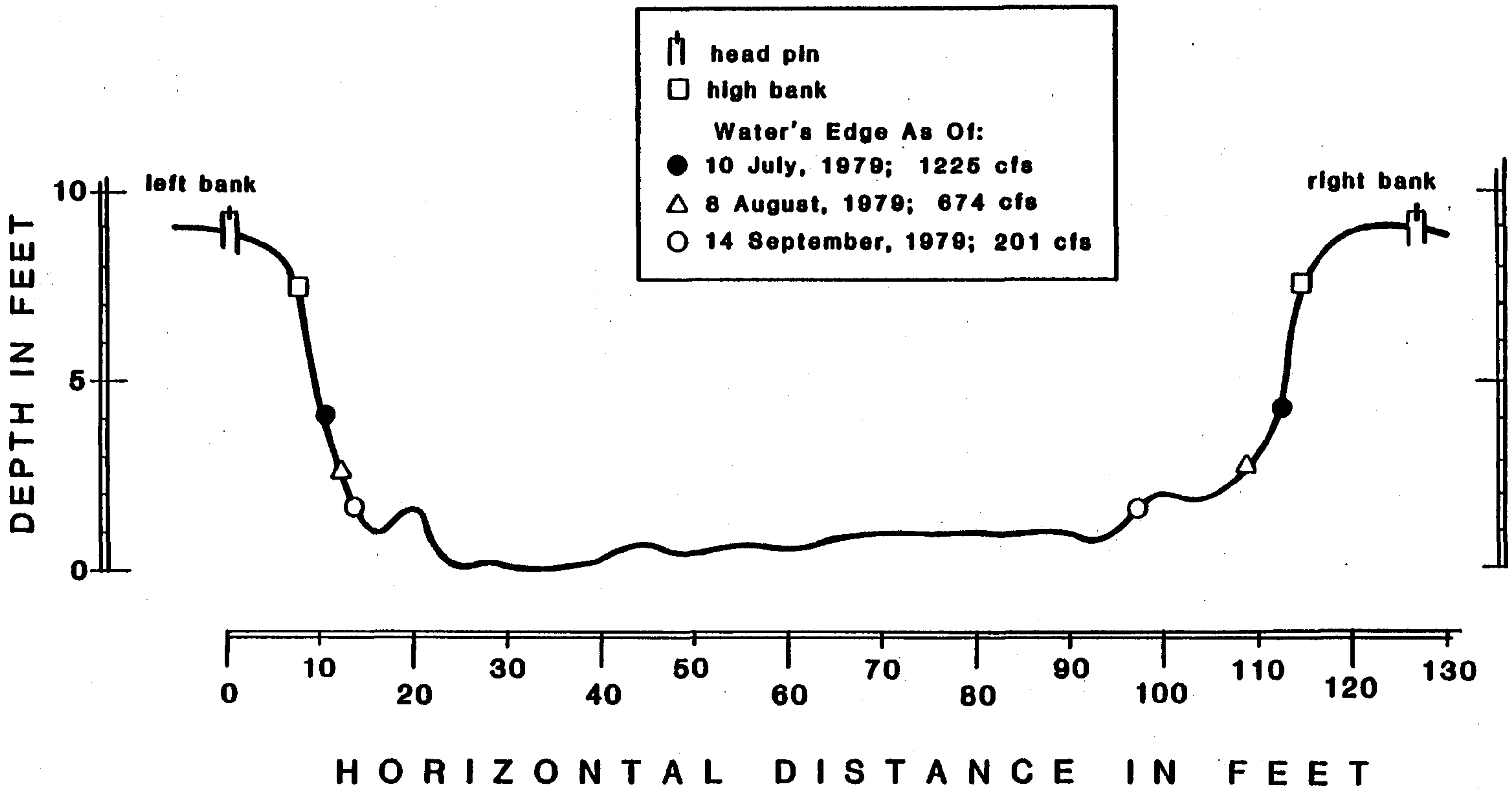
Figure 6.



LOWER WILLOW CREEK WATER'S EDGE & HEAD PIN STATIONING MAP
13 July, 1979
Average discharge 1163 cfs

Figure 7

Figure 8



CROSS-SECTIONAL PROFILE OF WILLOW CREEK LOWER REACH, TRANSECT #1.

(1 vertical foot equals 4 horizontal feet)

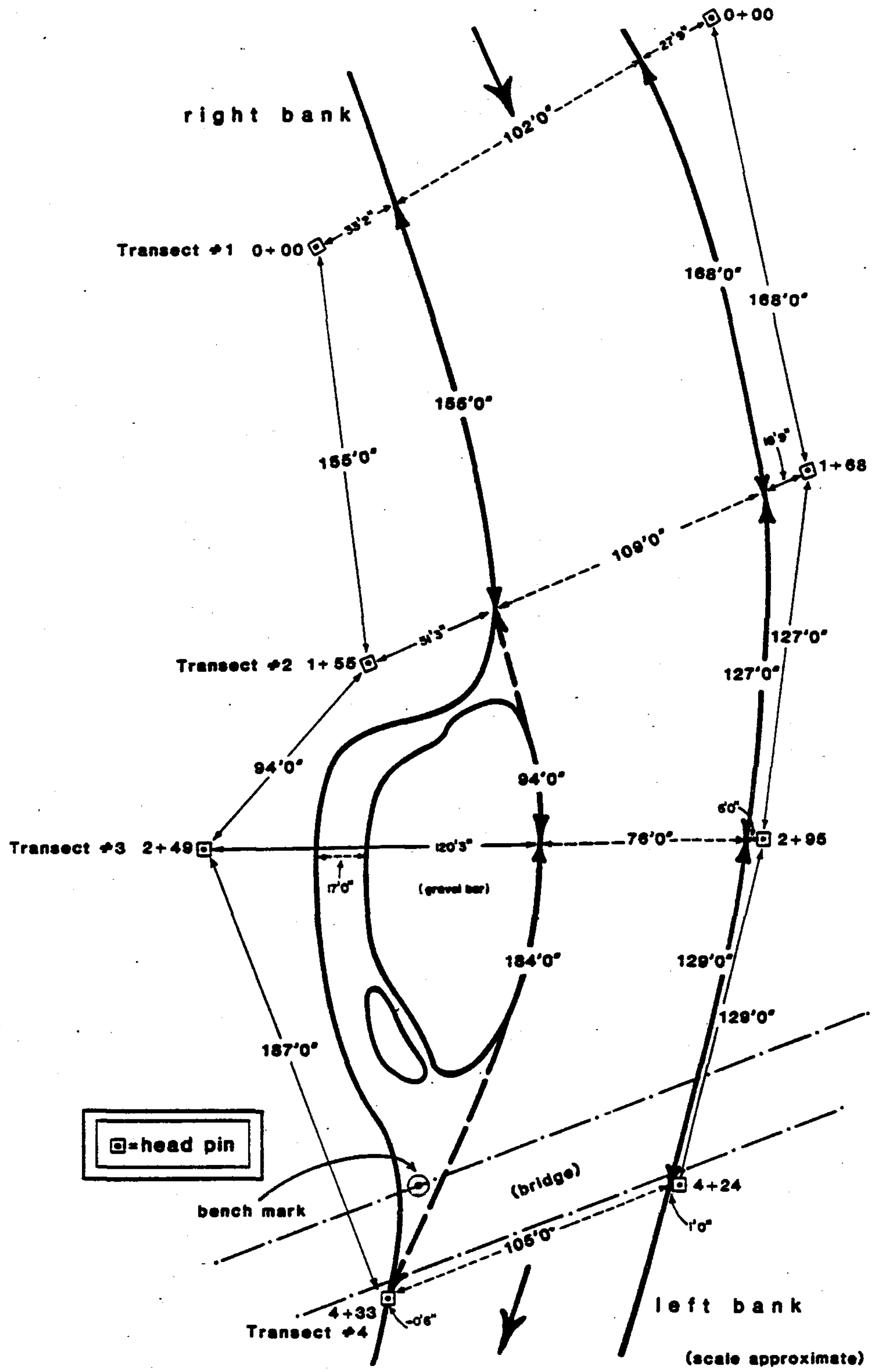
within this reach (Figures 9, 10). Both chinook and pink salmon used this area for spawning.

3. The upper Willow Creek reach was located 4.5 road miles upstream from the junction of the Parks Highway and Hatcher Pass Road on a large bend of a braided portion of Willow Creek. This reach was confined to the southernmost channel adjacent to the left bank (looking downstream) and thus represents only a portion of the flow for this stretch of Willow Creek. Three transects (Figures 11, 12) were established within this reach. A USGS gaging station (No. 15294005) is located approximately 1 mile upstream of this braided stretch of river and 3.5 miles upstream from the upper Willow Creek reach. Chinook salmon is the predominant species which utilizes this reach for spawning.

Physical Model

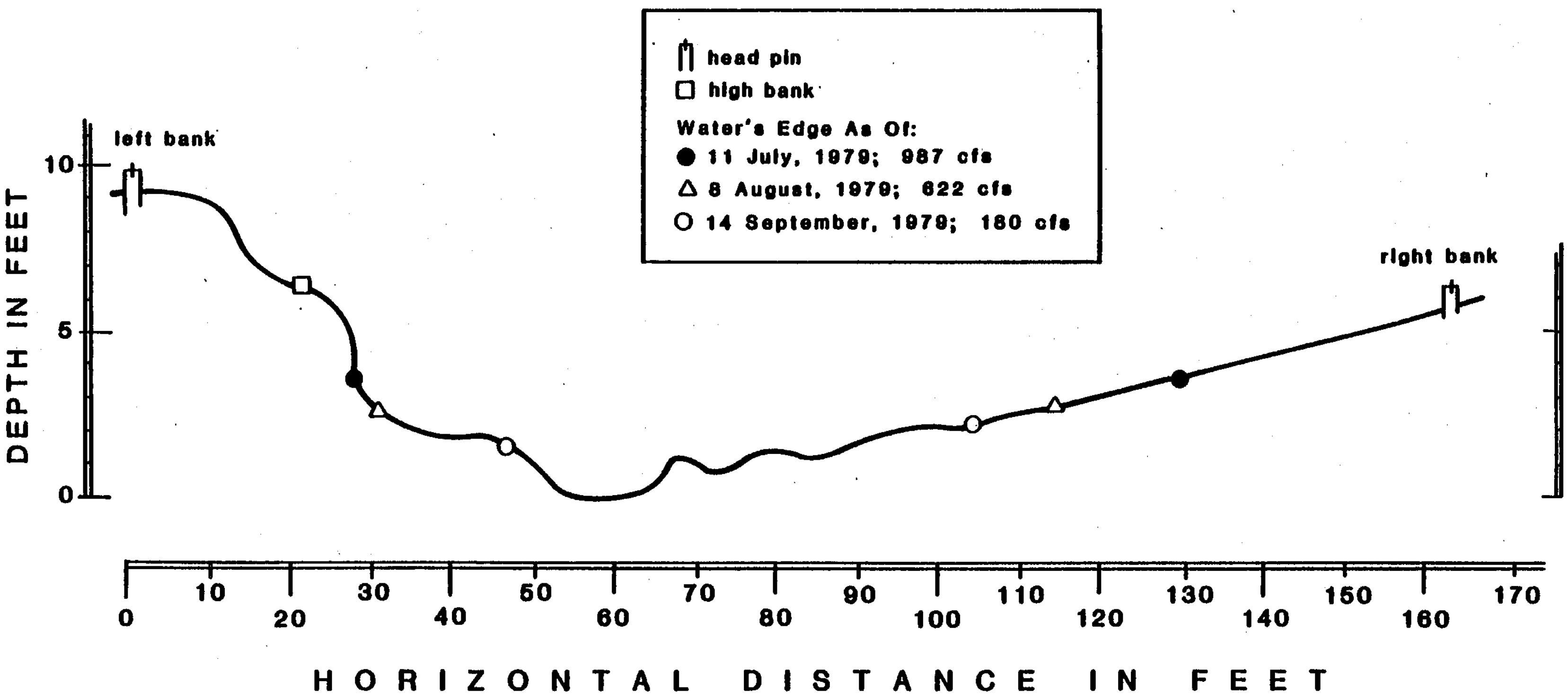
Analytical Approach

Hydraulic modeling is of central importance to the PHABSIM process because it makes the most efficient use of limited field observations to forecast the presence or availability of hydraulic characteristics of riverine habitat (depths and velocities) under a broad range of unob-

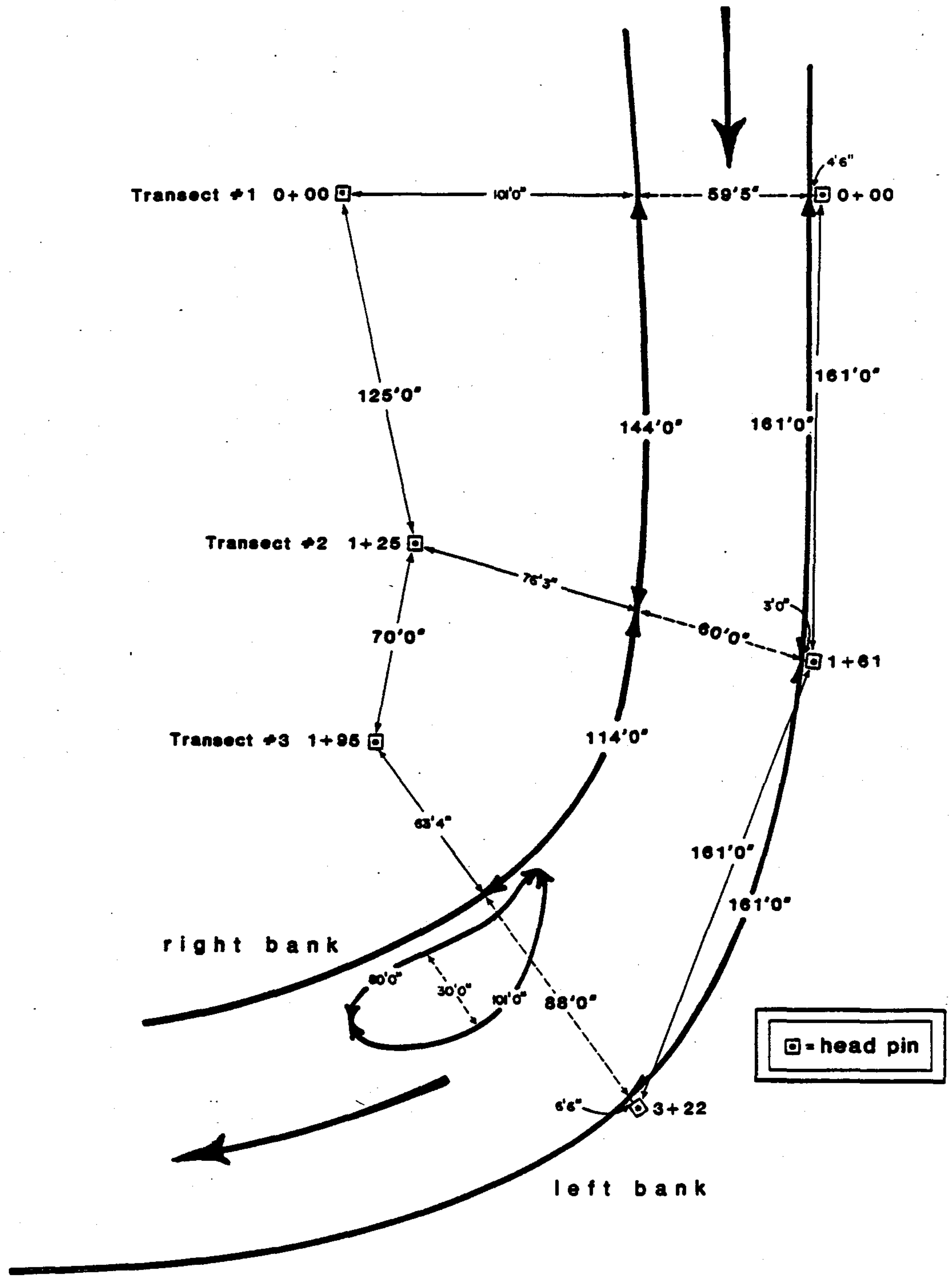


MIDDLE WILLOW CREEK WATER'S EDGE & HEAD PIN STATIONING MAP
11 July, 1979
Average discharge 990 cfs
Figure 9

Figure 10



CROSS-SECTIONAL PROFILE OF WILLOW CREEK MIDDLE REACH, TRANSECT #1.
(1 vertical foot equals 4 horizontal feet)

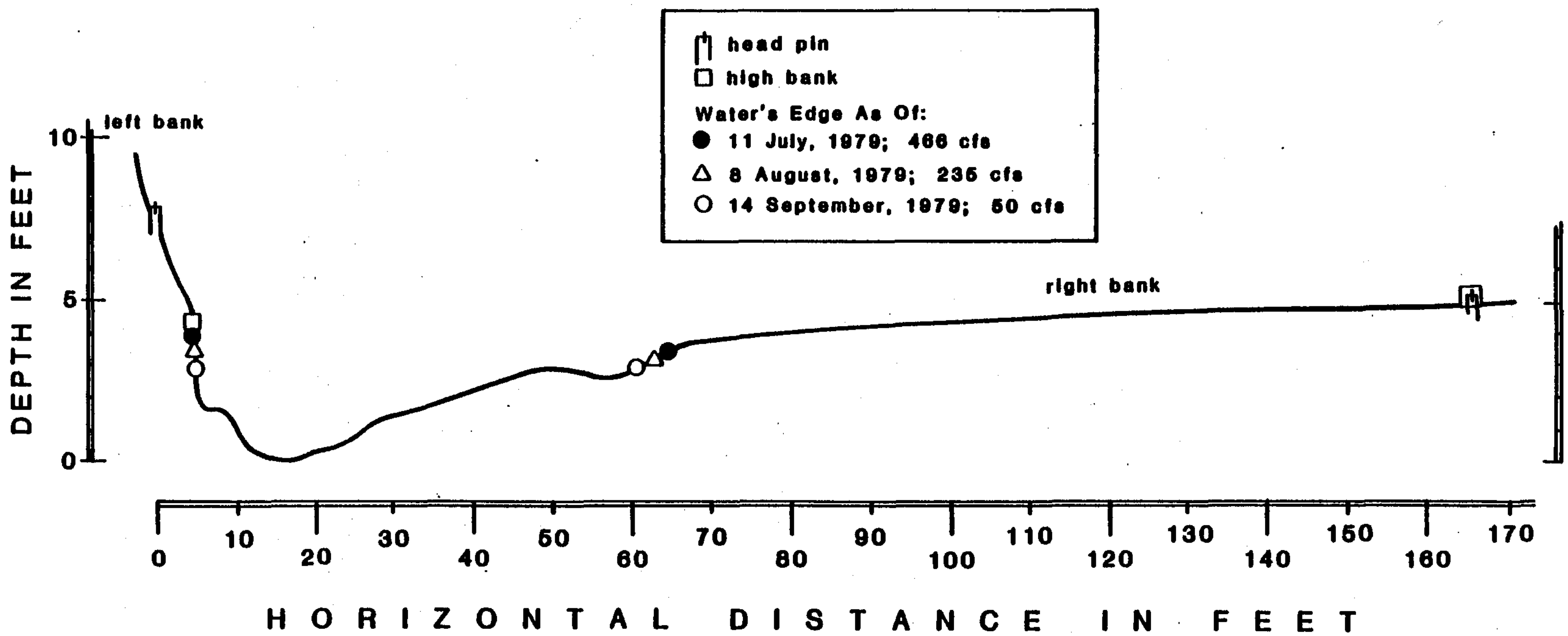


(scale approximate)

UPPER WILLOW CREEK WATER'S EDGE & HEAD PIN STATIONING MAP
11 July 1979
Average discharge 476 cfs

Figure 11

Figure 12



CROSS-SECTIONAL PROFILE OF WILLOW CREEK UPPER REACH, TRANSECT #1.

(1 vertical foot equals 4 horizontal feet)

served streamflow conditions.* The IFG specifically developed two hydraulic models (IFG-2 and IFG-4) during the late 1970's for evaluating quantitatively the availability of fish habitat characteristics which are related to flow variations (e.g., velocity, depth, substrate).

The IFG-2 hydraulic model is a water surface profile (WSP) program (U.S Bureau of Reclamation 1968) that has been modified to provide detailed descriptions of depth and velocity distribution at each cross section in a study site. The IFG-2 model can be used to predict the horizontal distribution of depths and mean velocities at 100 stations along a cross section for a range of streamflows with only one set of field data. According to Bovee and Milhous (1978), the IFG-2 model is based on the concepts of mass balance (continuity equation), energy balance (Bernoulli equation), and the relationships of energy to flow values (Manning's equation).

The IFG-4 model provides the same type of hydraulic predictions as the IFG-2 model, but it is more strongly based on field observations than hydraulic theory and formulae. Although a minimum of two data sets are required for calibrating the IFG-4 model, three are recommended. The IFG-4 model establishes linear regression equations for the $\log_{10}$ (stage) versus $\log_{10}$ (discharge) relationships for individual transects within a study reach, and $\log_{10}$ (discharge) relationships for selected

*Substrate composition is assumed to remain static.

intervals along each transect. Depth distribution is determined by subtracting the known streambed elevation from the predicted water surface elevation.

Both models must be calibrated so that values of velocities and depths for a measured discharge equal those simulated by the models. The IFG-2 model is usually calibrated by adjusting Manning's "n" (roughness coefficient) and the IFG-4 model by adjusting velocities. Guidelines and instructions for this process are explained by Milhous et al. (1981) and Trihey (1980). Milhous et al. (1981) do not underestimate the difficulty of the calibration process when they state that calibrating a model is like "balancing an egg on its end," but that "with continued iteration and fine tuning even difficult calibrations can be overcome."

In general, the extrapolation range for either hydraulic model (properly calibrated) ranges from 40 percent of the lowest calibration flow up to 250 percent of the highest calibration flow (Bovee and Milhous 1978; Milhous et al. 1981).

Vogel (1981) states that the IFG-4 model is the easiest of the two models to calibrate and is best for predicting stage. He notes the IFG-2 model as the better of the two for predicting average cross-section and segment velocities.

Both 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 at a given location in the channel remains constant during a time interval under consideration. This does not necessarily mean that depths and velocities of the flow rate (discharge) must remain constant through a stream reach.*

The definition of "rigid" does not mean that the stream boundary cannot change over time or as a result of high flows. A stream channel is rigid if it meets the following two criteria: (1) it must not change shape during the period of time over which the calibration data are collected; and (2) it must not change shape while conveying streamflows within the range of those that are to be simulated. Thus a channel may be "rigid" by the above definition, even though it periodically (perhaps seasonally) changes course (Bovee and Milhous 1978; Trihey 1981).

Application of Analytical Approach

All streamflow rates for this study were referenced to the average daily discharge of Willow Creek at the USGS stream gage (Station No. 15294005). This gaging site was selected as an index station for several reasons: a streamflow record exists; the gage is located near the stream segments that are of greatest interest in this particular analysis; and tributary inflow between the stream gage and the study sites is relatively small (estimated as being less than 10 percent of

*Referred to as nonuniform flow in hydraulic engineering terminology.

the total flow).

Site specific streamflow data collected during 1979 provided the basis for correlating flow rates through the various study sites to the average daily streamflow of Willow Creek at the USGS gage. Site specific channel geometry and hydraulic measurements provided the necessary data base to calibrate hydraulic models for each study site. Data on the hydraulically related variable of substrate were collected for input into the models. These data, correlations, and hydraulic models collectively form the hydraulic and related components of the physical habitat analysis. For a given discharge of Willow Creek at the USGS gage, the flow rate through each study site can be determined with the physical model to estimate site specific velocity, and depth and substrate to assist biologists with forecasting the effects of that discharge on the availability and quality of aquatic habitats in the Willow Creek study river segments.

Three seasonal discharges were measured at transects by ADF&G Sport Fish Division biologists with assistance from USGS, ADF&G Habitat Division, and ADNR personnel. Measurements were timed to correspond to seasonal high, medium, and low flow periods because of measurement requirements for analysis by the IFG-4 computer model (Bovee and Milhous 1978; Bovee 1982). Procedures for discharge measurements outlined by Spence (1975), the IFG (Bovee and Milhous 1978), and the USGS (Buchanan and Somers 1973; Smoot and Novak 1977) were followed. When depths and velocities were too large to allow study personnel to wade the stream, measurements were collected from a boat.

Staff gages were installed at each study reach to monitor reach specific stage/discharge relationships. Gages were placed to accommodate both low and high stream flows. Stage readings were recorded on a daily basis unless other study activities prevented an observation. If required, these data can be correlated to average daily discharge as recorded at the USGS station. Additional stage readings were recorded immediately before and after discharge measurements to determine if and how much the discharge had fluctuated while being measured.

Substrate data were collected along velocity measurement transects, each time velocities were measured, to characterize hydraulic roughness. Additional substrate data were collected at redd sites to identify the physical characteristics of substrate types at these sites (see "Spawning Habitat Criteria" section below). Substrate composition was assessed by observing the stream bottom and recording the percentages of predominant substrate groups. The sizes and types of substrate recorded were adapted from the Modified Wentworth Scale and grouped into seven classes (Table 1).

The above data were reduced and coded for input into the physical model following the procedures described by Trihey (1980). Encoded data were calibrated following the procedures described by Milhous et al. (1981).

Table 1. Equivalence of Modified Wentworth and Willow Creek Instream Flow Incremental Methodology Study substrate scales for classifying substrate.

MODIFIED WENTWORTH SCALE		WILLOW CREEK SCALE	
Class	Description*	Class	Description*
1	plant detritus		not considered
2	0.0001 - 0.0016	I	mud
3	0.0016 - 0.0024	II	sand
4	0.0024 - 0.079		
5	0.079 - 2.5	III	0.25 - 1.00
		IV	1.00 - 3.00
6	2.5 - 9.8	V	3.00 - 5.00
		VI	5.00 - 10.00
7	greater than 9.8	VII	greater than 10

*Description numbers represent inches.

Fish Habitat Criteria

Analytical Approach

An evaluation of the behavioral responses of fish to the flow related variables velocity, depth, and substrate is required to develop weighted spawning habitat utilization criteria for use in the PHABSIM system models for the calculation of WUA. These criteria, denoted as utilization criteria curves (Figure 13), were developed for the primary salmon species which spawn in the study area, pink and chinook salmon.

Spawning utilization criteria curves represent the relative preference of a salmon for an individual habitat variable (e.g. velocity, depth, or substrate). These criteria are developed from field measurements of velocity, depth, and substrate characteristics at spawning locations (redds). An index is scaled between 0 and 1, with 1 denoting optimum habitat utilization and 0 denoting no utilization (Figure 12). These index values are plotted on the y-axis against the appropriate velocity, depth, or substrate values on the x-axis, forming utilization criteria curves. The 0 to 1 values derived from the curves are entered into a curve file. The curve and physical model files are then combined in a program to calculate WUA. That is, the curve file for velocity, depth and substrate criteria are combined and compared with the estimated velocity, depth, and substrate characteristics estimated by the physical

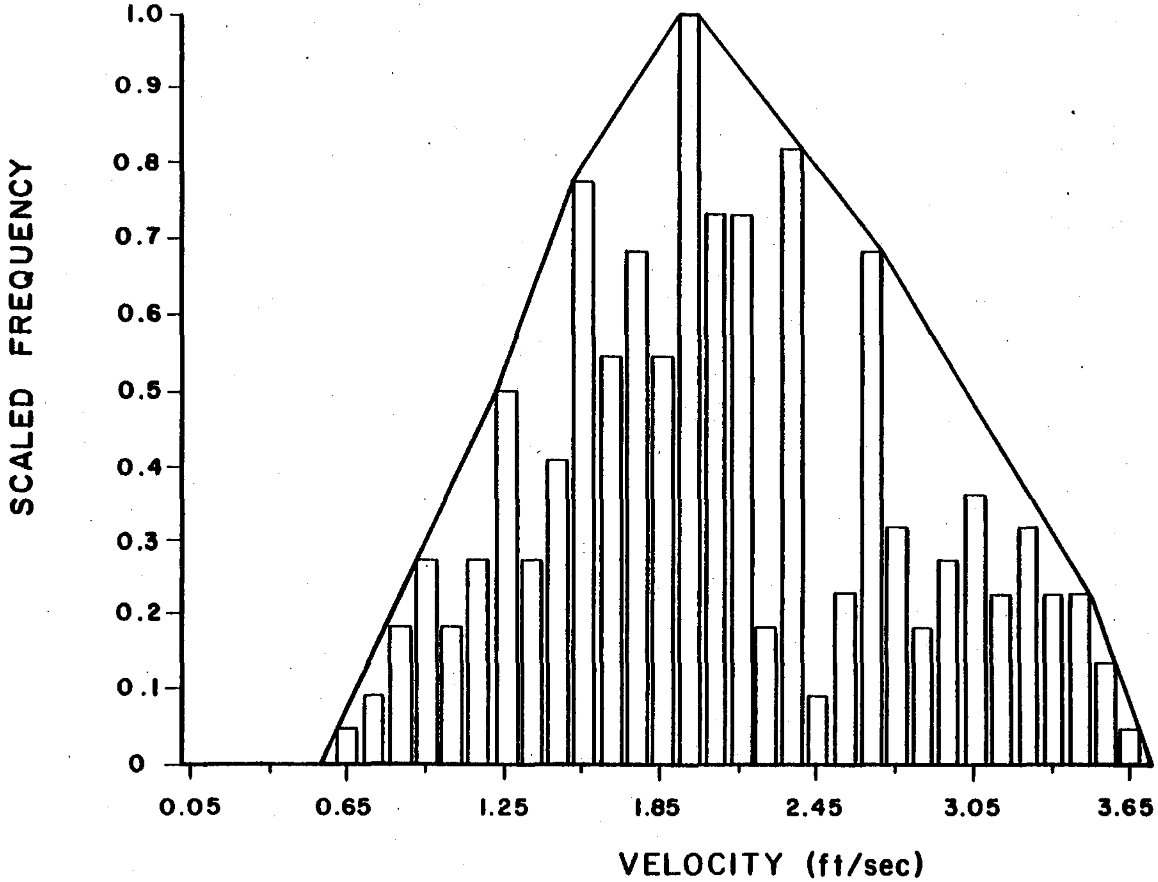


Figure 13. Conceptual drawing of velocity utilization curve with histogram of criteria data from which curve is derived.

model for cells* (Figure 14) within the study reach for predetermined flows. The velocity, depth and substrate values estimated for a cell by the physical model are assigned 0 to 1 index values derived from the appropriate utilization curve file. The three curve file values are combined to determine a joint preference factor (JPF) by one of three techniques (see WUA section). The JPF corresponds to the particular levels of the three projected habitat component (velocity, depth, or substrate) cell values and are used to "weight" each cell as a percentage of surface area that is suitable as spawning habitat. The weighted cell usabilities are summed for the entire site at each particular flow level to produce WUA.

Development of utilization curves, for each important spawning habitat criteria for chinook and pink salmon, follows a systematic approach to evaluate the relative importance of each habitat component. The first step in development of the utilization criteria curves involves the evaluation of utilization data, that is habitat values measured at redds utilized by pink and chinook salmon in Willow Creek.

The utilization data for an individual variable are plotted as a histogram based on the frequency of measurement of the variable. The

*A cell represents the water surface area between two verticals on a transect and a distance specified by the investigator upstream and downstream of the transect. The entire cell is assumed to have the same physical characteristics as at its center.

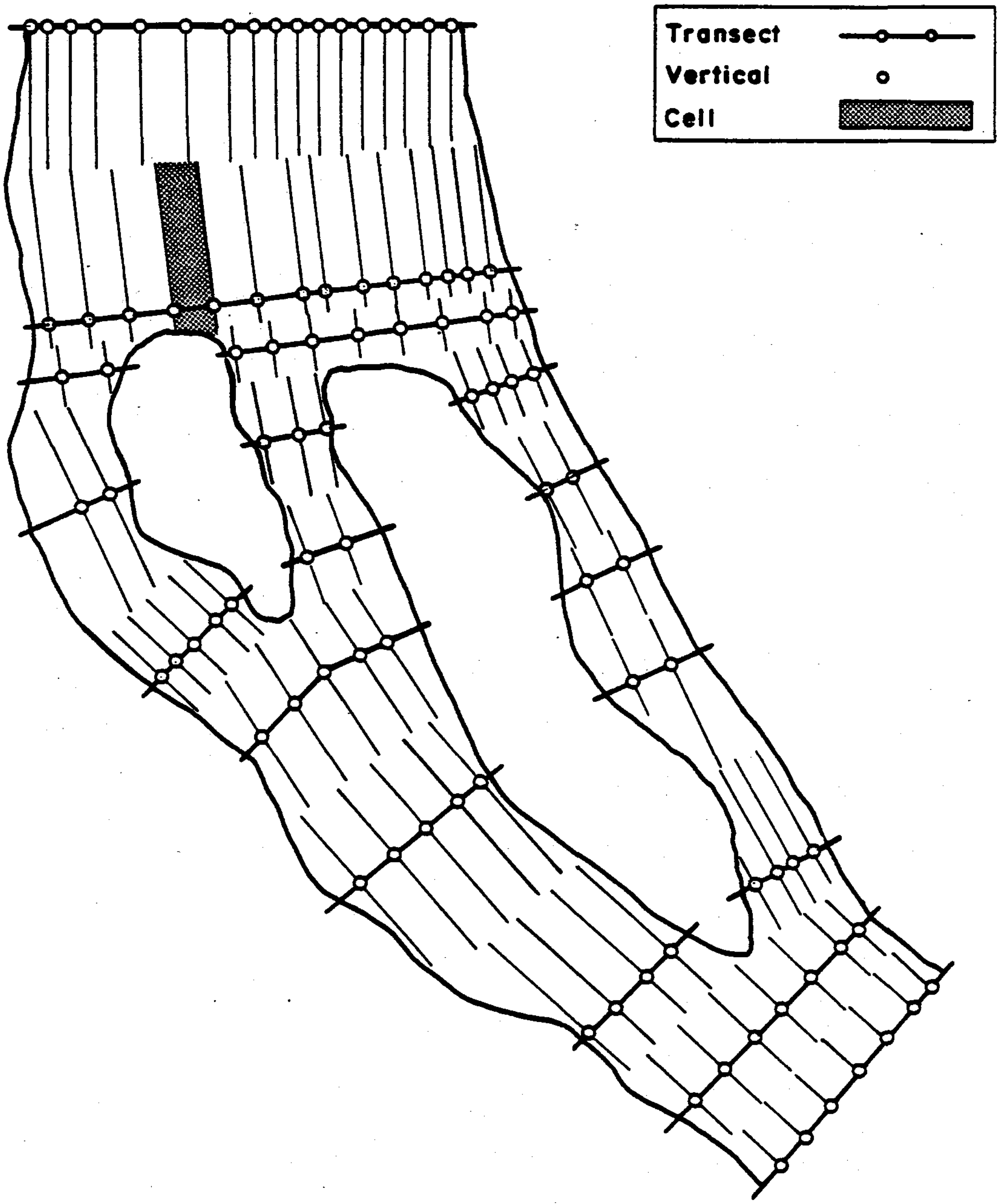


Figure 14. Conceptual drawing of transects to define stream cells, used to describe microhabitat distribution in a stream reach (adapted from Bovee 1982).

data are standardized, to the 0 to 1 scale, by dividing the frequency in each increment of the appropriate habitat component by the frequency in the increment with the highest occurrence. This standardization achieves a 0 to 1 scaling for frequency on the y-axis.

A curve is superimposed on the scaled frequency histogram and represents the utilization curve. The original scale of the increments for the frequency analysis corresponds to the measuring/recording accuracy for the particular habitat component of interest. Accordingly, the depth and velocity scaled frequency histograms are divided into appropriate increments. The substrate histograms are divided into one set of discrete substrate-class increments (e.g., silt, silt-sand, sand, etc). Further details and instructions for developing these curves are outlined by Bovee and Cochnauer (1977), ADF&G (1983), Estes et al. (1983a), and Vincent-Lang et al. (1984a,b).

Application of Analytical Approach

Water velocity, depth, and substrate characteristics, associated with chinook salmon redds, were recorded to characterize spawning habitat conditions in the study area. Visual observation of females fanning redd sites proved to be the most reliable means of identifying locations of redds. Because females were occasionally observed fanning false redds, it was necessary to observe females fanning the same site a number of times to verify active redd locations. Redds were also located by looking for clues such as the presence of Classes III and/or

IV substrate (Table 1), overturned stones, and a characteristic mound deposited downstream of the redds during their construction.

After redd sites were located, data were collected in the vertical plane above the upstream portion of the redds. When water was less than 3 ft deep, an average point velocity was measured at the data collection site by placing the velocity meter at 0.6 of the total depth measured from the surface of the water. When water depth was 3 ft or greater, two velocity readings were obtained, at positions 0.2 and 0.8 of the total depth, and later averaged to calculate the mean velocity. Substrate characteristics were classified and recorded, according to substrate procedures outlined above.

Velocity and depth curves were developed without data modifications. Development of substrate curves, however, required some data conversions. Substrate data were aggregated for use in developing utilization curves. The data collection method used resulted in potentially unlimited combinations of categories for substrate classification (i.e., categories could be based on any percentage of any or all of the seven substrate classes). By limiting substrate categories which could be used at a particular site to three dominant particle size classes, each of which had to comprise at least 10 percent of the substrate particle sizes present, the number of categories was reduced. These categories were then grouped according to predominant substrate size. After data were organized according to this system, frequency analysis (as described above) of substrate categories was performed to develop substrate curves. These substrate data groups were easily converted to the modified Wentworth classification (Table 1).

The above criteria were coded and entered into a curve file following the procedures described by Milhous et al. (1981).

Weighted Usable Area

Analytical Approach

The final step of the PHABSIM process is to combine the physical model with the fish criteria utilization file to project WUA for spawning habitat. WUA is an index of the capacity of a site to support the species and life stage being considered. It is expressed as square feet (ft^2) or percentage (%) of wetted surface habitat area predicted to be available per 1,000 linear feet of stream reach at a given flow. It does <u>not</u> predict the numbers of fish that will use a site or that fish will use a site. It provides an estimate as to how much area as a function of flow would be suitable for a life function of a fish species if the fish were present and other environmental conditions were satisfactory.

The physical model and the spawning habitat utilization criteria curve files are combined by the PHABSIM system to generate WUA (Milhous et al. 1981; Bovee 1982). Spawning habitat utilization criteria 0 to 1 values, (derived from the utilization curve file) are assigned to the depth, velocity, and substrate values for each cell at the given flow that are projected by the physical model file. The three utilization criteria values assigned to the cell are combined to produce a Joint Preference Factor (JPF) and multiplied times the surface area of the cell to derive a percentage of the cell which is considered suitable for spawning. These and the previous processes are summarized in Figure 2.

Three techniques were developed by the IFG (Milhous et al. 1981) to combine the velocity, depth and substrate 0 to 1 values to calculate the JPF:

1. <u>Standard Calculation</u> This is the calculation of the habitat area with the JPF equal to (a x b x c); where a, b, and c equal preference variables for velocity, depth, and substrate. This technique implies synergistic action; optimum habitat only exists if all variables are optimum.

2. <u>Geometric Mean</u> - This is the calculation of the habitat area with the JPF equal to $(a \times b \times c)^{0.33}$. This technique implies compensation effects; if two of the three variables are in the optimum range, the value of the third variable has little effect unless it is zero.

3. <u>Lowest Limiting Parameter</u> - This is the calculation of the habitat area with the JPF equal to the variable

> having the lowest preference factor at a given discharge. In other words, the optimum habitat will be based on the most limiting variable for a given discharge. This implies a limiting factor concept, or that the habitat is no better than its least suitable factor.

Selection of the JPF calculation technique is determined by the study participants familiar with the data base. A value, expressed as the square feet or percentage of surface area suitable for spawning, is then calculated for each cell for a predetermined flow. The values per cell are summed for the entire study site and the final value is WUA and is calculated per 1,000 feet of stream or habitat type length.

Application of Analytical Approach

The IFG-2 model for the middle reach of Willow Creek and six sets of fish utilization criteria are combined to calculate WUA for six flows in the next part of this section. The three JPF calculation techniques are used for these analyses.

Results

Results of the physical modelling and fish criteria data collection and analyses processes are followed by the WUA analyses.

Physical Model

Willow Creek flows measured for calibrating the hydraulic model ranged from 1163 cubic feet per second (cfs) on July 10, 1979 to 205 cfs on September 14, 1979 in the lower reach; from 991 cfs on July 11, 1979 to 175 cfs on September 14, 1979 in the middle reach; and from 918 cfs on July 11, 1979 to 174 cfs on September 14, 1979 in the upper reach (Table 2). Flows were 5 percent higher in the middle reach than in the upper reach and 10 percent higher in the lower reach than in the middle reach.* The difference in flow between the middle and lower Willow Creek reaches is higher than that between the upper and middle reaches because of the flow contribution of Deception Creek, a tributary to Willow Creek.

Daily stage data collected in Willow Creek indicate that the stage had peaked at all Willow Creek sites in mid-July after which it gradually declined until it increased abruptly in mid-September before falling again (Estes et al 1981). Predominant substrate classes ranged from

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*The accuracy of flow measurements are usually measured within ±5%.

Table 2. Flow (cfs) summary for Willow Creek Instream Flow Incremental Methodology Study reaches, 1979.

SITE	FLOW #1	FLOW #2	FLOW #3
LOWER WILLOW	(07/10/79)	(08/08/79)	(09/14/79)
Transect No. 1	1225	674	201
Transect No. 2	1215	661	212
Transect No. 5	1050	662	202
AVERAGE FLOW	1163	652	205
MIDDLE WILLOW	(07/11/79)	(08/08/79)	(09/14/79)
Transect No. 1	987	623	180
Transect No. 2	1025	620	155
Transect No. 3	929	571	165
Transect No. 4	1021	620	200
AVERAGE FLOW	991	598	175
UPPER WILLOW*	(07/11/79)	(08/08/79)	(09/14/79)
Transect No. 1	493	240	42
Transect No. 2	470	262	45
Transect No. 3	466	234	50
AVERAGE FLOW	476	245	46
Above Forks	918	569	174

*Upper Willow reach flows represent the south fork of the mainstem of Willow Creek. Therefore, the total discharge for this portion of Willow Creek was measured on the mainstem upstream of the braided section of the creek (Above Forks).

Table 3. Range of predominant substrate classes observed in the Willow Creek Instream Flow Incremental Methodology Study reaches, 1979.

STUDY REACH	SUBSTRATE CLASS RANGE
Lower Willow Creek	II - VI
Middle Willow Creek	III - VII
Upper Willow Creek	II - VI

Classes II to VII in Willow Creek (Table 3).

Financial and time limitations restricted computer analysis of hydraulic data to one reach. The middle Willow Creek reach was selected because it contained both pink and chinook salmon spawning habitat. Unstable channel geometry and an inability to obtain the assistance of a hydraulic engineer familiar with the IFG models prevented analysis with the IFG-4 program. Using the IFG-2 model, encoded data were calibrated to the highest discharge (991 cfs).* Data simulated for the three measured flows (991 cfs, 598 cfs, and 175 cfs) compared favorably with field measurements with estimated values equalling 100%, 96%, and 97% of observed values respectively. A range of 50 cfs to 2000 cfs was established as the limit of the model, based on the results of the calibration and the recommended range of extrapolation.

*This was based on the assumption that streambed elevations measured at this discharge level would be static for all predicted flows.

Fish Habitat Criteria

Insufficient resources limited the collection of spawning criteria data in 1979 to 33 chinook salmon redd sites. To extend the 1979 data base, similar data (50 chinook salmon and 114 pink salmon redds) collected by Watsjold and Engel (1978) in Willow Creek are analyzed in this report. Pink salmon data from a feasibility study for the proposed Terror Lake Hydroelectric project (AEIDC 1980) are used for a comparative analysis to evaluate the differences between the utilization of habitat by the same species from different watersheds. The original Terror Lake data used for this analysis are not included in this report.

The ranges of and most frequently measured water velocity, depth, and substrate characteristics for chinook and pink salmon redds are summarized in Table 4. A complete listing of these data is included in Appendix B. Examples of spawning utilization criteria curves derived from these data are illustrated in Figures 15-17. The complete set of curves is presented in Appendix C.

The most frequently measured water depth, at 33 chinook salmon redds, in 1979 was 1.60 ft, with a range of 0.95 to 3.00 ft; most frequently measured average water velocity was 2.25 feet per second (ft/sec), with a range from 0.28 to 4.75 ft/sec; and most frequently measured substrate was Class III, with a range of II to IV (Table 4; Appendix B).

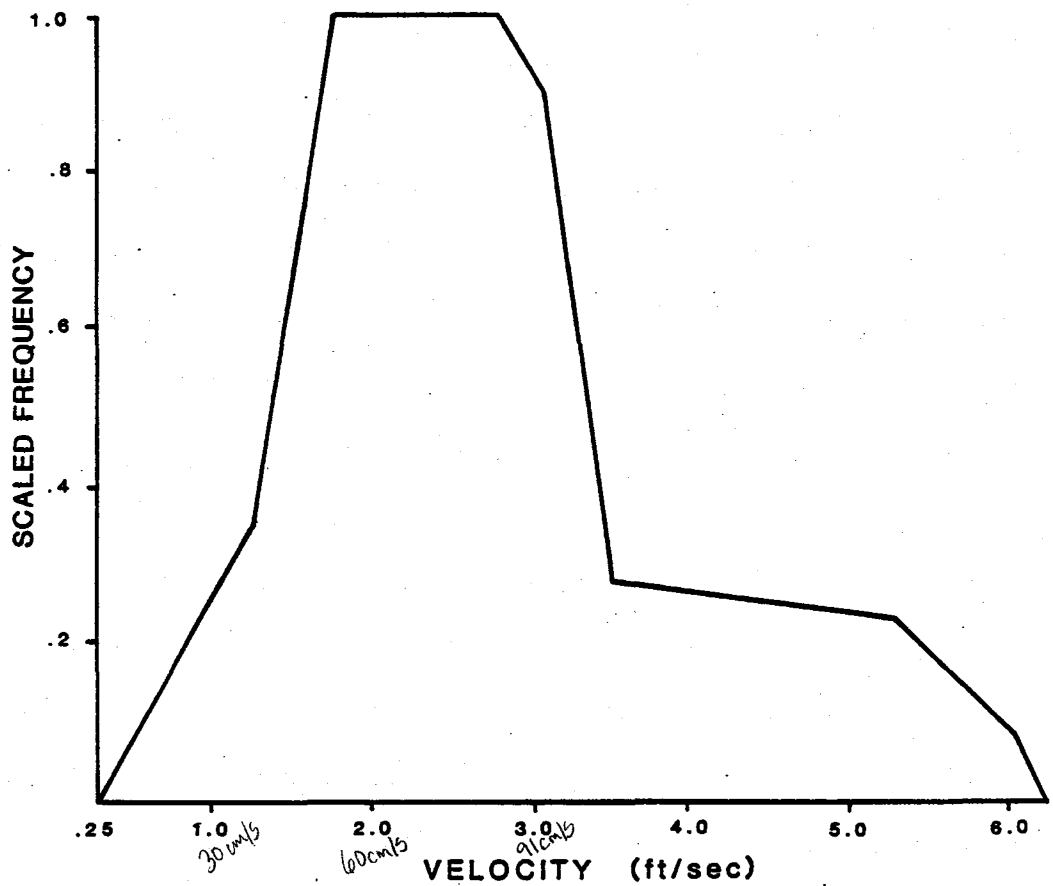

Figure 15. Velocity utilization curve for spawning chinook salmon in Willow Creek Alaska, Summer 1979.

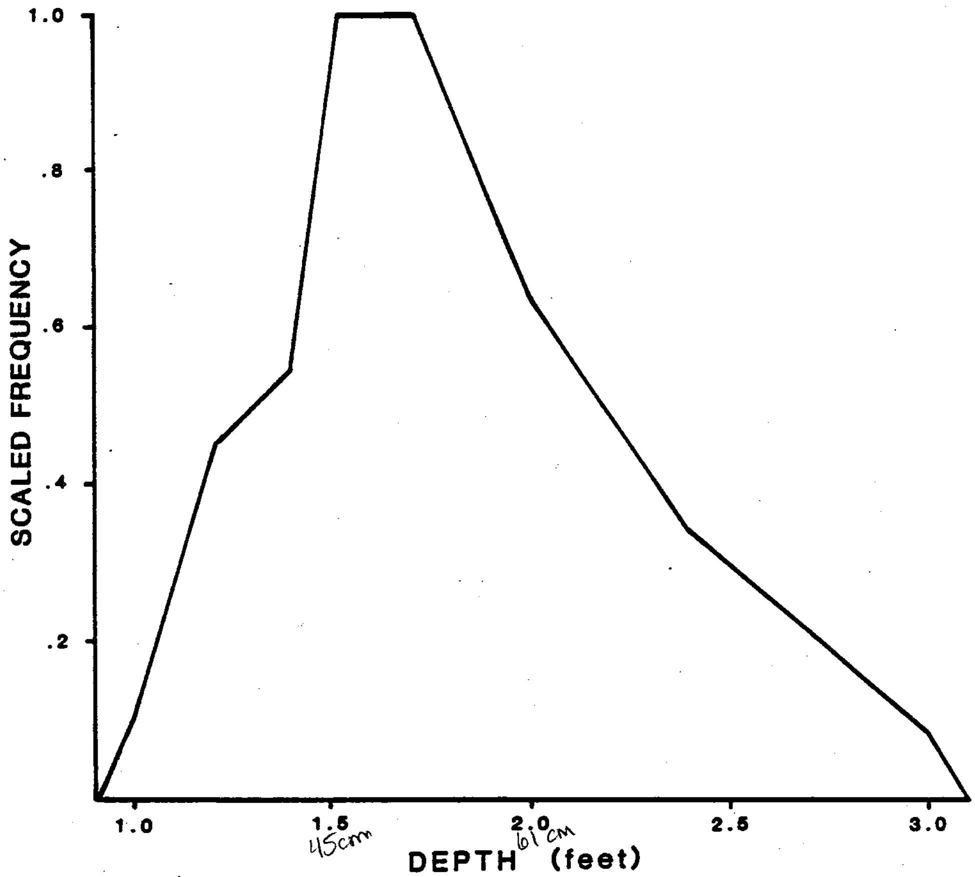

Figure 16. Depth utilization curve for spawning chinook salmon in Willow Creek, Alaska, Summer 1979.

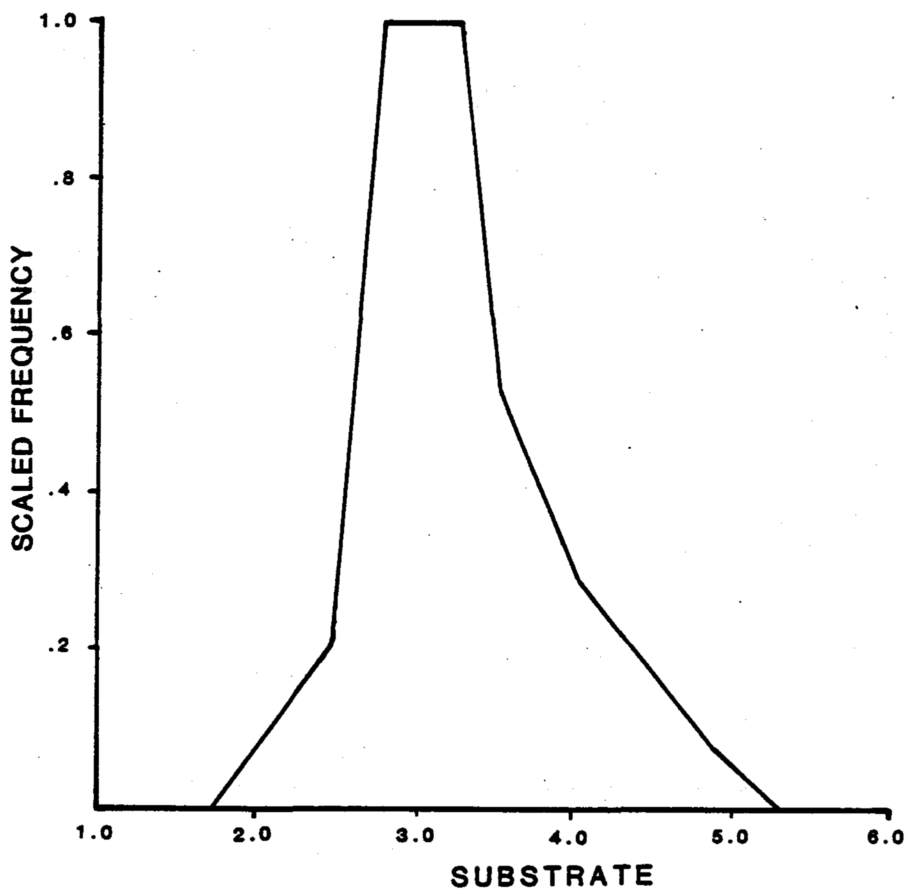

Figure 17. Substrate utilization curve for spawning chinook salmon in Willow Creek, Alaska, Summer 1979.

Table 4. Summary of redd measurements for chinook and pink salmon in Willow Creek (1978 data adapted from Watsjold and Engel 1978).*

Species	Depth (ft)		Velocity (ft/sec)		Substrate Classification	
Chinook	Range	MFM**	Range	MFM	Range	MFM
1979	0.95 - 3.00	1.60	0.28 - 4.75	2.25	II - IV	III
1978	1.00 - 2.20	1.65	1.50 - 4.75	3.16	III - VI	IV
Pink						
1978	0.60 - 2.40	1.38	1.00 - 4.00	2.40	II - IV	III

*Not recommended for application to other watersheds.
**Most frequently measured value.

The most frequently measured chinook salmon spawning depth measured in Willow Creek in 1978 was 1.65 ft, with a range of 1.0 to 2.2 ft; the most frequently measured average water velocity was 3.16 ft/sec, with a range of 1.51 to 4.75 ft/sec; and most frequently measured substrate was Class IV with a range of III to VI. Pink salmon spawning depth most frequently measured in 1978 was 1.38 ft, with a range of 0.6 to 2.4 ft; average water velocity most frequently measured was 2.4 ft/sec, with a range of 1.00 to 4.00 ft/sec; and substrate most frequently measured was Class III, with a range of II to IV.

Weighted Usable Area

Once calibrated, the IFG-2 hydraulic model was integrated with six different sets of fish utilization criteria for chinook and pink salmon to calculate predicted hypothetical WUA. WUA is hypothetical, because fish criteria data from three different sources are combined in the analysis. WUA values were predicted at six different discharges (50 cfs, 175 cfs, 598 cfs, 991 cfs, 1500 cfs, and 2000 cfs) within the range of calibration (50cfs-2500cfs) by the Standard Calculation (without matrices), Geometric Mean, and Lowest Limiting Parameter JPF calculation techniques.

Ten combinations of fish utilization criteria used in the WUA analysis are listed below (letters denote column headings on Tables 5-10). Six include velocity, depth, and substrate criteria (A - F) and four do not include substrate criteria (A^1 - D^1):

A. 1980 depth, velocity, and substrate preliminary data on pink salmon habitat from the Terror Lake Hydroelectric feasibility study, Kodiak Island (AEIDC 1980);

A^1. A data set without substrate.

B. 1978 depth, velocity, and substrate data on pink salmon habitat in Willow Creek (Watsjold and Engel 1978);

Table 5. Discharge vs. predicted surface area (ft^2) of available spawning habitat (velocity, depth, and substrate) as a percentage of total wetted surface area per 1000 ft of the Willow Creek Instream Flow Incremental Methodology Study middle reach (demonstration analysis - consult author for further interpretation).

Discharge (cfs)	Pink Salmon		Chinook Salmon			
	A	B	C	D	E	F
			Standard Calculation			
2000	10.73	0.00	00.31	00.28	00.03	01.92
1500	13.13	0.03	00.39	00.99	00.08	02.76
0991	16.18	0.03	00.90	02.51	00.23	05.69
0598	24.27	1.23	02.41	05.48	01.75	09.51
0175	39.52	0.51	02.42	09.24	01.17	14.47
0050	29.01	0.01	00.52	02.44	00.23	03.67
			Geometric Mean			
2000	30.50	0.00	01.96	02.57	00.72	05.38
1500	35.01	0.31	03.59	04.67	01.17	09.72
0991	39.66	0.51	08.94	09.66	03.46	19.80
0598	52.37	2.74	13.75	18.58	09.43	29.03
0175	68.59	2.18	15.15	29.63	10.79	32.11
0050	58.96	0.26	04.69	11.65	04.08	09.71
			Lowest Limiting Parameter			
2000	14.33	0.00	00.75	00.71	00.32	03.09
1500	17.11	0.15	01.25	01.99	00.40	05.56
0991	21.62	0.10	03.62	05.53	01.01	10.95
0598	31.12	1.31	05.80	10.52	03.81	16.57
0175	45.12	1.10	05.18	15.73	03.21	19.51
0050	37.94	0.05	01.83	05.70	01.26	06.53

A Pink salmon 1980 Terror Lake depth, velocity, and substrate data (AEIDC 1980).

B Pink salmon 1978 Willow Creek depth, velocity, and substrate data (Watsjold and Engel 1978).

C Chinook salmon 1979 Willow Creek depth, velocity, and substrate data.

D Chinook salmon 1978 Willow Creek depth, velocity, and substrate data (Watsjold and Engel 1978).

E Chinook salmon Willow Creek 1978 depth and velocity data (Watsjold and Engel 1978) 1979 substrate data

F Chinook salmon Willow Creek 1979 depth and velocity data; 1978 substrate (Watsjold and Engel 1978).

Table 6. Discharge vs. predicted surface area (ft²) of available spawning habitat (velocity, depth, and substrate) per 1000 feet of the Willow Creek Instream Flow Incremental Methodology middle study reach (demonstration analysis - consult author for further interpretation).

Discharge (cfs)	Wetted Area (100%)	Pink Salmon		Chinook Salmon			
		A	B	C	D	E	F
				Standard Calculation			
2000	149642	16051	0000	00463	00416	0042	02876
1500	139208	18273	0041	00538	01371	0117	03839
0991	099700	16133	0026	00897	02500	0234	05674
0598	080704	19586	0995	01941	04423	1411	07677
0175	064180	25361	0329	01552	05930	0751	09284
0050	049342	14315	0005	00255	01203	0112	01811
				Geometric Mean			
2000	149642	45640	0000	02933	03853	1072	08044
1500	139208	48735	0435	04999	06501	1633	13534
0991	099700	39540	0508	08916	09633	3447	19737
0598	080704	42264	2210	11093	14997	7612	23430
0175	061480	44018	1401	09726	19015	6923	20612
0050	049342	29093	0127	02315	05750	2013	04792
				Lowest Limiting Parameter			
2000	149642	21451	0000	1128	01070	0477	04631
1500	139208	23819	0064	1735	02775	0551	07741
0991	099700	21557	0096	3610	05513	1005	10916
0598	080704	25112	1060	4678	08492	3074	13376
0175	061480	28956	0709	3326	10095	2058	12521
0050	049342	18719	0025	0905	02814	0620	03223

A Pink salmon 1980 Terror Lake depth, velocity, and substrate data (AEIDC 1980).

B Pink salmon 1978 Willow Creek depth, velocity, and substrate data (Watsjold and Engel 1978).

C Chinook salmon 1979 Willow Creek depth, velocity, and substrate data.

D Chinook salmon 1978 Willow Creek depth, velocity, and substrate data (Watsjold and Engel 1978).

E Chinook salmon Willow Creek 1978 depth and velocity data (Watsjold and Engel 1978) 1979 substrate data

F Chinook salmon Willow Creek 1979 depth and velocity data; 1978 substrate (Watsjold and Engel 1978).

Table 7. Discharge vs. predicted surface area (ft^2) of available spawning habitat (velocity and depth) as a percentage of total wetted surface area per 100 ft of the Willow Creek Instream Flow Incremental Methodology Study middle reach (demonstration analysis - consult author for further interpretation).

Discharge (cfs)	Pink Salmon		Chinook Salmon	
	A'	B'	C'	D'
		Standard Calculation		
2000	17.52	01.82	03.67	01.55
1500	22.41	04.45	06.05	05.76
0991	31.16	05.40	09.95	06.76
0598	44.93	10.00	17.46	11.75
0175	76.27	24.58	24.03	23.74
0050	56.27	04.90	05.33	05.04
		Lowest Limiting Parameter		
2000	18.94	01.84	04.99	02.31
1500	24.75	05.07	08.25	06.71
0991	32.60	06.21	14.32	08.98
0598	45.80	10.83	24.02	15.60
0175	77.83	27.37	27.81	29.66
0050	58.76	05.95	06.72	07.32

A[1] Pink salmon 1980 Terror Lake depth and velocity data (AEIDC 1980).

B[1] Pink salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).

C[1] Chinook salmon 1979 Willow Creek depth and velocity data.

D[1] Chinook salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).

Table 8. Discharge vs. predicted surface area (ft²) of available spawning habitat (velocity and depth) per 1000 feet of the Willow Creek Instream Flow Incremental Methodology Study middle reach (demonstration analysis - consult author for further interpretation).

Discharge (cfs)	Pink Salmon A[1]	Pink Salmon B[1]	Chinook Salmon C[1]	Chinook Salmon D[1]
		Standard Calculation		
2000	26222	02717	05495	02315
1500	31191	06199	08424	08012
0991	31064	05388	09923	06742
0598	36256	08074	14088	09485
0175	48954	15776	15420	15240
0050	27766	02417	02631	02486
		Lowest Limiting Parameter		
2000	28338	02752	07468	03640
1500	34455	07058	11478	09342
0991	32504	06194	14275	08956
0598	36963	08741	19388	12594
0175	49951	17563	17850	19038
0050	28994	02938	03316	03614

A[1] Pink salmon 1980 Terror Lake depth and velocity data (AEIDC 1980).

B[1] Pink salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).

C[1] Chinook salmon 1979 Willow Creek depth and velocity data.

D[1] Chinook salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).

Table 9. Comparison of predicted surface area (ft²) of available spawning habitat (velocity, depth, and substrate) as a percentage of total wetted surface area per 1000 ft. of the Willow Creek Instream Flow Incremental Methodology Study middle reach with and without substrate (demonstration analysis - consult author for further interpretation).

Discharge (cfs)	Pink Salmon				Chinook Salmon			
	A	A'	B	B'	C	C'	D	D'
				Standard Calculation				
2000	10.73	17.52	0.00	01.82	00.31	03.67	00.28	01.55
1500	13.13	22.41	0.03	04.45	00.39	06.05	00.99	05.76
0991	16.18	31.16	0.03	05.40	00.90	09.95	02.51	06.76
0598	24.27	44.93	1.23	10.00	02.41	17.46	05.48	11.75
0175	39.52	76.27	0.52	24.58	02.42	24.03	09.24	23.74
0050	29.01	56.27	0.01	04.90	00.52	05.33	02.44	05.04
				Lowest Limiting Parameter				
2000	14.33	18.94	0.00	01.84	00.75	04.99	00.71	02.31
1500	17.11	24.75	0.05	05.07	01.25	08.25	01.99	06.71
0991	21.62	32.60	0.10	06.21	03.62	14.32	05.53	08.98
0598	31.12	45.80	1.31	10.83	05.80	24.02	10.52	15.60
0175	45.12	77.83	1.10	27.37	05.18	27.81	15.73	29.66
0050	37.94	58.76	0.05	05.95	01.83	06.72	05.70	07.32

A Pink salmon 1980 Terror Lake depth, velocity, and substrate data (AEIDC 1980).
A' Pink salmon 1980 Terror Lake depth and velocity data (AEIDC 1980).
B Pink salmon 1978 Willow Creek depth, velocity, and substrate data (Watsjold and Engel 1978).
B' Pink salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).
C Chinook salmon 1979 Willow Creek depth, velocity, and substrate data.
C' Chinook salmon 1979 Willow Creek depth and velocity data.
D Chinook salmon 1978 Willow Creek depth, velocity, and substrate data Watsjold and Engel 1978).
D' Chinook salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).

Table 10. Comparison of predicted surface area (ft²) of available spawning habitat (velocity, depth, and substrate) per 1000 ft of the Willow Creek Instream Flow Incremental Methodology Study middle reach with and without substrate (demonstration analysis - consult author for further interpretation).

Discharge (cfs)	Pink Salmon				Chinook Salmon			
	A	A¹	B	B¹	C	C¹	D	D¹
Standard Calculation								
2000	16051	26222	0000	02717	00463	05495	00416	02315
1500	18273	31191	0041	06199	00538	08424	01371	08012
0991	16132	31064	0026	05388	00897	09923	02500	06742
0598	19586	36256	0995	08074	01941	14088	14423	09485
0175	25361	48954	0329	15776	01552	15420	05930	15240
0050	25361	27766	0005	02417	00255	02631	01203	02486
Lowest Limiting Parameter								
2000	21451	28338	0000	02752	01128	07468	01070	03460
1500	23819	34455	0064	07058	01735	11478	02775	09342
0991	21557	32504	0096	06194	03610	14275	05513	08956
0598	25112	36963	1060	08741	04678	19388	08492	12594
0175	28956	49951	0709	17563	03326	17850	10095	19038
0050	18719	28994	0025	02938	00905	03316	02814	03614

A Pink salmon 1980 Terror lake depth, velocity, and substrate data (AEIDC 1980).

A¹ Pink salmon 1980 Terror Lake depth and velocity data (AEIDC 1980).

B Pink salmon 1978 Willow Creek depth, velocity, and substrate data (Watsjold and Engel 1978).

B¹ Pink salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).

C Chinook salmon 1979 Willow Creek depth, velocity, and substrate data.

C¹ Chinook salmon 1979 Willow Creek depth and velocity data.

D Chinook salmon 1978 Willow Creek depth, velocity, and substrate data (Watsjold and Engel 1978).

D¹ Chinook salmon 1978 Willow Creek depth and velocity data (Watsjold and Engel 1978).

B^1. A data set without substrate.

C. 1979 depth, velocity, and substrate data on chinook salmon habitat in Willow Creek;

C^1. Without substrate.

D. 1978 depth, velocity, and substrate data on chinook salmon habitat in Willow Creek (Watsjold and Engel 1978);

D^1. A data set without substrate.

E. 1978 depth and velocity data on chinook salmon habitat in Willow Creek (Watsjold and Engel 1978), and 1979 substrate data on chinook salmon habitat in Willow Creek; and

F. 1979 depth and velocity data on chinook salmon habitat in Willow Creek; and 1978 substrate data on chinook salmon habitat in Willow Creek (Watsjold and Engel 1978).

The six fish utilization criteria sets and three JPF calculation techniques are analyzed to evaluate their influence on the final WUA output. The four data sets (A^1 - D^1) calculated without substrate were analyzed in this manner for comparison with results derived with the Orsborn techniques (see next chapter). Results of these six WUA analyses are presented in Tables 5-10 and Figures 18 and 19.

Descriptions of the JPF calculation methods in the Methods Section suggest that the Lowest Limiting Parameter calculation method would generate the most conservative* WUA value for a given discharge. However, results obtained by each of the three methods indicate that the Standard Calculation procedure will generate the most conservative WUA values (Figure 18; Tables 5-10). This occurs because the suitability values used to compute WUA must always range between 0 and 1.

Results of the above demonstration calculations to predict WUA values indicate that utilization data collected from one stream system may not necessarily apply to another (Figure 19; Tables 5-10).** For example, using the Standard Calculation, predicted WUA at a discharge of 175 cfs (based on criteria for pink salmon collected from different stream systems) ranged from 329 ft^2 (0.51%) per 1000 ft to 25,361 ft^2 (39.52%) per 1000 ft (Tables 5, 6). A flow of 175 cfs is preferred with one set of fish criteria (Table 6: column A) and 598 cfs (Table 6: column B) with the other emphasizing further the importance of the source of fish criteria.

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*Conservative WUA values, as defined in this thesis, represent the lowest predicted WUA values for a given discharge when more than one calculation method is applied.

**It should be noted that utilization data presented in this thesis were derived from dissimilar samples in terms of the population size sampled and location of the sampling. These factors may also have influenced the results.

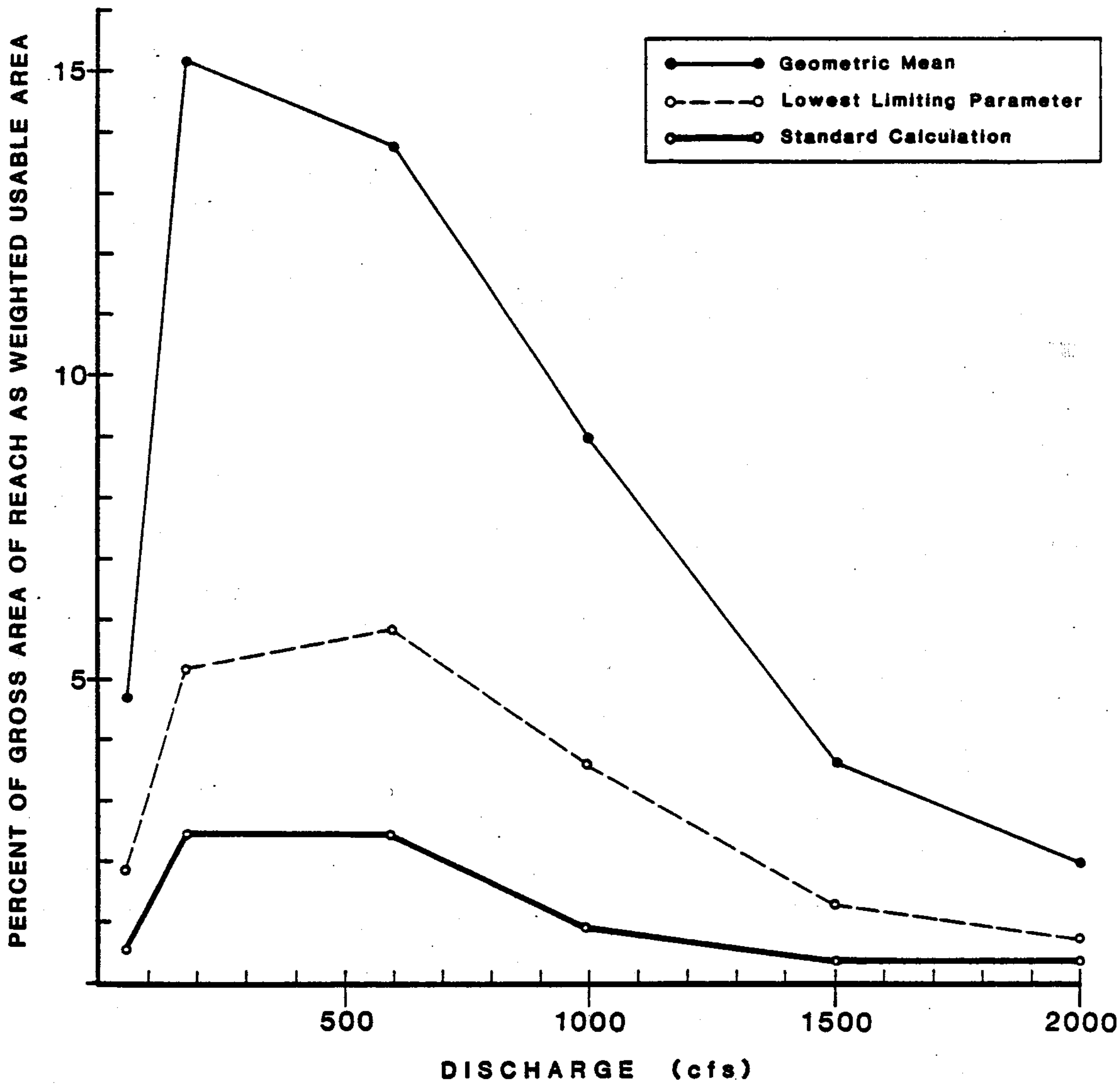

Figure 18. Comparison of three methods for calculating weighted usable area for spawning by chinook salmon, 1979 (demonstration analysis).

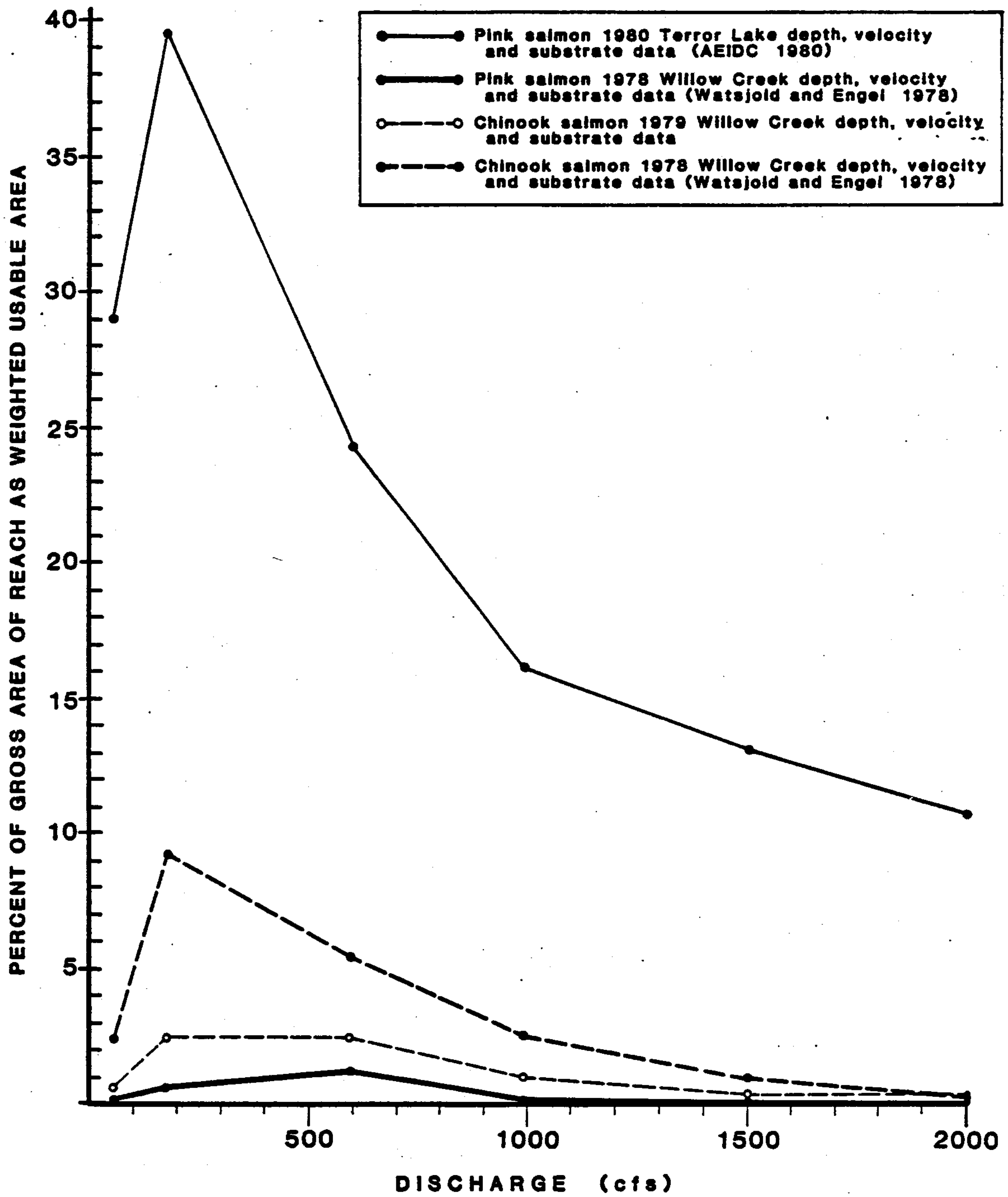

Figure 19. Effects of applying different habitat utilization curves to the same hydraulic model to calculate weighted usable area using Standard Calculation joint preference factors (demonstration analysis).

Discussion

Physical Model

The Willow Creek IFIM evaluation constituted an initial "hands-on" experience at collecting and analyzing Alaskan instream flow data for the ADF&G and cooperating agencies, following IFIM procedures established by the IFG (Bovee and Cochnauer 1977; Bovee and Milhous 1978; Milhous et al. 1981; Trihey 1980). This demonstration project enabled the participants to develop the capability to perform this type of instream flow field data collection and analysis, identify the limitations of the methodology, develop suggestions for its improvement, and recommend a plan of study for determining instream flow values in Willow Creek.*

Of the six individuals required to collect hydraulic data for this project, only two were actually employed to perform the study. To compensate, volunteers were recruited from other projects and from cooperating agencies. Flexible scheduling necessary to accommodate changes in weather and to insure that one set of data was collected

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*Additional recommendations and strategies for determining instream flow values are presented in the publications: A synthesis and evaluation of ADF&G fish and wildlife resources information for the Willow and Talkeetna sub-basins (Estes and Lehner-Welch 1980) and Opportunities to protect instream flows in Alaska (White 1981).

during each period of high, medium, and low flows often prevented the same volunteers from returning to the project. As a result, substitutes had to be recruited and trained in the field, while collecting data. This proved to be time consuming, and hampered efforts to insure quality control and minimize data gaps and/or errors.

Another disadvantage was that resources were not available to employ a hydraulic engineer, familiar with instream flow investigations. Without this technical input, it was difficult to determine whether site selection and related activities associated with hydraulic data collection and analysis were properly executed.

These problems can be minimized in future studies if sufficient funding is secured to employ adequate numbers of full-time experienced personnel, including at least one biologist and hydraulic engineer having knowledge of these techniques.

As would be expected in a first-time study, problems and complications arose in the data reduction and computer analysis portions of the project. A check list of procedures for field collection of hydraulic data was developed to insure that future data will be suitable for analysis (Estes et al. 1981).

It is recommended that a hydraulic engineer, familiar with these models, evaluate the hydraulic model calibration and output to check the validity of this analysis. An evaluation of whether a IFG-4 analysis can be run with the existing data should be attempted and if possible, the IFG-4 analysis compared with the IFG-2 Results to further expand this evaluation.

Fish Habitat Criteria

Presently, limited information exists concerning the specific spawning, rearing, incubation, and passage streamflow requirements of culturally and economically important fish. These data are essential for wise land-use planning and development (Hunter 1983; Estes and Lehner-Welch 1980). Bell (1980), Bovee (1980), and Estes and Lehner-Welch (1980) recommend that habitat requirements for a particular life phase of a fish species should be determined by collecting and analyzing comprehensive stream-specific data in addition to reviewing all pertinent literature.

Literature review alone is not usually adequate because data and findings cited for one area may not accurately represent another specific location (e.g. a stock of chinook salmon in one drainage area may have different velocity, depth, and substrate criteria requirements than another stock from a dissimilar drainage). Furthermore, literature may only summarize results and not provide a sufficient basis for comparing methods, analyses, and the physical characteristics of the fish species and watershed.

It is recommended that fish habitat data collected for a particular life phase of a fish species in a specific geographic location not be applied to another location unless an evaluation is completed to determine if such an application is valid. This could include discussions with biologists familiar with the biology of the region in question and cursory field measurements.

Habitat criteria data collection for this study was limited to the spawning phase of 33 chinook salmon. Utilization curves for spawning, although better than having no data, may not represent the complete range of spawning conditions available to salmon or the actual range of preference. That is, utilization criteria are measurements of velocity depth, substrate or other relevant habitat characteristics at only locations where spawning is known to occur. These measurements in Willow Creek were limited in number due to resource limitations.

Utilization measurements for Willow Creek do not reflect utilization of greater depths and velocities by chinook salmon than those recorded because of the physical difficulty of obtaining these measurements and the inability to confirm spawning sites in deep (greater than 3 ft of water) swift water. Accordingly, utilization data for Willow Creek were biased towards lower velocities and depths than actually utilized by the chinook salmon.

Another problem is that once a site for hydraulic modelling is located, there is no guarantee that a sufficient number of fish will utilize the area, even if measurements can be made for the range of conditions present. A shortage of fish at the site could result from a downstream passage obstruction or a poor escapement. Having too many fish at a site (e.g. crowding during a low water year) may result in the usage of ranges of conditions not otherwise used. This would provide a poor measure of habitat utilization if habitats used for spawning would not support incubation.

Having a sufficient number of utilization measurements is important. The criteria curves based on the 1979 chinook data sample size are rated "fair" based on standards established by Bovee and Cochnauer (1978). They state that a minimum of 200 criteria measurements should be obtained for an "excellent" criteria utilization curve.

Reiser and Wesche (1977); Baldridge and Amos (1982); and Estes et al. (1983a) recommend that preference curve data be collected and analyzed as opposed to utilization criteria alone. The preference curve is based on measuring the complete range of conditions available and utilized at a spawning area to differentiate between conditions actually used and those that are available and ignored or avoided. In developing a preference curve, the following assumptions (Baldridge and Amos 1983) adapted from Bovee and Cochnauer (1977) are applied:

1) individual fish tend to select the most favorable habitat from within the total range of available habitat. They use less favorable habitat with lesser frequency and eventually leave the area, if possible, before microhabi-

tat conditions become lethal;

2) individual fish are most frequently observed in their most preferred habitat conditions; therefore, frequency of observation can be accepted as an indication of habitat utilization and frequency of observation weighted by habitat availability can be accepted as an indication of preference; and

3) individual fish select values of one habitat variable independently of the other habitat variables as long as all these other variables are within the tolerable range of the species/life stage.

To collect preference data under ideal situations, spawning should occur within the physically modelled site, making it possible to estimate the full complement of physical characteristics as opposed to only those utilized. Or, the site should be small enough to measure the hydraulic characteristics for the area without requiring too many field personnel.

Preference curves, similar to utilization curves, can be biased if the range of conditions measured are not representative of those expected for the site. Assume that a physical model is developed for a site with the calibration range of flows extending from 50 cfs to 4000 cfs. Depths of 8 ft are estimated by the model at 4000 cfs. If spawning availability and preference data were only collected at flows representing 1,000 cfs, with depths no greater than 5 ft, preference curves would indicate that the higher depths are not preferred. This would be contrary to the belief of researchers who do no believe that deep water in itself is not always limiting to spawning fish (Swift 1979; Vincent-Lang et al. 1984a,b).

A solution to the limitations of utilization and preference curves is to develop a suitability curve which consists of either a utilization or preference curve which has been modified with professional judgment based on field experience, literature data, or a combination of both.

Another approach for improving the assessment of fish habitat criteria is to conduct a multivariate analysis of fish habitat criteria (Voos 1981). Voos (1983) suggests that this approach requires field testing and adds that it is resource intensive, requiring large samples of measurements and therefore may not be cost effective.

Resources were not available to modify the Willow Creek fish criteria data base and resulting curves. As such, it is highly recommended that a combined preference and suitability analysis be conducted for Willow Creek and the results of this analysis be adjusted accordingly. Odd and even years should be evaluated for pink salmon to differentiate usage during years of crowding (even) and those without (odd).

Another area for further evaluation is the assumption that depth, velocity and substrate are independent. Orth and Maughan (1982) found this assumption to be invalid for warm water species they evaluated. Testing of this assumption was beyond the scope of this study, yet is undoubtedly important.

Depending on the species/life phase being evaluated, it is important to consider criteria other than velocity, depth, and substrate (ADF&G 1983). Estes et al. (1983a) and Vincent-Lang et al. (1984a,b) consider upwelling equal to, if not more important as a flow related variable for spawning by chum salmon; and, Wesche (1974, 1980) emphasizes the importance of cover for rearing salmonids.

Developing an understanding of other chinook and pink life phases and the life phases of other fish species in Willow Creek will require a considerable amount of work over all seasons of the year (Watsjold and Engel 1978). It is recommended that future instream flow studies assign at least two individuals to fish utilization criteria field data collection for species and life phases of interest.

Research should be performed jointly by a hydraulic engineer and fishery biologist to evaluate the various techniques for collecting fishery habitat data. For example, the topic of whether to measure water velocity at the mean depth of the water column as opposed to the actual depth of the fish should be addressed to better quantify habitat usage. This topic could not be evaluated within the confines of this study. Hunter (1973) prefers to measure water depths for spawning at

0.4 ft above the streambed; other investigators consider the mean depth of the water column as an adequate measure of the depth utilized by fish (Bovee and Cochnauer 1977). Hunter (1973) provides a series of recommended depth measurements for different species. At a minimum, an investigator should state which depth is measured in their study when reporting their data.

Weighted Usable Area

Five man-months were expended in familiarizing project personnel with methods of IFIM computer analysis to estimate WUA. Because of their familiarity with and day-to-day use of their programs, the IFG has inadvertently underestimated the limitations of user groups who are inexperienced or use the models infrequently. Limitations of and recommendations for improving computer analysis processes are discussed in Estes et al. (1981)*:

The hypothetical WUA calculations for the middle Willow Creek reach presented in this report demonstrate the variability which can result from applying habitat suitability data collected for different stocks of the same fish species at different locations and times to the same sets of hydraulic data. They demonstrate also that the use of a particular

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*Recommendations concerning the IFG computer manual used in this analysis (Milhous et al. 1981) may have been addressed in the 1984 revised edition which was circulated when this thesis was in press.

calculation procedure will influence the WUA output. This variability illustrates the complexity of data acquisition, analysis, and interpretation, and emphasizes the importance of both understanding how to select and interpret a particular calculation, as well as insuring that habitat utilization data external to the project apply to the system under question.

WUA spawning habitat values should not be applied to the river reaches or habitats in which spawning has not been documented. If spawning does not occur at a site which can be physically represented by the model, it must first be determined whether variables other than those represented by the model are limiting or whether other life phase habitat requirements are lacking. Other habitat variables (e.g., pollutants, excessive sedimentation, and temperature) may prevent successful reproduction from occurring regardless of the flow (Reiser and Wesche 1977).

Applying a WUA model to a site without verification of utilization could result in predicting the availability of habitat at a site based on flow characteristics which may in fact not support fish, regardless of the flow.

The Montana Method analysis follows.

Montana Method

At first examination, the Montana Method (Tennant 1972, 1975, 1976a,b) appears to be one of the simplest techniques for identifying instream flows for fish and wildlife. Habitat characteristics to support fish and wildlife are based on percentages of average annual flow (QAA) derived from field measurements and observations (Table 11).

Table 11. Instream flow regimens for fish, wildlife, recreation and related environmental resources (adapted from Tennant 1975).

Narrative Description of Flows	Recommended Seasonal Base Flow Regimens as percentages of average annual flow	
	Oct.-Mar.	Apr.-Sept.
Flushing or Maximum	200%	200%
Optimum Range	60%-100%	60%-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	<10%	<10%

Assessment of physical, chemical, and biological characteristics associated with 38 flows in 11 streams in Nebraska, Wyoming, and Montana form the basis of the method. According to Tennant (1975), evaluations of the method in 21 other states over a 17 year period indicate the method is consistent from state to state and stream to stream and is suitable for application throughout the world. Sites evaluated included cold and warm water streams ranging from small precipitous brooks to large low-gradient rivers.

Because the method is simple to apply, it has the potential for inadvertent misuse because QAA alone does not describe short or long-term changes in flow rates, seasonal variability, or channel geometry (Cuplin et al. 1979). These factors are represented by Figures 20 and 21, which illustrate the relationships of QAA to hypothetical flow variability and the influence of channel geometry. Knowledge of seasonal flow patterns is essential for determining whether a percentage of the QAA exists during the time of interest. The relationship of flow to channel geometry is important because the channel shape and flow boundary roughness will dictate the velocity and depth characteristics for a given flow, and thus influence the suitability of the habitat for fish utilization.. For example, Channel A in Figure 21 would probably provide more habitat area than Channel B.

One of the principal shortcomings is that users of this method do not always read beyond the "Abstract" of the methods presented in Tennant (1975). Accordingly, these practitioners are unaware of Tennant's advice within the body of his report to observe the site under investigation at three percentages of the QAA (10, 30 and 60 percent), and evaluate whether his ratings (Table 11) for supporting fish and wildlife are applicable or require adjustment. He states that application of his percentages of QAA to spring creeks or streams that have a very uniform flow throughout a year may provide too low of flow recommendations.

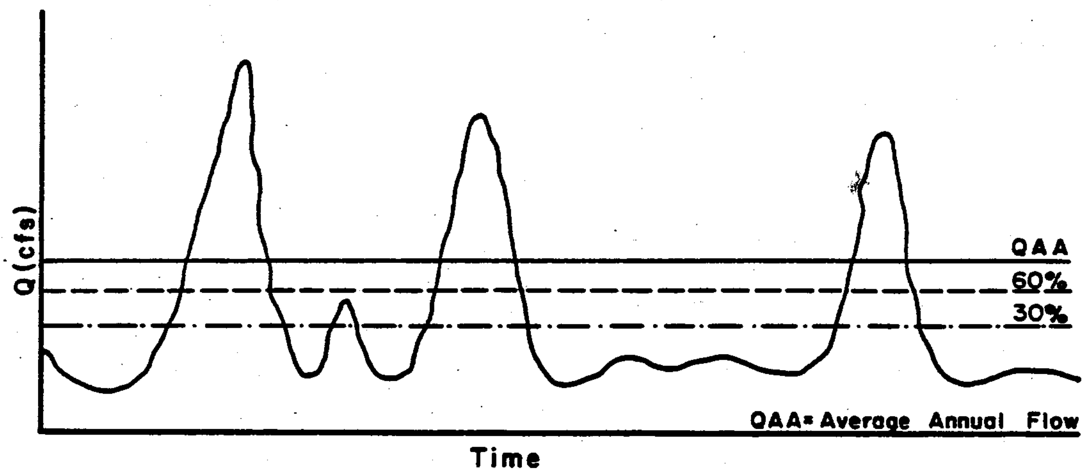

Figure 20. Hypothetical annual hydrograph illustrating flow variability not accounted for by average annual flow (from Cuplin et al. 1979).

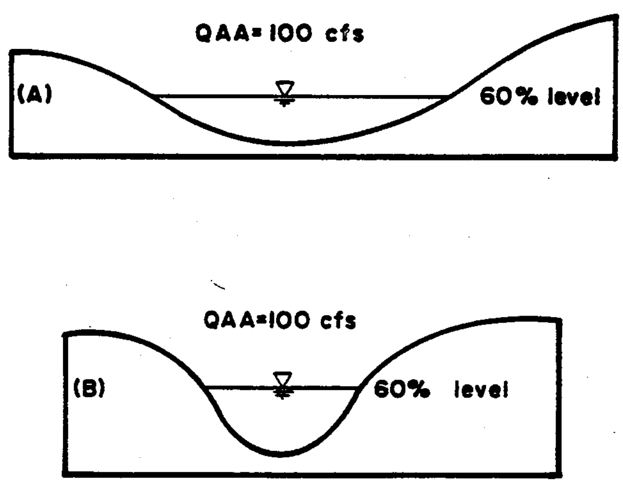

Figure 21. Channel geometry variations illustrating different wetted surface areas at the same percentage of average annual flow (from Cuplin et al. 1979).

Tennant further cautions that the relationship of fish periodicity, especially of salmonids, may influence the seasonal application of his recommended timing of flows or the percentage of flow required itself (Tennant 1972, 1975). Tennant suggests that photographing the site under varying flow conditions will assist with the assessment of which flows support fish and wildlife. He advises potential practioners to study base flow patterns for determining and justifying flow recommendations.

Bayha (1978), heeding Tennant's advice, has used a modification of Tennant's recommended flows to calculate Spring seasonal flows in the midwest. Cuplin et al. (1979) recommend that, if available, the average 10-day and 30-day natural low flows at a site be compared with low flow values recommended by Tennant (Table 11) to determine if flows estimated with the Tennant percentages exist for the period of time in question.

The Montana Method is applied to Willow Creek for demonstration purposes under the assumption that three data bases exist: a long-term flow record, a limited-flow record, and no flow record.

Methods

Data Base Generation

To determine instream flows for a site corresponding to Table 11 recommendations, the QAA for the site must be calculated. Investigators most likely will encounter one of three conditions concerning the availability of stream flow data when they begin this process:

1. Long-Term Flow Record - a historical flow record equal to or greater than 10 years duration at or near the site;

2. Limited-Flow Record - a historical flow record of less than 10 years duration has been compiled at or near the site. The record may or may not be continuous; or

3. No Flow Record - flow data have not been recorded at or near the site under investigation; or if they have, they are not published in a readily available source.

Accordingly, descriptions of procedures for deriving the QAA in these situations follow.

Long-Term Record

Stream flow data are collected predominantly by the USGS. These data are summarized in an annual "Data Report" (early records are contained in "Water Supply Papers"). Data collected over a period of ten or more years are defined as long-term data in this thesis. The QAA is referred to as "mean" discharge by the USGS and is calculated on an annual basis for a "water year"*. A long-term QAA is also calculated each year and is referred to as the "average" discharge for the period of record (a running average). Water data standards established by the USGS require that a minimum of 10 years of record be acquired to provide a statistical minimum data base for calculating the long-term average QAA; but, a 20-year or longer record is better (Boner and Buswell 1970).

Limited-Flow Record

Stream flow data covering a period less than 10 years are considered short-term because of statistical limitations. If data are incomplete within a water year, the data are published as a "partial record". Because a short-term data base covers less than 10 years of record, the QAA value for the period of record may not reflect the long-term conditions for the site and thus will not provide a reliable basis for calculating a percentage of QAA. Accordingly, methods for enhancing the data base are required. Five approaches should be considered for extending a limited-flow record:

1. Calibrate the site having a limited-flow record with a nearby site having a long-term flow record. Daily, 30-day, and QAA records from the short-term

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*QAA values in this report, similar to the USGS, are based on a "water year" (October to September).

station should be correlated with the long-term station to account for seasonal variations. Data from the descending limb of the hydrograph should be used in this process, because data from ascending limb events do not represent comparable relationships between basin and flow characteristics. This correlation is accomplished by plotting the data from the site having a long-term record on the X-axis, and comparable data from the limited-flow record on the Y-axis (Figure 22);

2. If time were not a consideration, one could continue to monitor the short-term site until the desired period of record is obtained;

3. If a regional model relating flows to basin characteristics and precipitation were available, the results of the limited-term record could be compared with that information;

4. Daily flows could be measured at the short-term site during the period of interest to further check the reliability of the model; and

5. Various combinations of the preceding four approaches could be used to extend a limited-flow

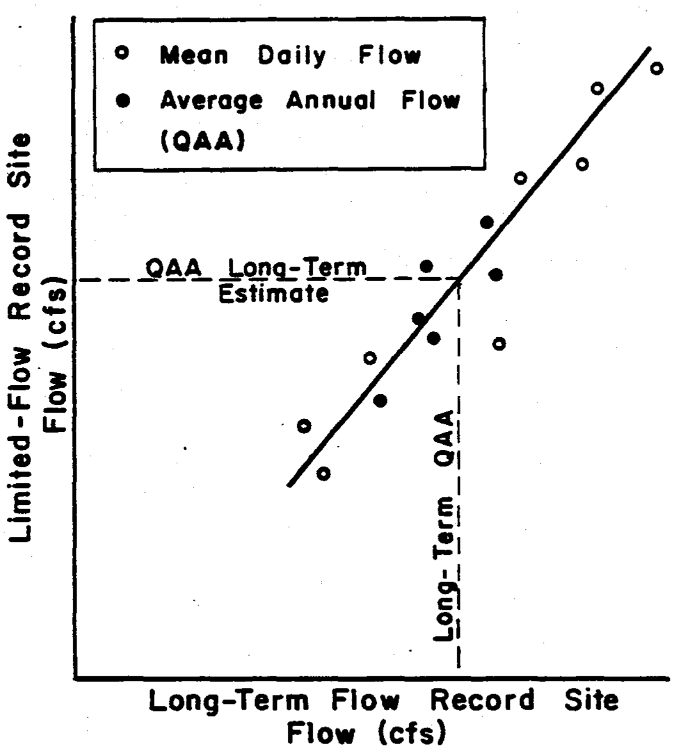

Figure 22. Conceptual representation of the correlation of a limited flow record site with a long-term flow record site to extend a limited flow record.

data base and test its validity.

No Flow Record

In this situation, a limited-flow record must initially be generated at or near the study site. It can then be extended to estimate a long-term record as discussed above. Flow records can be generated by:

1. Measuring a minimum of three flows which represent high, medium and low flow conditions on the descending limbs of hydrographs. If desired, a stage/discharge relationship can be developed from the measurements to estimate additional flows from stage readings.

2. Using basin characteristics to generate general flow conditions if a regional model is available; or,

3. Combining these two approaches.

After an approach is selected to develop what is equivalent to a long-term record, Orsborn (1980, 1981) recommends that the long-term QAA, two-year peak or mean flood flow (QF2P), and seven-day average two-year (Q7L2) and twenty-year (Q7L20) low-flows (or long-term average 30-day minimum flow) for the period of interest be estimated. This provides the opportunity to compare estimated QAA values against other flow conditions that are experienced during the periods of interest. In this report, the period of interest is July and August because these two months represent the spawning period for chinook and pink salmon.

In summary, the selection of an approach to calculate the QAA will depend on the availability of data, resources for collecting and analyzing the data, and the level of expertise of data analysts. Regardless of which approach is selected, it is highly recommended that a hydrologist or hydraulic engineer be consulted when estimating, extending, and interpreting hydrological records.

Flow Calculation

Once a satisfactory QAA value is obtained, the percentages of QAA (Table 11) as recommended by Tennant (1975) are calculated.

The above methods are used to determine QAA and instream flow values for Willow Creek in the next part of this section.

Results

Data Base Availability

Long-term flow records are not available for Willow Creek. When this study was initiated in 1979, there was only one partial year of flow data. Since then, continuous record keeping has occurred. Accordingly, a five-year (1978* to 1982a) continuous flow record (USGS Gage No. 15294005) is presently available (USGS 1979, 1980, 1981, 1982a, 1983), and a sixth year of data (1984) will be released in the near future.

A nearby river, the Little Susitna River (USGS Gage Number 1529000), has a 34-year (1949 to 1982a) long-term continuous flow record (USGS 1977, 1978, 1979, 1980, 1981, 1982a, 1983; Scully et al. 1978**). The Little Susitna River (Figure 23) is 60 miles by road to the north of Anchorage and is 52 miles in length. Gage Number 15290000 is 37 miles upstream from the mouth of the Little Susitna River and represents a drainage area of 62 square miles. Five percent (3.1 square-miles) of this upper drainage area is glacial. A flood frequency analysis for the Little Susitna River at this site is available (Lamke 1979) as are three equations (Table 12) relating basin characteristics to flows for Cook Inlet and the Little Susitna River basins (Freethey and Scully 1979; Orsborn 1980).

Precipitation estimates for this area are available in Lamke (1979) from the U.S. Department of Agriculture Soil Conservation Service (Merrell 1979), and Freethey and Scully (1980).

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*The flow record for water year 1978 is incomplete and begins in June.

**Summarizes data for Gage Number 15290000 from 1948-1975.

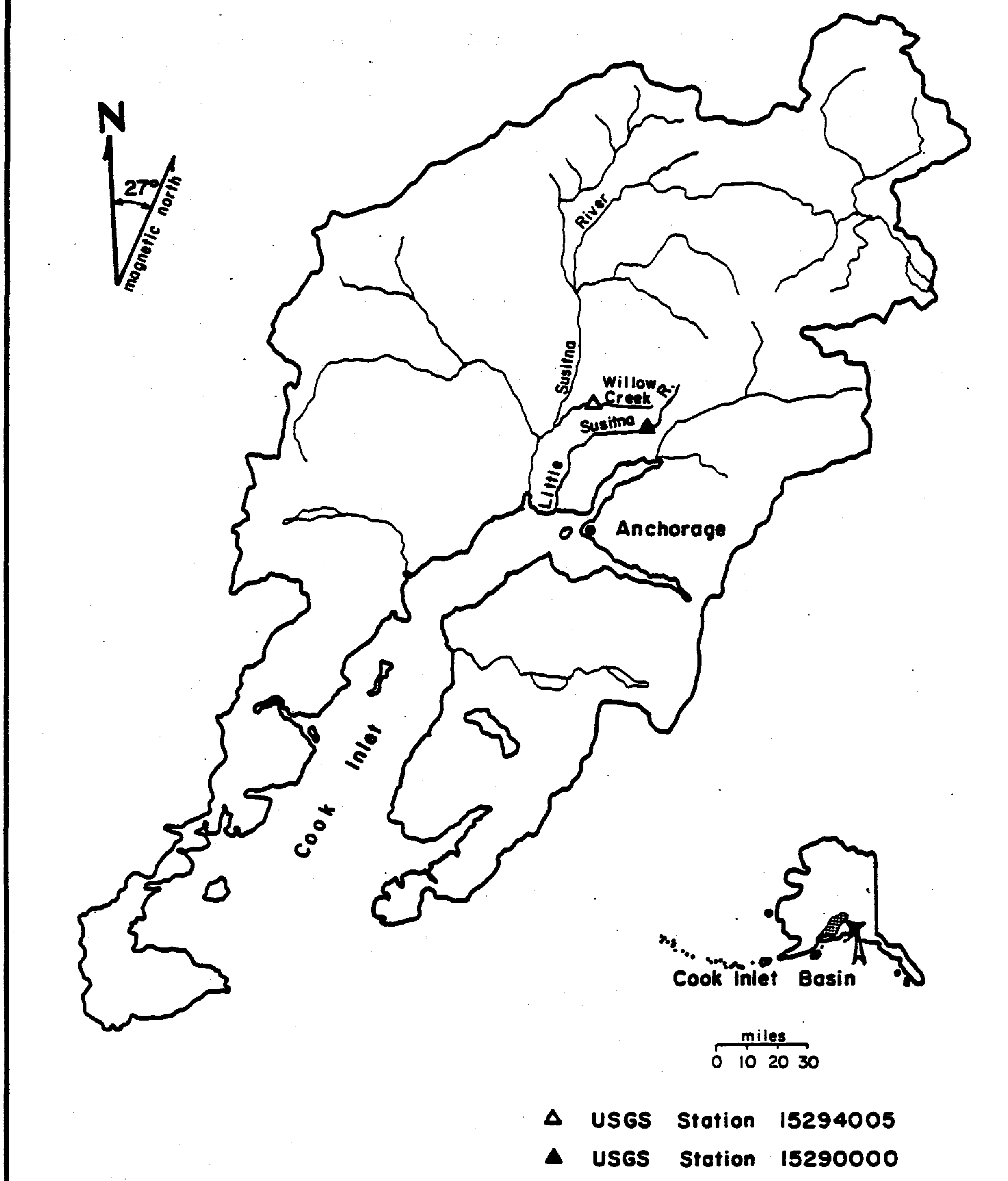

Figure 23. Cook Inlet Basin.

Table 12. Equations (One and Two) relating average annual flow (QAA) to basin characteristics for the Cook Inlet Basin (Freethey and Scully 1980; Orsborn 1980) and two-year peak flood flow(QF2P) to basin characteristics for the Little Susitna River (Orsborn 1980).

Equation

One Cook Inlet Basin $QAA = 0.012\ (A)^{0.99}\ (P)^{0.93}\ (E)^{0.22}$

QAA - Average Annual Flow (cfs)

A - Drainage Area (mi²)

P - Mean Precipitation (in/yr)

E - Mean Basin Elevation (ft MSL)

Two Cook Inlet Basin $QAA = (C)\ (P \cdot A)$

C - Coefficient

P - Mean Precipitation (in/yr)

A - Drainage Area (mi²)

Three Little Susitna River $QFP2 = 3.5\ (P \cdot A \sqrt{H})^{0.82}$

QF2P - Two-Year Peak Flood (cfs)

P - Mean Precipitation (in.)

A - Drainage Area (sq.mi.msl.)

H - Basin Relief ($\frac{\Delta \text{Elevation}}{5280\ \text{ft}}$)

* For comparison of Flushing flow estimates.

Analyses

The application of three different hydrological data bases for determining instream flow recommendations with the Montana Method are compared. QAA values are calculated below using:

1. no flow record for Willow Creek;

2. a limited-flow record; and

3. a limited-flow record extended by correlations with the Little Susitna River long-term flow records.

These analyses test the applicability of the Montana Method for estimating flow conditions as percentages of QAA for the site in question. They do not test the ability of the method to identify flows which support spawning by salmon. An analysis of the suitability of the percentages of flow recommended by Tennant for spawning is discussed in the final two chapters.

No Flow Record

Equation One from Table 12 was used to estimate a QAA of 276 cfs for Willow Creek (Table 13).

Table 13. Calculation of Willow Creek average annual flow (QAA) from basin characteristics (Table 12: Equation One).*

(a) $QAA = 0.012\ (A)^{0.99}\ (P)^{0.93}\ (E)^{0.22}$

(b) $QAA = 0.012\ (166)^{0.99}\ (32)^{0.93}\ (3000)^{0.22}$

(c) $QAA = 0.012(158)(25.1)(5.8)$

(d) QAA = 276 cfs

*Drainage Area (A) and Mean elevation (E) are derived from USGS topographic maps. Precipitation values are derived from (Merrell 1979).

Table 14. Average annual flows (QAA) for Willow Creek (Gage No. 15294005) and the Little Susitna River (Gage No. 15290000), 1979-1982.

Station Year	Little Susitna River QAA (cfs)	Willow Creek QAA (cfs)
1979	257	433
1980	294	511
1981	212	367
1982	264	427
Average	257	435

Limited-Flow Record

QAA values from the four years of record (1979-1982) at the Willow Creek gage (Number 15294005) are summarized in Table 14 and an average QAA value of 435 cfs is calculated. The flow data are derived from USGS (1980, 1981, 1982a, 1983) records.

Limited-Flow Record Extended by Correlations with a Long-Term Flow Record

Average daily flows for Willow Creek and the Little Susitna River (Table 15) for the similar periods of record (1978-1982) are plotted in Figure 24. A good correlation is indicated by these data and seasonal variations are of interest.

During the summer months, the rate of increase of Willow Creek flows (>200 cfs) to Little Susitna River flows (>200 cfs) appears to be greater than in the winter. During the fall it appears as though a transitional period is experienced when Willow Creek flow (200 cfs) is stable and Little Susitna River flows (80 cfs to 200 cfs) begin to decline, temporarily shifting the logarithmic relationship between the two systems indicating a period of independence. The smaller drainage area of the Little Susitna River drainage (62 square miles) and higher elevations above the flow station, plus its glacial area, may influence this pattern. Groundwater storage in the Little Susitna Basin may also be less than that in the Willow Creek drainage.

Table 15. Examples of mean daily flow values for the Little Susitna River (Gage No. 15290000) and Willow Creek (Gage No. 15294005).

Station Date	Little Susitna River Flow (cfs)	Willow Creek Flow (cfs)
07/06/78*	353	545
07/11/78*	314	426
08/08/78*	241	317
08/19/78*	203	250
08/30/78*	147	207
09/30/78*	94	210
10/10/78*	84	210
10/31/78*	66	179
02/05/79*	27	76
02/28/79*	25	70
05/29/79*	1610	2700
07/10/79*	706	1100
07/20/79*	627	984
07/30/79*	475	688
08/05/79*	383	570
12/10/79*	66	160
12/27/79*	50	140
01/15/80*	40	110
06/15/80*	726	1240
07/28/80*	2090	3370
07/28/80**	2640	4450
07/29/80*	1340	1800
08/01/80*	950	1490
08/26/80*	493	782
09/11/80	160	348
10/22/80*	108	242
06/26/81	296	434
08/03/81	1250	1550
09/28/81*	90	276
09/30/81*	84	267
07/06/82***	543	589
07/12/82***	676	680
07/26/82***	1740	1750
07/29/82***	999	892
08/01/82***	850	996
08/09/82	470	536
09/17/82*	1020	1810

*Plotted on Figure 24.
**Instantaneous peak flow (plotted on Figure 25).
***Low water year for Willow Creek for the month of July based on comparison of relationship with Little Susitna River for other years.

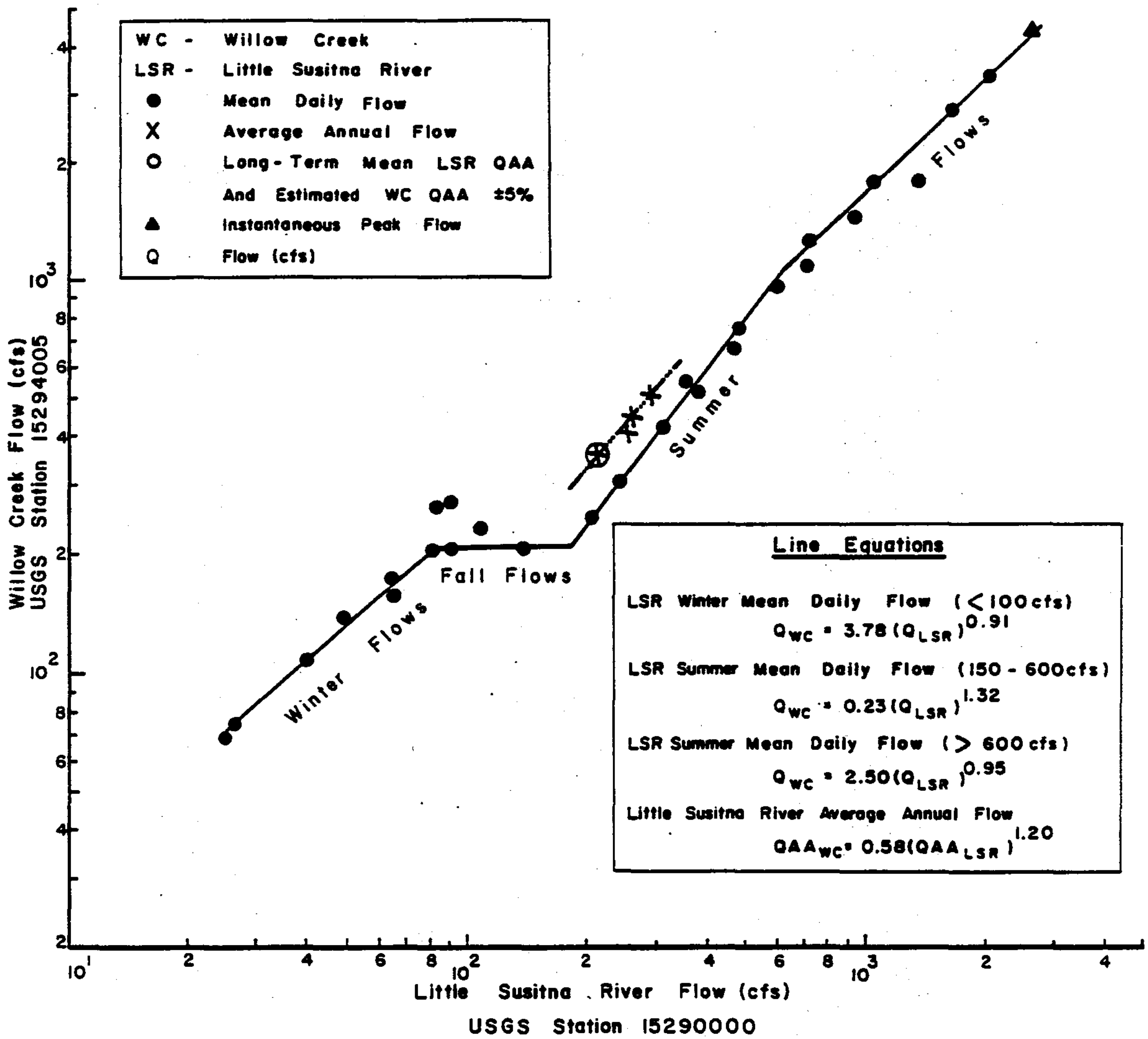

Figure 24. Correlation of Willow Creek mean-daily and average annual (QAA) flows to the Little Susitna River flows.

As winter approaches, a logarithmic relationship is reestablished between the two systems with the exception that flows in the Little Susitna River (<80 cfs) vary at a higher rate in proportion to Willow Creek flows (<200 cfs) as opposed to mid- and late summer.

By plotting QAA (Table 14) for the period 1979 to 1982 on the same figure (Figure 24), QAA flows for the Little Susitna River are less than those projected on a daily average basis. This pattern illustrates the apparent influence of long winters and lower flows on the Little Susitna River. Assuming the QAA relationships between Willow Creek and the Little Susitna River are correct, a long-term QAA can be projected for Willow Creek by calculating the average of the 1949 to 1982 (34-years) QAA values (Table 16) for the Little Susitna River (208 cfs) and deriving a comparable value (350 cfs) for Willow Creek from Figure 24.

Arithmetically, the four-year QAA for the Little Susitna (257 cfs) is 1.24 times greater than the 34-year average (208 cfs), indicating a wet cycle in 1979-1982. By dividing the average four-year QAA (435 cfs) for Willow Creek by 1.24, a QAA of 351 cfs is calculated, supporting the relationships represented by Figure 24.

Another means of deriving the QAA would be to apply Equation Two* from Table 12 to the Little Susitna River to back calculate the coefficient

*The Little Susitna River and Willow Creek are both within Cook Inlet Basin.

Table 16. Thirty-four year (1949-1982) record of average annual flow (QAA) values for the Little Susitna River (Gage No. 15290000) and four-year (1979-1982) record of QAA values for Willow Creek (Gage No. 15294005).

Year	Little Susitna River QAA (cfs)		Willow Creek QAA (cfs)
1949	316	maximum	
1950	140		
1951	219		
1952	243		
1953	186		
1954	160		
1955	222		
1956	186		
1957	197		
1958	134		
1959	231		
1960	179		
1961	205		
1962	247		
1963	297		
1964	191		
1965	209		
1966	168		
1967	236		
1968	210		
1969	96	minimum	
1970	158		
1971	232		
1972	228		
1973	184		
1974	181		
1975	229		
1976	161		
1977	250		
1978	142		
1979	257		433
1980	294		511
1981	212		367
1982	264		427
Average	208		435

"C" based on the 34-year QAA of 208 cfs. The coefficient from the back calculation of the long-term Little Susitna River QAA can be used to estimate the long-term QAA for Willow Creek (Table 17). A QAA value of 356 cfs is calculated for Willow Creek and is only 6 cfs greater (<2%) than the estimated long-term QAA value of 350 cfs derived from Figure 24.

Table 17. Calculation of long term average annual flow (QAA) for Willow Creek using basin and precipitation characteristics (Table 12: Equation Two).

a. Little Susitna River 34-year QAA 208 cfs = (C)(50)(62)

(C) = coefficient

(50) = mean precipitation

(62) = drainage area

b. $C = \frac{208}{3100} = 0.067$

c. Willow Creek Long Term QAA = (0.067)(32)(166) = 356 cfs.

The range of possible high (570 cfs) and low (150 cfs) long-term QAA values for Willow Creek are estimated in Figure 25 by comparison with long-term high (316 cfs) and low (96 cfs) QAA values for the Little Susitna River.

Long-term July and August maximum, mean and minimum average monthly flows are estimated for Willow Creek in Figures 26 and 27.

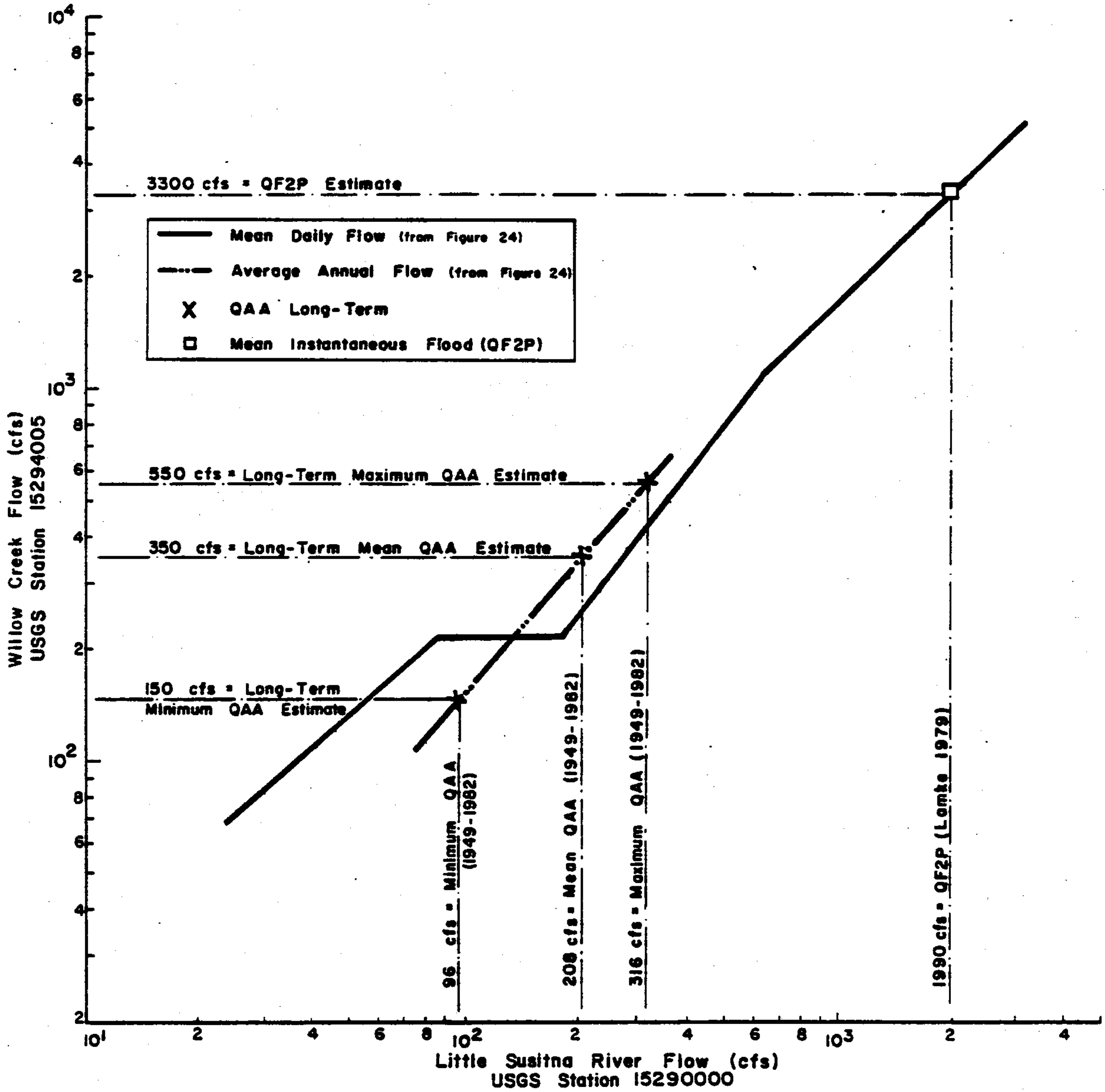

Figure 25. Correlation of Willow Creek four year average annual flow (QAA) record with the long-term (34 year) QAA record for the Little Susitna River.

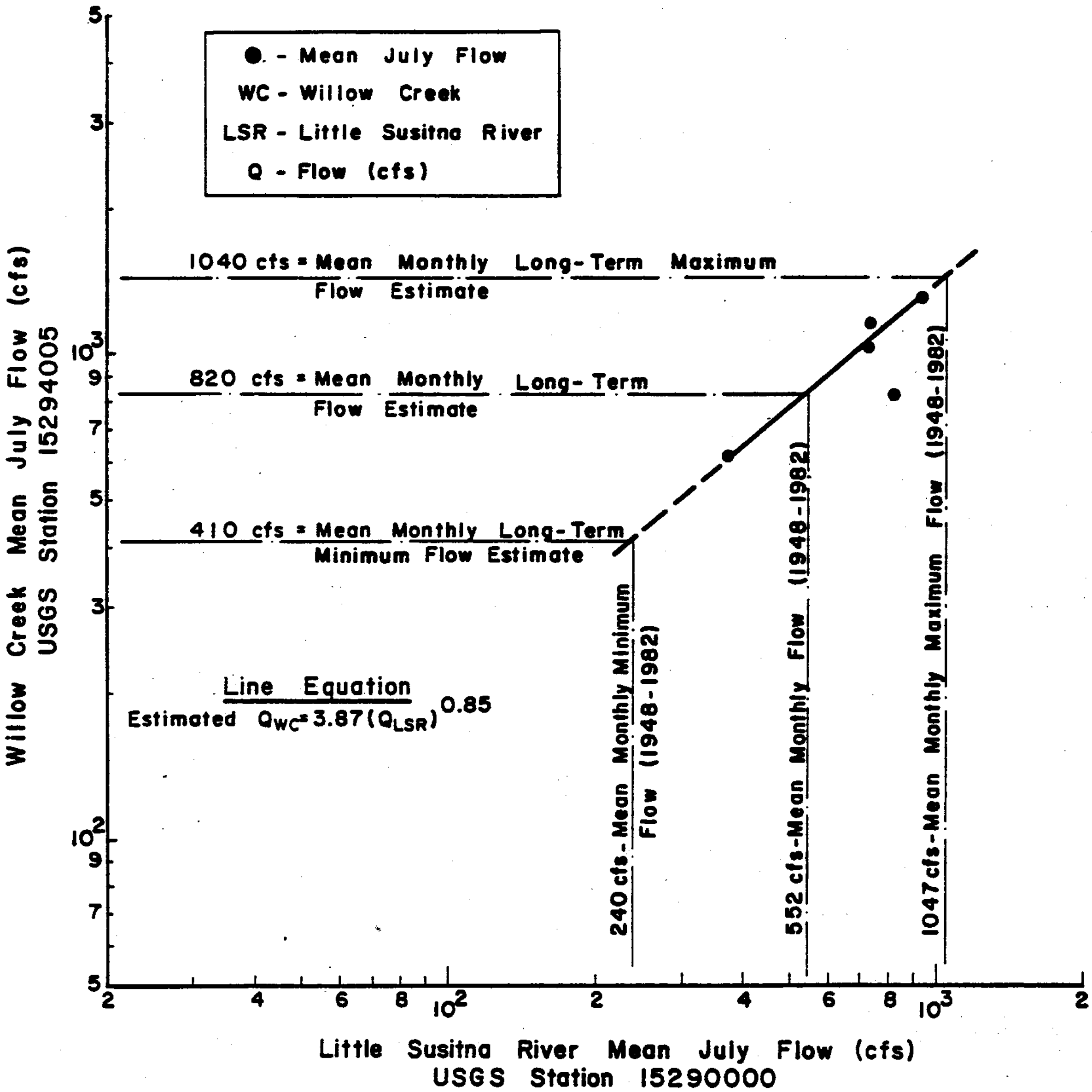

Figure 26. Correlation of Willow Creek mean July flows (1978-1982) with long-term (1948-1982) mean July flows for the Little Susitna River.

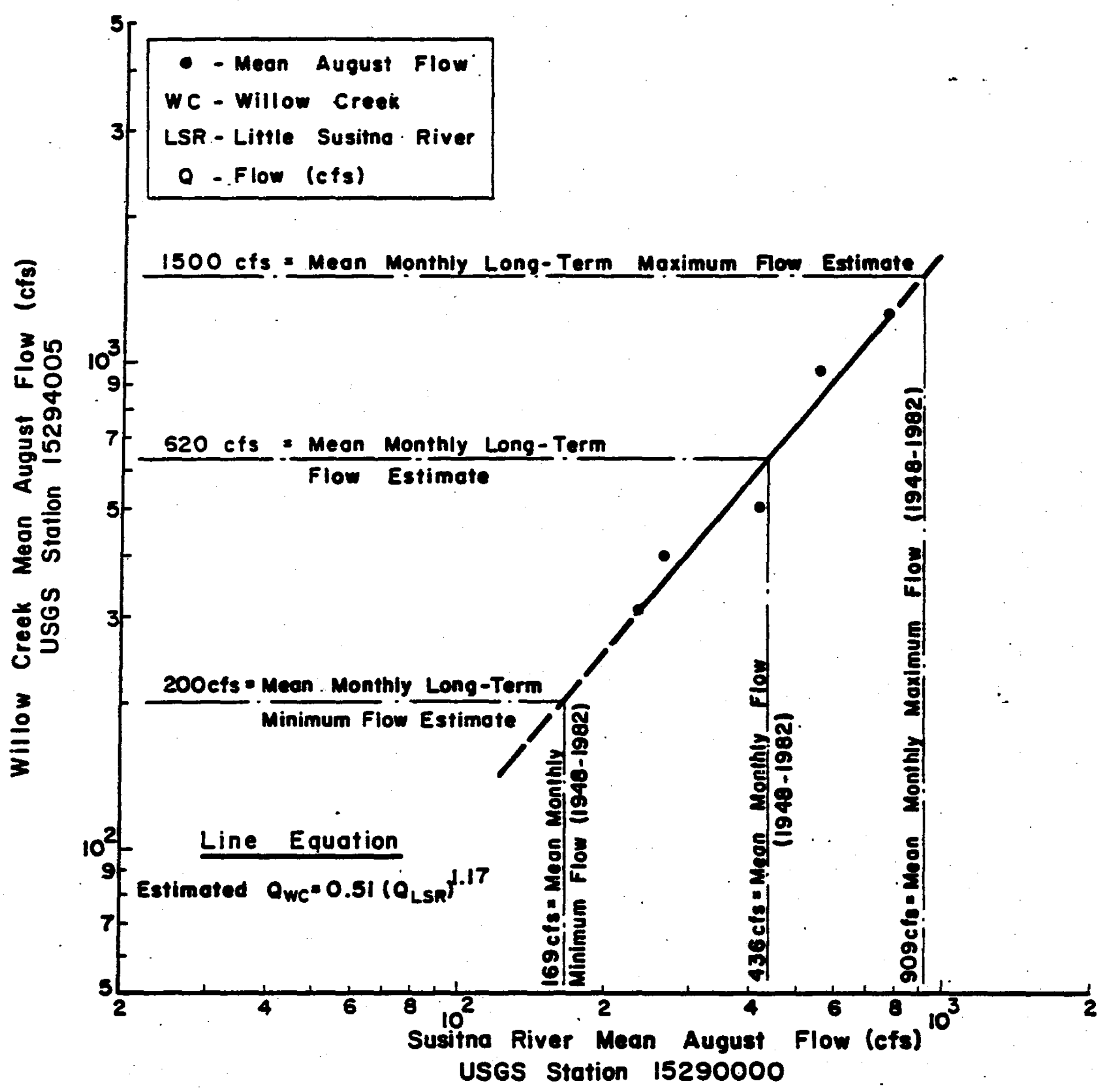

Figure 27. Correlation of Willow Creek mean August flows (1978-1982) with long-term (1948-1982) mean August flows for the Little Susitna River.

Thirty-one day average flow values for July and August for the Little Susitna River over a 34-year period (Tables 18, 19) are correlated with five years of flow data for Willow Creek in Figures 26 and 27. This correlation was executed to determine whether the Tennant percentages of maximum and minimum QAA flow values (Table 11) represent estimated long-term flow conditions that exist during these two months. Average monthly values estimated in Figures 26 and 27 for Willow Creek are: maximum flows of 1040 cfs (July) and 1,500 cfs (August); mean flows of 820 cfs (July) and 620 cfs (August); and minimum flows of 410 cfs (July) and 200 cfs (August). Monthly values for these two months are estimated because July and August represent the months when chinook and pink salmon spawn in Willow Creek. The mean long-term flow monthly average estimates for Willow Creek are 234% (July) and 177% (August) greater than the long-term QAA estimate (350cfs). Accordingly, these monthly values are compared below with the percentages of QAA recommended by the Montana Method to evaluate whether the various percentages of QAA recommended in Table 11 are present in Willow Creek. This does not, however evaluate which percentages of flow recommended in Table 11 are suitable or preferred for spawning by chinook and pink salmon.

Instream Flow Calculations

Instream flow values are calculated as percentages of the three QAA values derived from no flow record (276 cfs), limited-flow record (435 cfs) and limited-flow records extended by correlation (350 cfs) in Table 20. A comparison of these values with the long-term 30-day

Table 18. July mean flows for the Little Susitna River (Gage No. 15290000) and Willow Creek (Gage No. 15294005).

Station Year	Little Susitna River Flow (cfs)		Willow Creek Flow (cfs)
1948	558		
1949	940		
1950	358		
1951	489		
1952	697		
1953	278		
1954	381		
1955	806		
1956	610		
1957	310		
1958	240	minimum	
1959	459		
1960	367		
1961	506		
1962	569		
1963	1047	maximum	
1964	456		
1965	497		
1966	361		
1967	633		
1968	601		
1969	242		
1970	419		
1971	622		
1972	743		
1973	374		
1974	407		
1975	720		
1976	427		
1977	619		
1978	375		607
1979	742		1154
1980	930		1287
1981	724		1019
1982	823		816
Average	552		977

Table 19. August mean flows for the Little Susitna River (Gage No. 15290000) and Willow Creek (Gage No. 15294005).

Station Year	Little Susitna River Flow (cfs)		Willow Creek Flow (cfs)
1948	661		
1949	681		
1950	296		
1951	446		
1952	428		
1953	444		
1954	500		
1955	556		
1956	398		
1957	218		
1958	305		
1959	736		
1960	361		
1961	456		
1962	534		
1963	825		
1964	294		
1965	451		
1966	402		
1967	524		
1968	231		
1969	169	(minimum)	
1970	422		
1971	909	(maximum)	
1972	297		
1973	392		
1974	259		
1975	348		
1976	216		
1977	246		
1978	238		307
1979	266		398
1980	555		955
1981	776		1286
1982	414		500
Average	436		689

Table 20. Comparison of July and August instream flow values for Willow Creek as determined by the Montana Method using three methods to calculate the average annual flow (demonstration analysis).

Flow Classification and Percentage of Average Annual Flow	FLOW (cfs) CALCULATION		
	No Flow Record	Limited Flow Record	Flow Record Extended by Correlation
Average Annual 100%	276	435	350
Flushing 200%	552	870	700
Optimum Range 60%-100%	166-277	261-435	210-350
Outstanding 60%	166	261	210
Excellent 50%	138	218	175
Good 40%	110	174	140
Fair or Degrading 30%	83	131	105
Poor 10%	28	44	35
Severe Degradation <10%	<28	<44	<35

minimum average flow estimates for Willow Creek for July (410 cfs) and August (200 cfs) from Figures 26 and 27, indicates that "outstanding" to "optimal" flows (as defined by Tennant) appear to naturally occur in Willow Creek on a minimum average monthly basis for July regardless of the QAA calculation technique.

The long-term August mean value (620 cfs) from Figure 27 indicates that outstanding to optimal flows can be expected on an average basis using either the no-flow and extended-flow record QAA estimates. Percentages of the limited-flow record QAA estimates indicate that "good" to "excellent" conditions can be expected on an average basis in August.

According to Tennant (1975), flushing flows equalling 200% of the QAA are required to move sediment and other bed load material without doing extensive damage to the banks and riparian vegetation. Lister (1976) refers to a flow having these characteristics as the "dominant discharge." Flushing flow values for Willow Creek are summarized in Table 20 and calculated to be 552 cfs (no flow record); 870 cfs (limited-flow record), and 700 cfs (extended-flow record). These values can be expected during average years for July for each of the QAA techniques and for the no flow record and extended-flow record calculations in an average August. Not defined by Tennant, however, is the duration required of the flushing flow.

According to Orsborn (1981), a flushing flow is more equivalent to a mean annual peak flood (QF2P) event or its associated high three-day or seven-day average flows, which range from 60% to 75% of the QF2P. The three-day and seven-day flows are better measures of sediment flushing flows because of their flow duration.

The QF2P for Willow Creek can be estimated with Figure 24 or with Equation Three in Table 12. Using the correlations developed in Figure 25, a long-term QF2P of 3300 cfs for Willow Creek is estimated from the QF2P of 1990 cfs for the Little Susitna River calculated by Lamke (1979). Using Equation Three in Table 12 generates a QF2P of 3475 cfs (Table 21) which is within the accepted range of stream gaging accuracy (±5%). Comparisons of the relationships between the QAA and QF2P for Willow Creek and six other Alaskan sites (Table 22) indicates that on the average the QF2P instantaneous value is equivalent to 600% of the QAA as opposed to the 200% suggested by Tennant (Table 11).

To determine the three-day and seven-day mean flows for flushing sediments in Willow Creek, consecutive three-day and seven-day highest mean daily values are averaged which include the day the annual peak flow occurs and the days immediately following and/or preceding the event. These values are 2593 cfs for a three-day flow and 2159 cfs for a seven-day flow (Table 23). These values equal 75 percent (three days) and 62 percent (seven-days) of the QF2P (Table 23) and are in the range suggested by Orsborn (1982) based on records in other parts of the country. By dividing the three-day and seven-day flows by the long-term QAA (350 cfs) estimated for Willow Creek, values of 741 percent and 617

Table 21. Calculation of mean flood (QF2P) for Willow Creek (Table 12: Equation Three).*

a. Willow Creek $QF2P = 3.5(P \cdot A \cdot \sqrt{H})^{0.82}$

b. $QF2P = 3.5\ (32 \cdot 166 \cdot \sqrt{0.73})^{0.82}$

c. $QF2P = 3.5\ (32 \cdot 166 \cdot 0.85)^{0.82}$

d. $QF2P = 3.5\ (32 \cdot 166 \cdot 0.85)^{0.82}$

e. QF2P = 3475 cfs

$$H = \frac{4000 - 150}{5280} = 0.73$$

*Values for P and A are derived from Table 13. H is from USGS topographic map 1:63,360 - Tyonek D-1, Anchorage D-8.

Table 22. Relationships of average annual flow (QAA) to mean annual flood flow (QF2P) at seven USGS gaging stations in the Cook Inlet area, Alaska (Lamke 1979; USGS 1983).

Station	Gage Number	QF2P (cfs)	QAA (cfs)	QF2P/QAA (%)	Area (sq.mi.)
Campbell Creek	15274600	233	65	358	70
Chester Creek	15275100	83	18	461	27
Eagle River*	15277100	3000	528	568	192
Knik River	15281000	32200	6952	338	1180
Little Susitna River	15290000	1990	208	957	62
Maclaren River	15291200	5690	978	582	280
Willow Creek	15294005	3300**	350**	943	166

* USGS 1981.
** Estimated.

Table 23. Sample calculation of mean high daily three-day and seven-day flow values as percentages of recorded peak flood flow and long-term average annual flow (QAA)* for Willow Creek (Gage No. 15294005).

Date	Three-day highest mean daily flows (cfs)	Seven-day highest mean daily flows (cfs)	Peak Flow** QF2P (cfs)
08/12/81		1990	
08/13/81	2320	2320	
08/14/81	2700	2700	
08/15/81	2760	2760	3470**
08/16/81		2280	
08/17/81		1640	
08/18/81		1420	
Average	2593	2159	

Calculations:

a. Three-day percentage of peak flow = $\frac{2593}{3470}$ = 75%

b. Seven-day percentage of peak flow = $\frac{2159}{3470}$ = 62%

c. Three-day percentage of QAA = $\frac{2593}{350}$ = 741%

d. Seven-day percentage of QAA = $\frac{2159}{350}$ = 617%

*Long-term QAA estimate is 350 cfs.

**Assumed equal to the long-term QF2P estimate of 3300 cfs (3470 cfs = ±5% of 3,300 cfs).

Table 24. Flushing flows as a percentage of average annual flow (QAA) as recommended by Tennant (1975) and Orsborn (1981).

Percentage of QAA	High Flow Duration	FLOW (cfs) CALCULATION No Flow Record	Limited Flow Record	Flow Record Extended by Correlation
100% average annual flow	----	276	435	350
200% Tennant	----	552	870	700
943% Orsborn	instant.*	2603	4102	3300
741% Orsborn	3-day	2045	3223	2593
617% Orsborn	7-day	1703	2684	2159

*Instantaneous mean flood (QF2P) or annual peak flows do not represent sediment flushing flows as well as do the longer term 3-day or 7-day average high annual flows associated with a QF2P or annual peak event.

percent are calculated (Table 23). Flushing flow values as percentages of the QAA suggested by Tennant (1975) and Orsborn (1982) are compared in Table 24. All values are within the average range of conditions expected for Willow Creek with the exception of the QF2P (4102 cfs) calculated with the limited-flow record.

Discussion

The preceding calculations of QAA to determine recommended instream flow values are based on office data (e.g., existing published data).

Results from these analyses are compared with the IFIM analysis as a means of evaluating which of the percentages of QAA would be preferred for spawning by salmon. It is important to note that the percentages of flow as defined by Tennant may not be appropriate for all species, life phases, and seasons evaluated.

Referring to Figure 20, illustrating the conceptual relationship between QAA and seasonal variation, a similar illustration (Figure 28) has been prepared based on data from Willow Creek (Gage No. 15294005) in water year 1981 (USGS 1982a); Two Medicine River below South Fork, near Browning, Montana (Gage No. 06091700) for water year 1982 (USGS 1982b) and Boulder River, near Contact, Montana (Gage No. 06175000) for water year 1963 (USGS 1963). These years were selected because the annual QAA flow for each site was close to the estimated long-term QAA (350 cfs) for Willow Creek. All three systems have short-term QAA values within five percent of each other, yet represent the influence of climatic and seasonal variation on flow availability as functions of their individual relationships. Accordingly, all three are compared to Tennant's percentages of QAA based on a QAA of 350 cfs.

Although this comparison may not be exactly representative of long-term mean conditions, it is interesting because the Tennant Method (1975) is primarily based on data collected in Montana and neighboring states. It is also important to note that the Two Medicine River has 54 acres of diversions for irrigation and the Boulder River 10 acres of diversions.

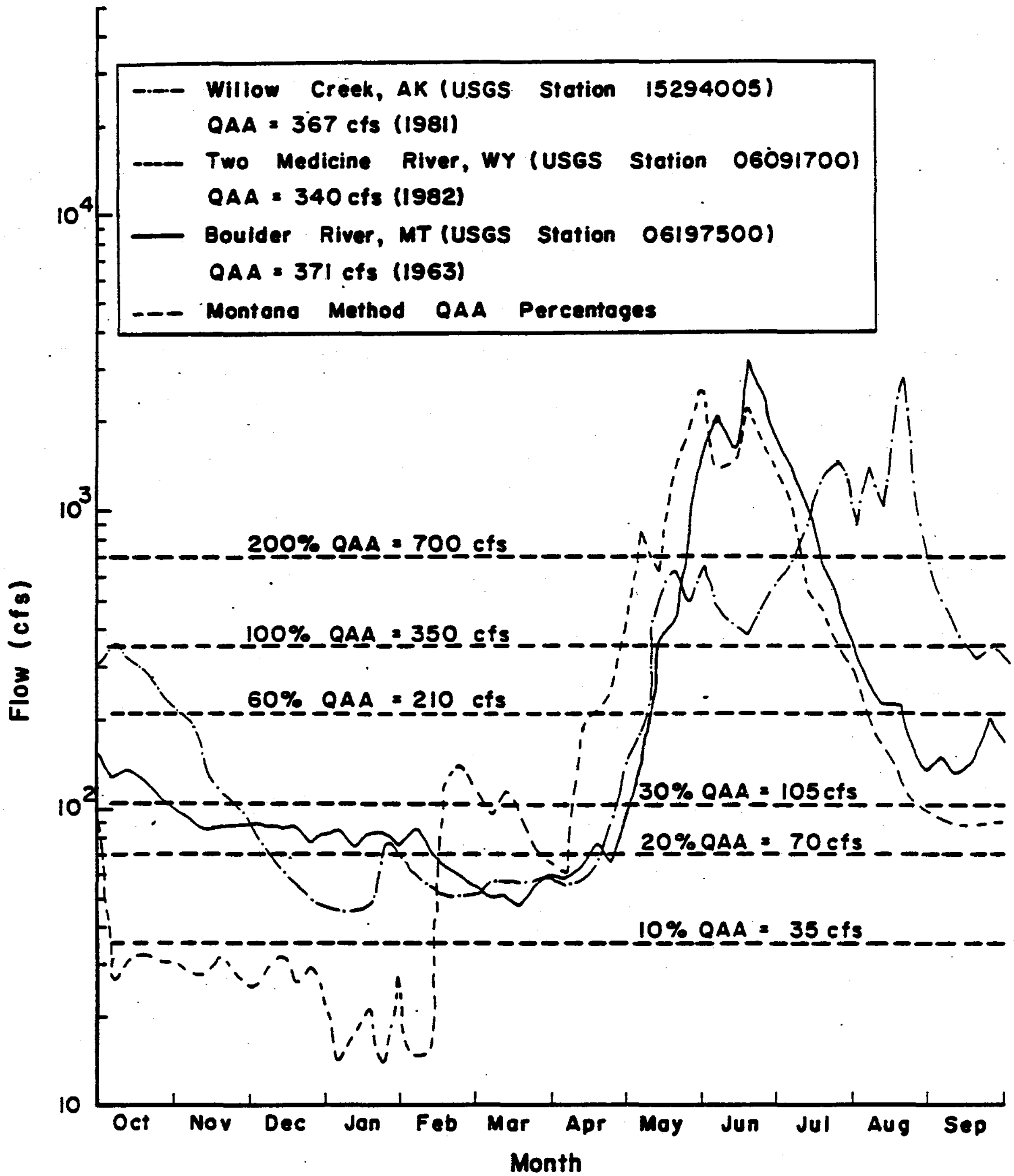

Figure 28. Comparisons of annual hydrographs for Willow Creek and two Montana streams with the long-term average annual flow (QAA) for Willow Creek.

From Figure 28, it can be observed that in Montana flows equal to or greater than the 1981 QAA for the two Medicine River and the 1963 QAA for the Boulder River extend from late April through July with flows peaking in late May and the middle of June. Flows equal to or greater than the 1982 QAA for Willow Creek in Alaska extend from May through early October and peak in mid-August, two months later than the systems in Montana. All three systems have similar ranges of high flows; low flows vary significantly. Low flows for Two Medicine River extend from October through mid-February and average less than 10 percent of the average annual flow. Low flows for the Boulder River extend from November through mid-April at an average 15 percent of the QAA. Willow Creek low flows, on the other hand, occur between late December and mid-April at an average 15 percent of the QAA.

This climatic and seasonal variability illustrates the danger (as noted by Tennant 1975) in using a percentage of the QAA as a basis for recommending a flow regime without evaluating seasonal variations and natural flow patterns. Milhous (1974) also supports this advice based on an evaluation of several streams.

The relationship of these patterns to fish and wildlife must also be considered. For example, fish and wildlife in the Montana systems have adapted to high flows in May and June; whereas salmon in Willow Creek spawn primarily in mid-July through August during periods of higher flows for that region. Therefore, one must be careful before applying seasonal percentages of flow criteria from one system to another, unless it can be determined that such a relationship is acceptable. Individual requirements of various species and life phases are other equally important considerations when recommending flows.

The influence of diversions must be considered when determining a flow recommendation. Diversions are presently not a major concern in Alaska, but may be some day. Tennant (1975) recommends that when diversions are evaluated, that instantaneous flows be guaranteed. An average condition which is suitable for fish which, includes instantaneous flows that are unsuitable, can be lethal to or, at a minimum, will stress the fishery.

Accordingly, it is recommended that observations of biological activities at various flow regimes be monitored to determine if the Tennant (1975) percentages of QAA are appropriate for the system from a biological perspective. This topic is expanded in the final chapter.

Orsborn's Methods

This is a demonstration analysis testing the application of two methods by Orsborn (1982) for defining the maximum spawning area flow (QMSA) and maximum spawning area (MSA) for chinook salmon at Willow Creek. Using these techniques,

1. QMSA can be estimated as a function of channel and basin characteristics (Method A); and

2. MSA as surface area (ft^2) per 100 linear feet of streamreach can be estimated as a function of bankfull wetted area (ft^2 per 100 linear feet) for a streamreach (Method B).

The premise of the Orsborn techniques is that streams flowing within comparable bed and bank materials exhibit consistent relationships among width, depth, and velocity as functions of discharge (Orsborn and Deane 1976; Orsborn and Watts 1980; Orsborn 1974, 1982). Channel and flow characteristics are related to basin characteristics and can be related to spawning preference (Rantz 1964; Tennant 1972; Collings et al. 1970, 1972a,b, 1974; Collings and Hill 1973; Swift 1976; Newcombe 1981).

Orsborn analyzed existing hydrological, basin and channel characteristics and spawning habitat criteria (velocity and depth) for steelhead (<u>Salmo gairdneri</u>) collected at thirteen sites in western Washington to define the relationships of basin, channel and flow characteristics to the QMSA and MSA for steelhead.

An evaluation of the application of these relationships to Willow Creek follows.

Methods

Method A is an office method whereby QMSA is calculated for a particular species from existing data using the Method A equation in Table 25. Method B is a field method requiring a measurement of the bankfull wetted perimeter area at the study site.

Data sources and techniques for deriving equation variables for Methods A and B which are not included in this section are described in the Montana Method Section.

MSA is calculated using the Method B equation in Table 25. To calculate the bankfull area for Method B, channel geometry is measured at transects which are representative of the reach. The area calculations are averaged as 1000 ft^2/100 ft. The bankfull area of the IFIM middle Willow Creek reach (Appendix A: Figure 8) is used for this analysis to allow for comparison of the results with those from the IFIM analyses in the next chapter. The average wetted bankfull area for the four transects (Appendix A: Figures 9-12) in the middle IFIM reach is 182 ft^2 per transect. Method B calculations are based on converting this average

Table 25. Orsborn (1982) methods to estimate maximum spawning area flows (QMSA) as a function of basin, channel and flow characteristics (β) and maximum spawning area (MSA) as a function of bankfull wetted surface area.*

Method A - QMSA = 40 $(\beta)^{0.33}$

QMSA - maximum spawning area flow

$$\beta = \left[\frac{A\sqrt{H}}{SC} \cdot \frac{(QAA)^3}{(QF2P)^2}\right]$$

A - drainage area

H - basin relief = upper elevation of reach - lower elevation of reach divided by 5280ft

SC - slope of channel = average slope of stream channel for the 10% of total streamlength immediately upstream from the reach multiplied by 10^{-2}.

Method B - MSA = 0.45 $(BFA)^{1.25}$ in 1000 ft²/100 ft

MSA - maximum spawning area

BFA - average bankfull wetted area of study reach 1000 ft²/100 ft (calculated by field measurements of channel geometry and notation of high bank at representative transects.

Adjustment Factor - FCAF = $\frac{V_c}{V_s} \cdot \frac{D_c}{D_s}$

V - difference between range of velocities
D - difference between range of depths
FCAF- fish criteria adjustment factor
s - steelhead
c - chinook salmon

*Methods were developed for evaluation of steelhead spawning habitat based on Hunter (1973).

value to (18.2) (1000 ft^2/100 ft) of bankfull wetted area. Orsborn's equations for Methods A and B are based on fish utilization criteria developed for steelhead.

To adjust the Method A and B equations for chinook salmon criteria (the species having the most similar requirements to steelhead in this study), a coefficient (Fish Criteria Adjustment Factor) is developed based on calculating the ratio of the differences in the ranges of velocity and depth criteria for both species (Table 25). The Fish Criteria Adjustment Factor (FCAF) is multiplied times the QMSA and MSA calculations to adjust the results accordingly. Velocity and depth ranges for chinook salmon are derived from Figures 15 and 16. These criteria represent the range of spawning conditions at 60% of the spawning sites measured for chinook salmon in 1979 in Willow Creek. Steelhead criteria are derived from Orsborn (1982). The relationships between these criteria are illustrated in Figure 29.

Results

Method A

A QMSA of 509 cfs and adjusted value of 402 cfs is calculated with the Method A equation (Table 26).

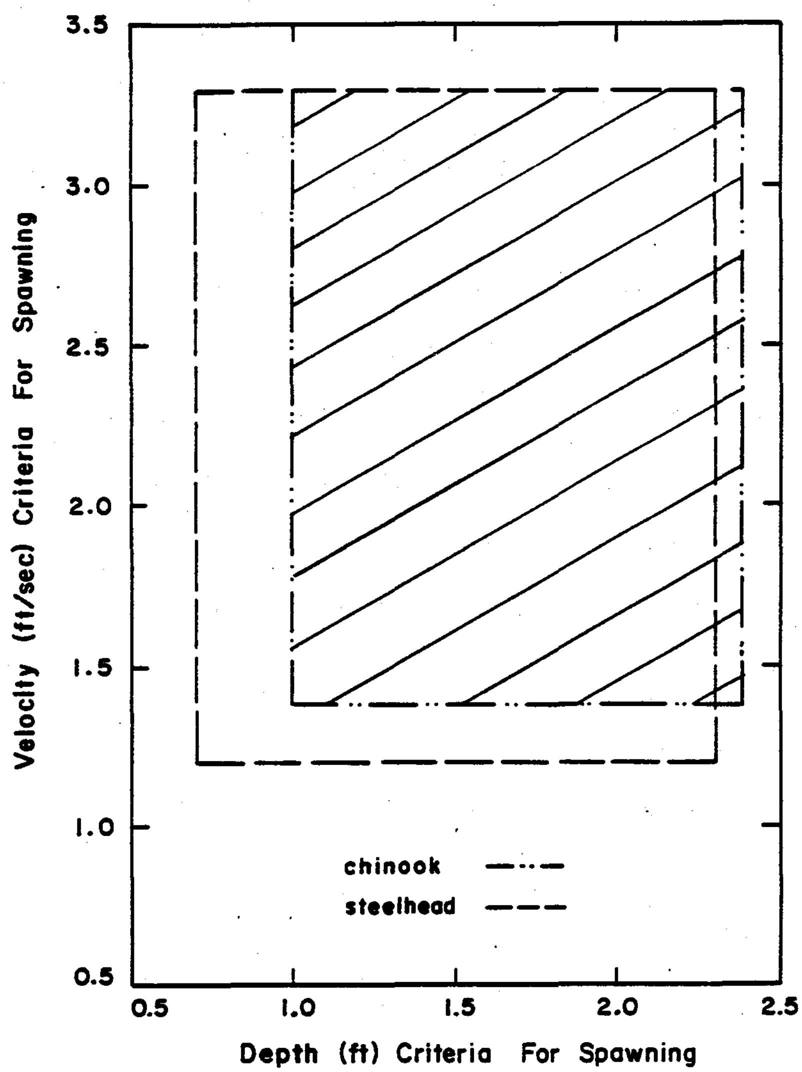

Figure 29. Ranges of spawning depth and velocity criteria for steelhead (adapted from Orsborn 1982a) and chinook salmon analyzed in Tables 26 and 27.

Table 26. Calculation of maximum spawning area flow (QMSA) for chinook salmon in Willow Creek.

a. $QMSA = 40^{*} (\beta)^{0.33}$

b. $QMSA = 40[(2222)^{0.33}]$

c. QMSA = 509 cfs

d. $QMSA_{adj} = FCAF(QMSA)$

e. $QMSA_{adj} = 0.79(509)$

f. $QMSA_{adj}$ = 402 cfs

QMSA = maximum spawning area flow

$$\beta = \left[\frac{166\sqrt{0.73}}{0.25} \bullet \frac{(350)^3}{(3300)^2}\right] = \left[\frac{166(.85)}{0.25}(3.94)\right] = 2222$$

A = drainage area = 166

$$H = \text{basin relief}^{**} = \frac{4000-150}{5280} = \frac{3850}{5280} = 0.73 \text{ mi}$$

$$SC = \text{slope of channel}^{**} = \left(\frac{250-175}{3}\right) 10^{-2} = .25$$

QAA = from Figure 24 = 350 cfs (long-term record)

QF2P = from Figure 24 = 3300 cfs (long-term record)

FCAF = fish criteria adjustment factor

$$= \frac{3.3 - 1.4}{3.3 - 1.2} \bullet \frac{2.4 - 1.0}{2.3 - 0.7}$$

$$= \frac{1.9}{2.1} \bullet \frac{1.4}{1.6} = \frac{2.66}{3.36} = 0.79$$

adj = adjusted

*Coefficient "40" is a mean value and may vary by ±15-20%
**From USGS topographic map - 1:63,360 - Tyonek D-1 and Anchorage D-8.

Table 27. Calculation of maximum spawning area (MSA) for chinook salmon in Willow Creek.

a. $MSA = 0.45\ (BFA)^{1.25}\ (1000ft^2/100ft)$

b. $MSA = 0.45\ (18.2)^{1.25}\ (1000ft^2/100ft)$

c. $MSA = 0.45\ (37.59)\ (1000ft^2/100ft)$

d. $MSA = 16.92\ 1000ft^2/100ft$

e. $MSA_{adj} = 0.79\ (16.92\ 1000ft^2/100ft)$

f. $MSA_{adj} = 13.36\ 1000ft^2/100ft$

g. $MSA_{adj} = 133{,}600ft^2/1000ft$

MSA = maximum spawning area

BFA = bankfull area $1000ft^2/100ft$
(wetted perimeter @ bankfull flow for reach of interest)

MSA_{adj} = adjusted maximum spawning area
= (coefficient of 0.79 from Table 26)•(MSA)

Method B

The adjusted MSA for chinook salmon in Willow Creek is estimated to be 133,600 ft² per 1,000 ft of stream reach for Willow Creek (Table 27). This is equal to 73 percent of the 182,000 ft² of wetted area which is estimated to be available during a bankfull condition.

Discussion

Method A

The adjusted QMSA of 402 cfs is 1.15 times greater than the long-term QAA estimate (350 cfs) for Willow Creek. Referring to Figures 26 and 27, an average long-term monthly minimum flow of 410 cfs for Willow Creek has been estimated for July which would be equivalent to the QMSA using the Orsborn Method A. The long-term August average monthly minimum and mean flows estimated for Willow Creek are 200 cfs and 620 cfs, respectively or 57% and 177% of the QMSA. According to Orsborn (1982), a variation of 50 percent in flow about the optimum would result in the availability of 80 percent of the MSA. Therefore, it can be assumed that the estimated long-term average monthly flow for Willow Creek in August will provide approximately 80 percent of the MSA. These conclusions are based on the assumption that the relationships developed by Orsborn (1982) are correct as are the chinook spawning habitat criteria and steelhead habitat criteria ratios for adjusting the differences in habitats utilized.

Method B

An MSA of 133,600 ft^2 has been estimated for the middle IFIM reach of Willow Creek. This value is compared with weighted usable area estimates in the next chapter.

Orsborn compared the ratio of QMSA to QAA values for thirteen sites he analyzed. He found that sites having Beta (β) factors greater than 100 or QMSA values greater than 150 cfs had a ratio less than one. Sites having β factors less than 100 or a QMSA less than 150 cfs had a ratio greater than one. The ratio of the QMSA (402 cfs) to the QAA (350 cfs) for Willow Creek is 1.15 or opposite of that expected from the analysis of the Washington streams. The significance of this difference is unknown and will require comparison with other Alaskan systems. It may, however, be partly attributed to the fact that the Orsborn analysis is based on habitat measurements of known steelhead spawning areas; whereas, Willow Creek does not support spawning steelhead.

As originally demonstrated by Orsborn, these analyses, if correct further establish that spawnable area in a stream can be related to basin, channel, and streamflow factors. Orsborn recommends that further site specific testing of hydraulic characteristics be conducted including the reexamination of the sites from which he based these methods.

It would also be of value to combine a biological reexamination of the fish criteria used to derive the physical characteristics which are assumed to represent optimal spawning habitat at conditions for chinook salmon in Alaska. In essence, these two methods appear to be quick and are a relatively inexpensive means of defining physical limits for spawning habitat area and flows. It is hoped that these methods could be expanded to allow for an incremental evaluation of a series of flows for spawning and other life phases.

COMPARISON OF ANALYSES

Results of the analyses by the Instream Flow Incremental Methodology, (IFIM), Montana (MT), and Orsborn (A and B) methods to evaluate which flows provide optimal habitat for spawning by chinook salmon are compared in this chapter. Chinook salmon have been selected for this analysis because they are the species common to the IFIM and Orsborn analyses. Table 28 summarizes the flow and habitat area estimates derived by each of the four methods. Values within the table should not be compared without first reviewing this discussion because all of the methods are not directly comparable.

Instream Flow Incremental Methodology

The first three columns of the table represent the IFIM evaluation; the next four, the Montana Method; and the last two, the two Orsborn methods (A and B). The IFIM summary is subdivided vertically by the three calculation techniques used to estimate weighted usable area (WUA): Standard Calculation, Geometric Mean, and Lowest Limiting Parameter. Each of these three calculation categories has two listing of WUA values (ft^2) for six flows ranging from 50 cfs to 2000 cfs in the second and third columns. The second column represents WUA values derived from a velocity and depth joint preference factor (JPF). A geometric mean analysis with a velocity and depth JPF was not possible because IFIM models only calculate the geometric mean of the JPF as a cube root as opposed to the square root which is required for two

Table 28. Summary of results from instream flow analysis of spawning habitat in Willow Creek for chinook salmon with the Instream Flow Incremental Methodology, Montana, and Orsborn methods (demonstration analysis).

INSTREAM FLOW INCREMENTAL METHODOLOGY

Flow (cfs)	V,D,S Area (ft²/1000 ft)	V,D Area (ft²/1000 ft)
	Standard Calculation	
2000	00463	05495
1500	00538	08424
0991	00897	09923
0598	01941	14088
0175	01552	15420
0050	00255	02631
	Geometric Mean	
2000	02933	----
1500	04999	----
0991	08916	----
0598	11093	----
0175	09726	----
0050	02315	----
	Lowest Limiting Parameter	
2000	01128	07468
1500	01735	11478
0991	03610	14275
0598	04678	19388
0175	03326	17850
0050	00905	03316

MONTANA METHOD / **ORSBORN METHODS**

	FLOW (cfs)			ORSBORN METHODS	
Percentage of QAA	No Flow Record	Limited Flow Record	Flow Record Extended by Correlation	Method A $QMSA_{adj}$ (cfs)	Method B MSA_{adj} (ft²/1000 ft)
100%	276	435	350	402	133,600
60-100% (optimum range)	166-277	261-435	210-350		
60% (outstanding)	166	261	210		
50% (excellent)	138	218	175		
40% (good)	110	174	140		
30% (fair or degrading)	83	131	105		
10% (poor)	28	44	35		
<10% (severe degradation)	<28	<44	<35		

V - velocity
D - depth
S - substrate
QAA - average annual flow
QMSA - maximum spawning area flow
MSA - maximum spawning area

variables. A flow of 598 cfs provided the maximum amount of WUA for each of the three IFIM calculation techniques using a velocity, depth, and substrate JPF. Without substrate criteria, a flow of 175 cfs provides the most WUA when using a Standard Calculation, and 598 cfs when using a Lowest Limiting Parameter calculation. The Standard Calculation estimate of WUA without substrate at a flow of 598 cfs is only 9% less than that projected for 175 cfs. Accordingly, the IFIM analyses of the six flows indicate the optimal flow for chinook spawning is 598 cfs.

Long-term estimates of mean monthly flows for Willow Creek in July and August range from 410 cfs to 1040 cfs (July) and 200 cfs to 1500 cfs (August) and average 820 cfs (July) and 620 cfs (August).

Accordingly, the 598 cfs IFIM value appears to be within the range of monthly flows estimated for these two months and is not an unreasonable flow request if one assumes all aspects of the IFIM analysis as being valid. On a broader basis, the IFIM analyses indicate that flows ranging from 175 cfs to 598 cfs would provide relatively similar amounts of WUA.

However, if one reviews the depth utilization criteria for Willow Creek in 1979 (Figure 16) depths exceeding 3.25 ft are rated as limiting for spawning by chinook salmon. Suitability criteria for spawning by chinook in the Susitna River basin (Vincent-Lang et al. 1984b) indicate that depths greater than 1.0 ft are optimal spawning conditions. If this latter statement is valid, the flows estimated for Willow Creek with existing criteria are too low, because average depths in Willow Creek exceed 3 ft at flows higher than 600 cfs. This biases the WUA towards flows less than 600 cfs.

Montana Method

The fourth column in Table 28 lists the percentages of average annual flow (QAA) from Table 11 and their qualitative values of fish habitat as defined by Tennant (1975). The next three columns summarize the percentages of QAA which are calculated from three different QAA values. Flows range from 166 cfs to 435 cfs in the optimum range category, from 166 cfs to 261 cfs in the outstanding category, 138 cfs to 218 cfs in the excellent category and 110 cfs to 174 cfs in the good category. Flow calculations equal to or less than 131 cfs are considered of minimal or no value for fish and wildlife. It is interesting that even the highest flow estimates are less than the long-term flow average monthly estimates for July and August. Instead, these flows approximate the range of mean low monthly flows for these two months. On this basis alone, one should be suspicious of the percentages of QAA recommended by Tennant without field investigation and a more detailed hydrological analysis, such as monthly flow duration curves for July and August.

Orsborn's Methods

Method A

The eighth column of Table 28 lists the estimated flow which should provide the maximum spawning area flow (QMSA) for chinook salmon in Willow Creek based on basin and flow parameters. The 402 cfs value is representative of the July (410 cfs) long-term mean monthly flow and is in between the long-term mean low (200 cfs) and average (620 cfs) monthly flows for August for Willow Creek. As long as the 410 cfs is recognized as an approximation of average conditions, this appears in itself a reasonable flow estimate for supporting spawning.

Method B

The last column of Table 28 lists the maximum spawning area (MSA) estimate (133,600 ft^2) for chinook salmon in Willow Creek. Considering that the bankfull area for the middle reach of Willow Creek is 182,000 ft^2/1,000 ft, the value in itself does not appear unreasonable. The estimate of 133,600 sq ft/1000 ft is an estimate of the maximum area that could be available based on a model of streams in Northwest Washington. It is not an estimate of the optimum value.

Comparisons

The above discussions provide summaries of more detailed analyses of the individual instream flow methods provided in the previous chapter. Table 28 is somewhat misleading with its complete summary of results. This is because the IFIM and Montana methods have more than one flow projection based on different calculation techniques. Therefore one must differentiate between methods and determine how to apply each method in itself. By using only the Lowest Limiting Parameter approach of the IFIM, the extended flow record QAA calculation in the Montana Method Analysis, and the two Orsborn methods, it is easier to compare methods.

The IFIM provides a quantitative estimate of habitat area (WUA) at different increments of flow selected by the investigator and is limited by the calibration range of the hydraulic model from which it is based. The Montana Method is an assessment of percentages of the QAA based on qualitative terminology assigned to each percentage of flow. Without actually conducting a field investigation, it is not possible to translate the true value of Tennant's ratings to the specific resources it is being applied. Method A of the Orsborn methods provides one quantitative flow representing the optimum spawning condition. Method B provides a quantitative estimate of the upper limit of spawning habitat that could physically be available in a stream based on depth and velocity criteria.

Each method is based on a completely different level of data and analysis. Comparisons that are made among the results of these analyses can be made only if the individual elements of each analysis is kept in perspective. For example, based on the Montana Method, regardless of the QAA value, a flow in the range of 166 to 435 cfs is considered within the "optimum range". The IFIM analysis estimates an optimum flow range of 175 cfs to 1,000 cfs; and Method A, 402 cfs as an optimum condition. Accordingly, the Tennant projections fall within the lower end of the optimum flow range of the IFIM analyses. However, it is suspected that criteria data for depth may be biasing the IFIM projections in favor of flows less than 600 cfs.

Annear and Condor (1984) support this hypothesis. They compared different flow recommendations to the size of the system evaluated. As stream size increased, IFIM recommendations became progressively lower, corresponding to the increase in difficulty of collecting biological criteria in deeper and swifter water.

This further emphasizes the importance of fish criteria and the advisability of developing suitability curves as opposed to preference or utilization curves which can bias the results.

Comparing the flow recommendations from the three methods with average monthly flows for July and August, favors the 598 cfs IFIM flow projection, the 402 cfs flow projection with Method A; and the highest values projected with the optimum flow range of the Montana Method.

A flow duration analysis for July and August flow would probably help define which of these values is better by estimating the frequency of flows. This would provide a basis for not requesting more water than actually exists in the system.

The Method B MSA estimate should only be compared with the optimum velocity and depth WUA estimates. Accordingly, an area of 133,600 ft^2/1,000 ft is projected by Method B and 19,388 ft^2/1,000 ft is estimated with the IFIM for 598 cfs (as calculated by a Lowest Limiting Parameter JPF). By referring to Table 6, the maximum wetted surface area in the middle reach of Willow Creek at a flow of 991 cfs is 99,700 ft^2. Therefore, the 133,700 ft^2/1,000 ft value projected by Method B suggests that this analysis is sensitive to channel geometry and requires calibration for the region under consideration. The 19,388 ft^2/1,000 ft value estimated with the IFIM is probably low, based on the fish criteria used; but, as an index of which flow is best for spawning it still serves its purpose.

CONCLUSIONS

In Alaska, the burden of proof for requesting an instream flow reservation is placed upon the applicant. Specific methods are not designated or required for supporting a flow reservation. This enables an applicant with limited resources to apply simple evaluations when applicable to justify the flows requested.

In spite of the intent of the law, the myriad of methods for determining and defending instream flows creates a dilemma for potential users. Results, if not measured against a standard, are difficult to substantiate or determine their worth. Existing literature does not provide a methodological approach for selecting instream flow methods or substantiating the results produced by those following specified methods.

Accordingly, application of an instream flow method is not sufficient in itself to guarantee that an instream flow request will be approved by the Alaska Department of Natural Resources.

This thesis contributes to the development of standards for conducting an instream flow evaluation. The Instream Flow Incremental Methodology, Montana Method, and the two methods by Orsborn were examined. A description of each and their application for estimating spawning flows in Willow Creek was evaluated.

Individual results varied requiring closer examination of the recommendations derived from each method.

By comparing the results of these methods, flows between 600 and 800 cfs are recommended to support spawning by chinook salmon in Willow Creek. These values are based upon comparisons of the output from each method and an evaluation of hydrological conditions for Willow Creek for the period of interest.

The validity of any recommendation depends on how well the assumptions are met. The IFIM method is based upon the assumption that the physical model represents the range of physical conditions pertaining to the seasonal utilization of the stream reach by a species. It is assumed that the criteria used to define fish utilization, preference, or suitability reflects the species/physical relationships of the study area. The Montana Method is based on the assumption that percentages of QAA in Table 11 have universal application. The Orsborn methods assume that regional basin and channel characteristics can be applied.

Regardless of these assumptions, an investigator should review basic hydrological characteristics, if nothing more than to evaluate trends. None of these methods should be applied without comparing these trends to the results of their analyses. Biological criteria must be representative of the species and system evaluated (Hunter 1973).

In summary, each of the methods evaluated can be used to generate valid instream flow recommendations if calibrated to the site or area studied. The IFIM, unlike the other methods considered, allows for incremental evaluations of any flow within the calibration range of the hydraulic model developed for a site. The Montana and Orsborn methods will provide good measurements of average conditions for comparison with the IFIM.

Once adjusted to the species and basins of interest, the Orsborn and Montana methods should be used to develop initial or reconnaissance flow recommendations for areas where competition for water is minimal. When competition is keen, an IFIM or similar approach is required to support a complete evaluation of all flow options and responses to the various species/life phases emphasized. A level One to Four approach for selecting instream flow studies as summarized in Smith (1979) is a good basis for determining the applicability of a technique.

Recommendations

1. Regulations for Alaska's instream flow law should be amended to require all instream flow applicants to provide a basic analysis of the site hydrology. Included should be the long-term average annual flow or estimates, mean monthly high, average and low flows, and an annual hydrograph of monthly flows with their high and low values.

2. Fish criteria data should be collected for all species and life phases of interest representing the full range of hydrological and biological conditions in Willow Creek.

3. The IFG-4 model for Willow Creek should be calibrated for comparison with the IFG-2 output. Both models should be combined with suitability criteria for chinook and pink salmon.

4. A representative reach in Willow Creek should be selected for instream flow analysis for comparison with this analysis. A hydraulic engineer and biologist familiar with the IFIM methodology should conduct the project on a joint basis.

5. Regional investigations should be initiated to calibrate the Montana and Orsborn methods to watersheds and fish species in Alaska.

6. An IFIM study of several of the sites evaluated by Collings (1968); Swift (1969), and Orsborn (1982), should be conducted to test the hydraulic modeling and fish criteria components of the model.

7. Research to expand the applicability of the Orsborn methods to other species and life phases should be initiated.

8. Projects to further improve the knowledge of users for selecting a method should be continued.

9. Studies to relate fish populations (standing crop) to habitat and flow characteristics should be conducted.

10. Studies to define minimum flows for sustaining fish populations should be conducted to provide a range of acceptable conditions for fish.

11. A Level One to Four approach summarized in Smith (1979) should be used as the basis for selecting instream flow methods.

12. Flow recommendations should only be made when there is evidence that natural reproduction is occurring in the stream.

13. Studies to define standards for collecting fish criteria (e.g., depth of water guidelines) should be conducted.

14. The USGS should establish additional long-term flow stations in Alaska. Only 140 sites have records of 10 or more years of which half are not presently in operation (Lamke 1984).

A quotation from Chow (1964) is the basis for the final recommendation:

> "As hydrology is not an exact science, application of hydrologic knowledge to practical problems requires a great deal of rich experience and sound judgement of the hydrologist."

This statement is equally true for biologists and the science of biology. Accordingly, it is recommended that biologists and hydrologists work together and share their experiences to solve problems common to both disciplines. This recommendation will only be realized when those at the university level take the lead in bridging the interdisciplinary void that presently exists.

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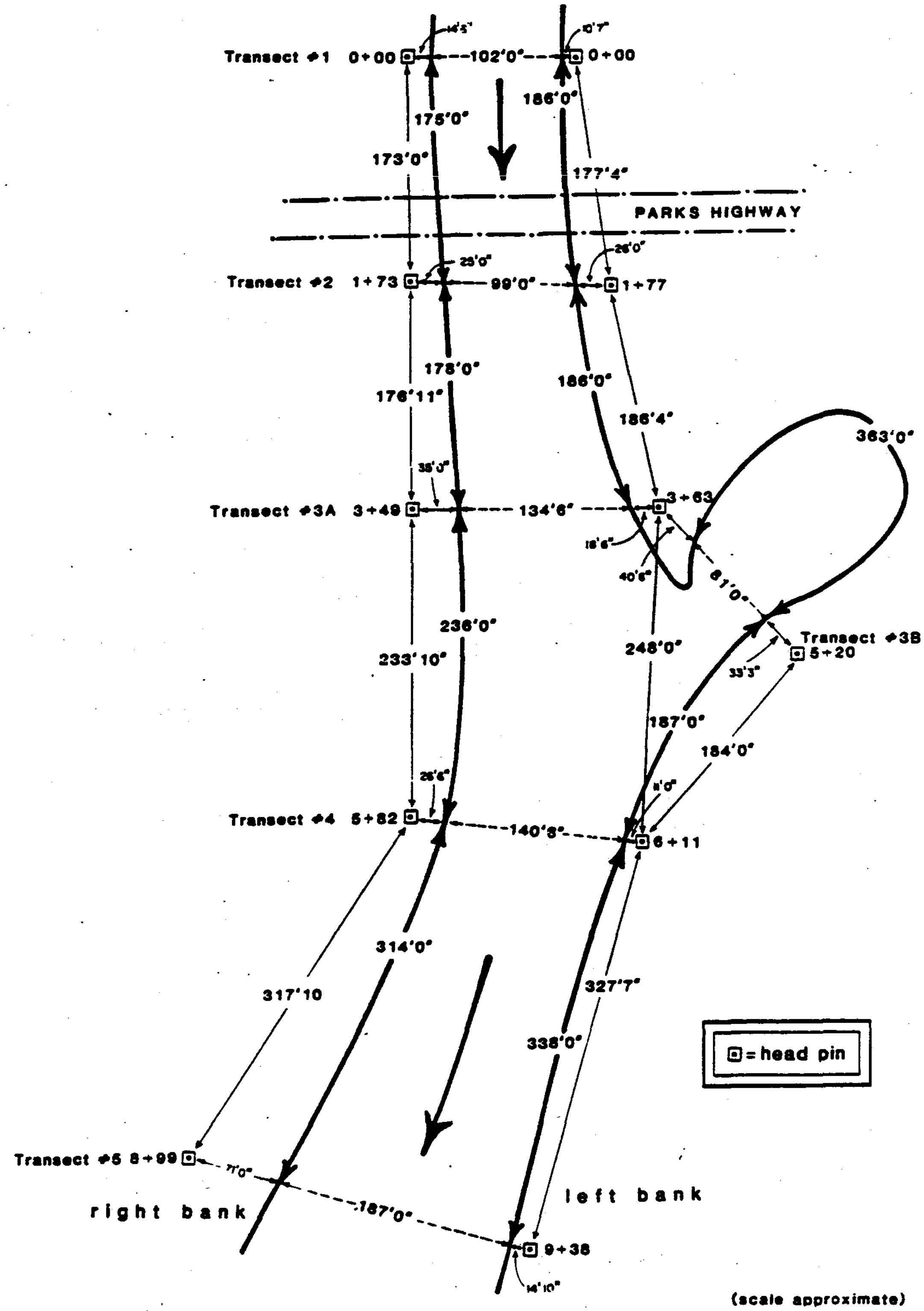
APPENDIX A

WILLOW CREEK IFIM STUDY REACH STATIONING MAPS AND CROSS-SECTIONAL PROFILES OF TRANSECTS

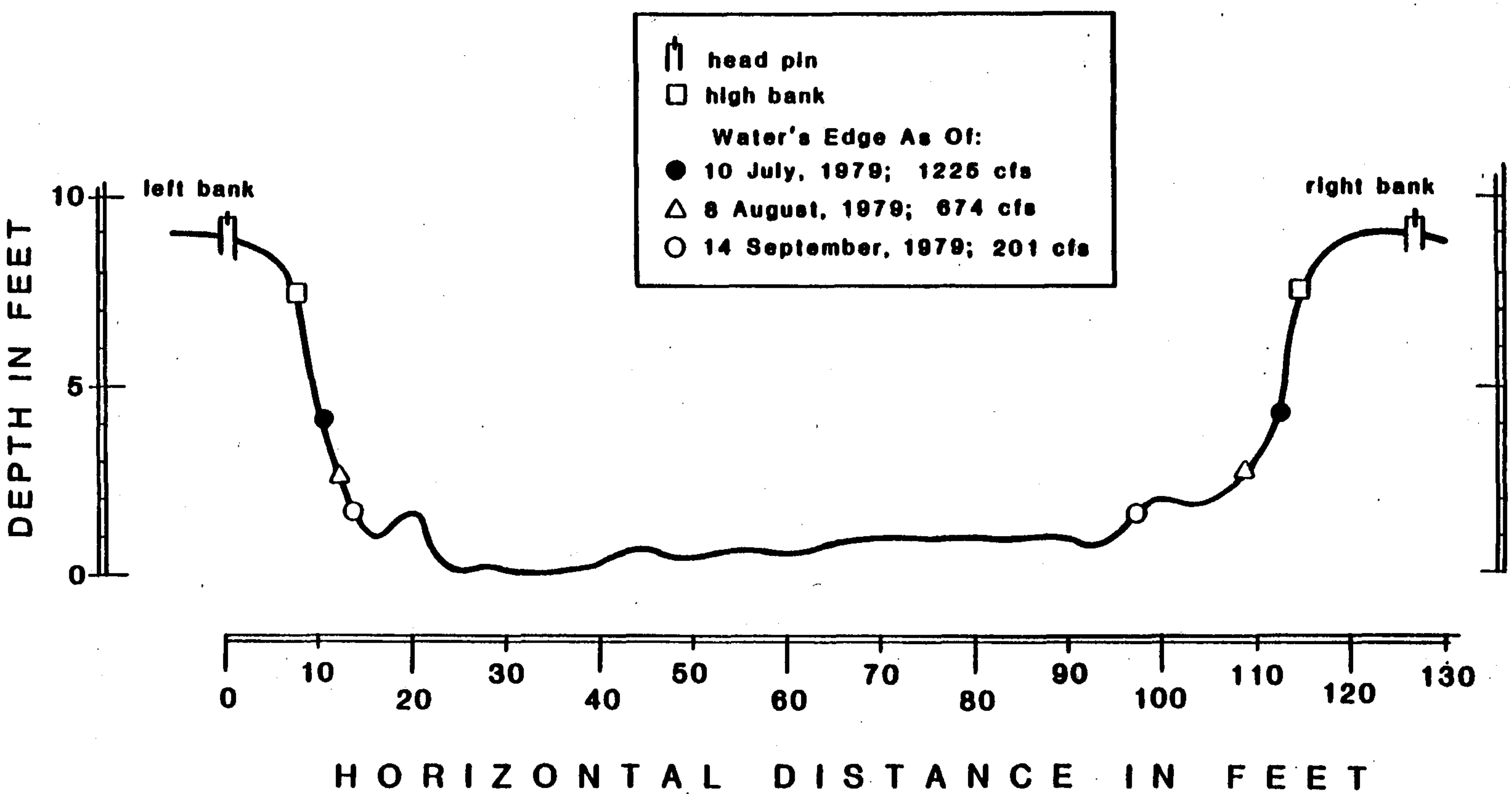


(scale approximate)

LOWER WILLOW CREEK WATER'S EDGE & HEAD PIN STATIONING MAP
13 July, 1979
Average discharge 1163 cfs

Figure I

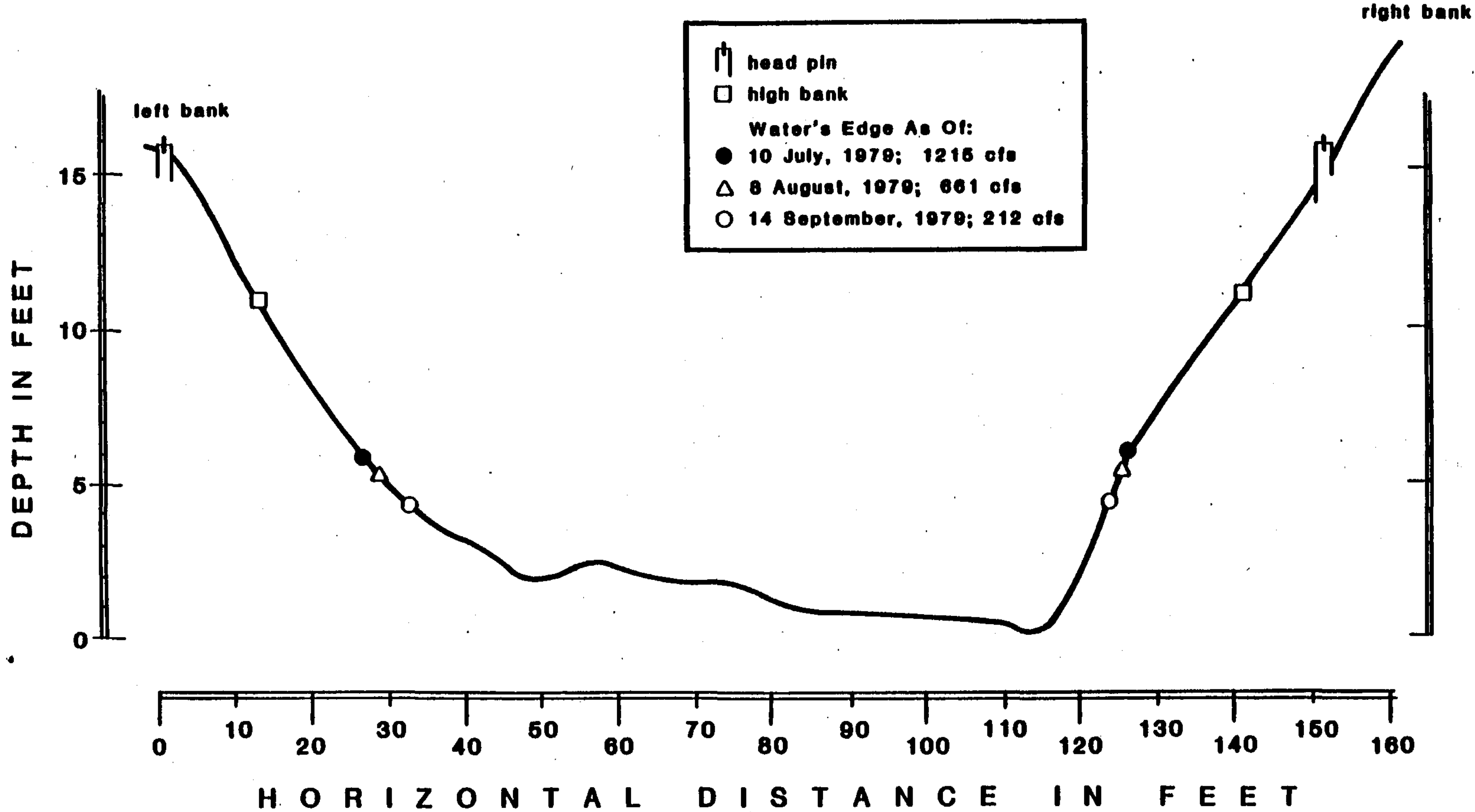
Figure 2



CROSS-SECTIONAL PROFILE OF WILLOW CREEK LOWER REACH, TRANSECT #1.

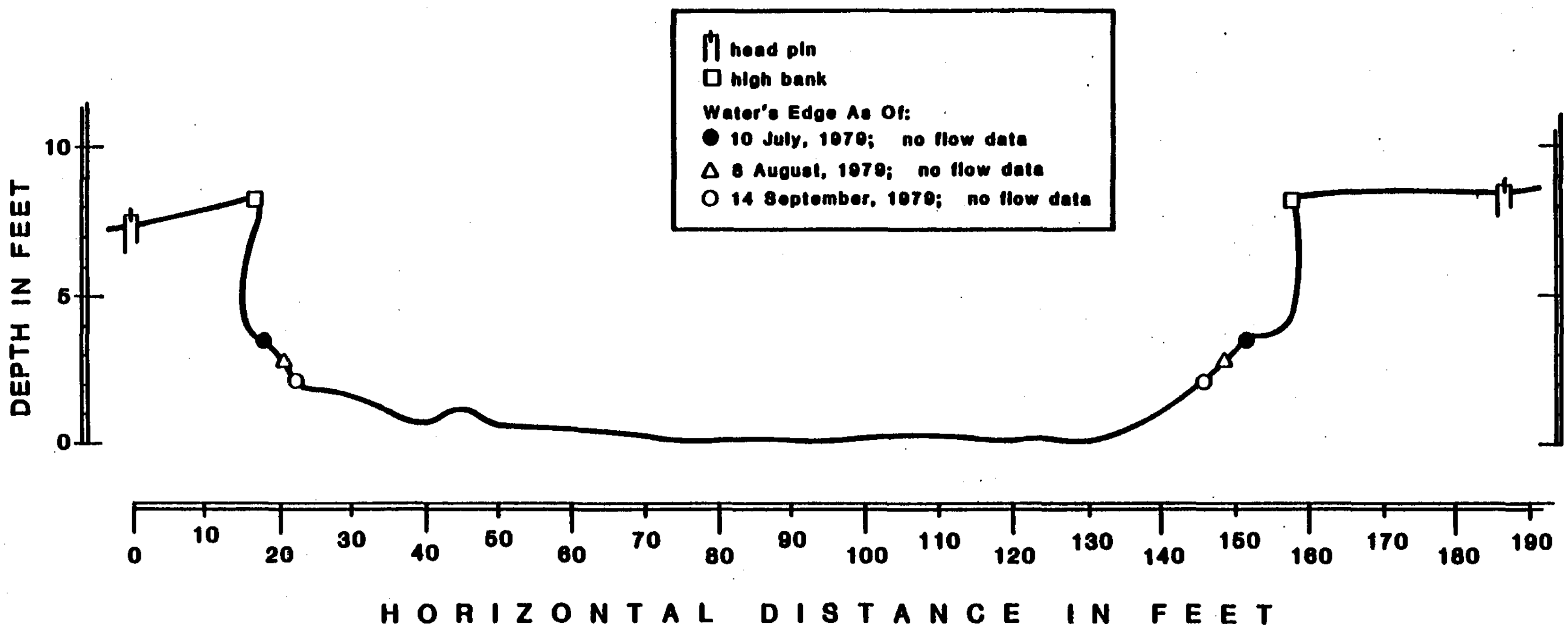
(1 vertical foot equals 4 horizontal feet)

Figure 3



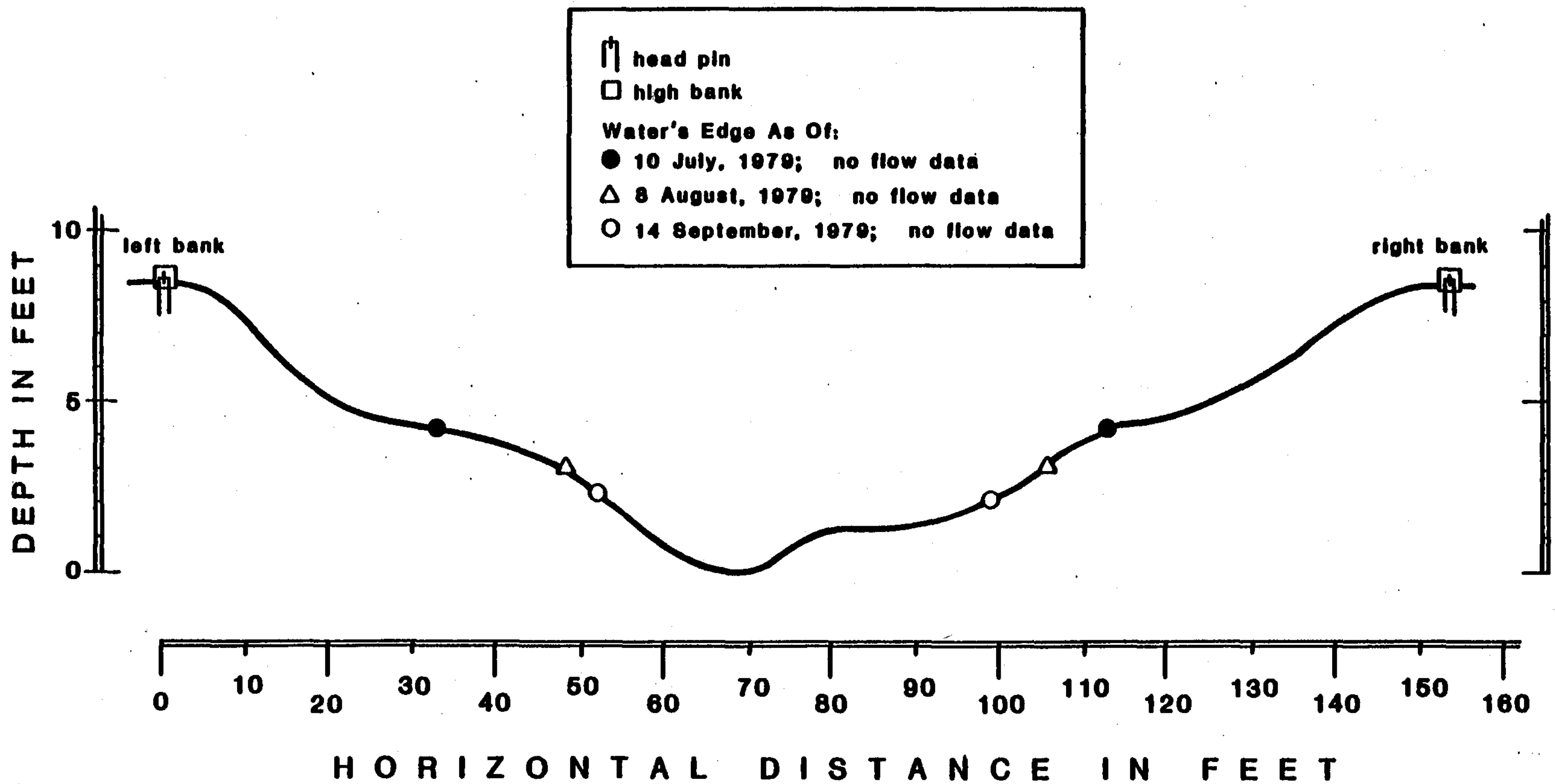
CROSS-SECTIONAL PROFILE OF WILLOW CREEK LOWER REACH, TRANSECT #2.
(1 vertical foot equals 4 horizontal feet)

Figure 4



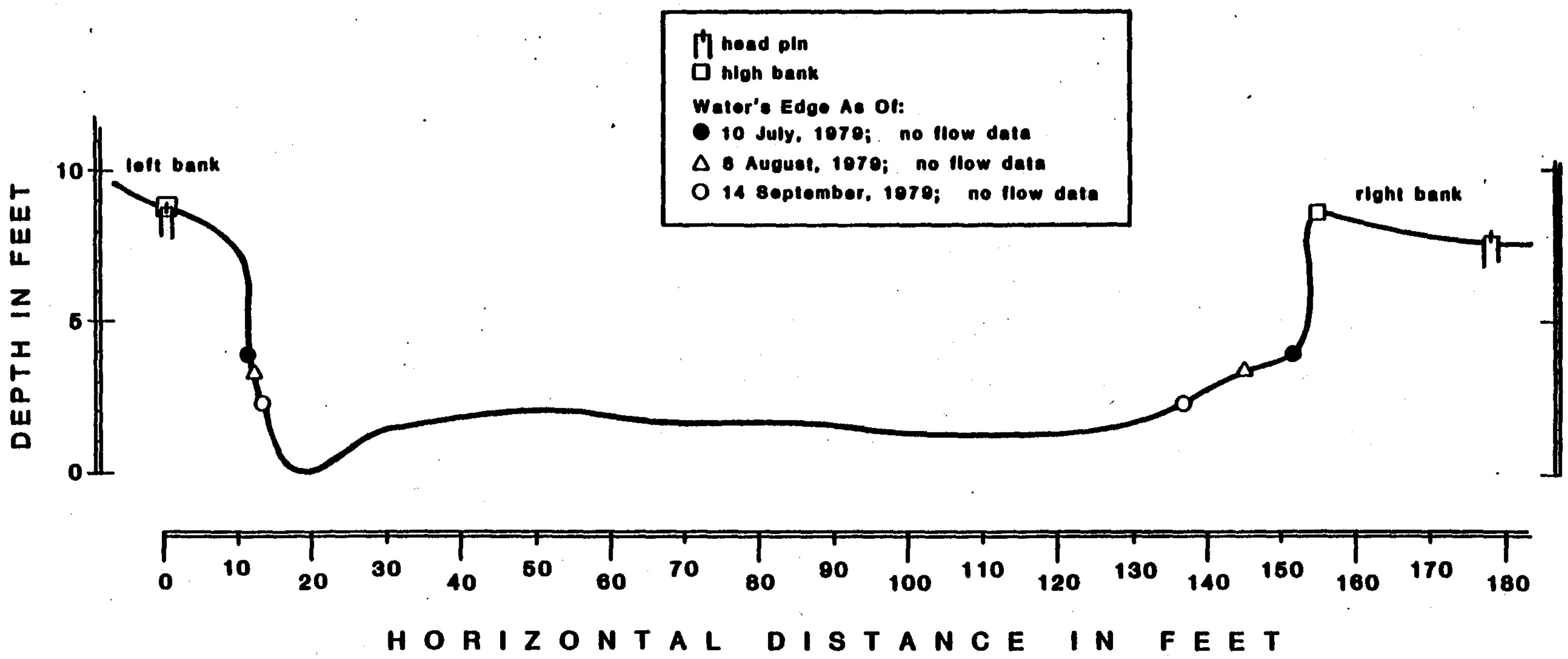
CROSS-SECTIONAL PROFILE OF WILLOW CREEK LOWER REACH, TRANSECT #3A.
(1 vertical foot equals 4 horizontal feet)

Figure 5



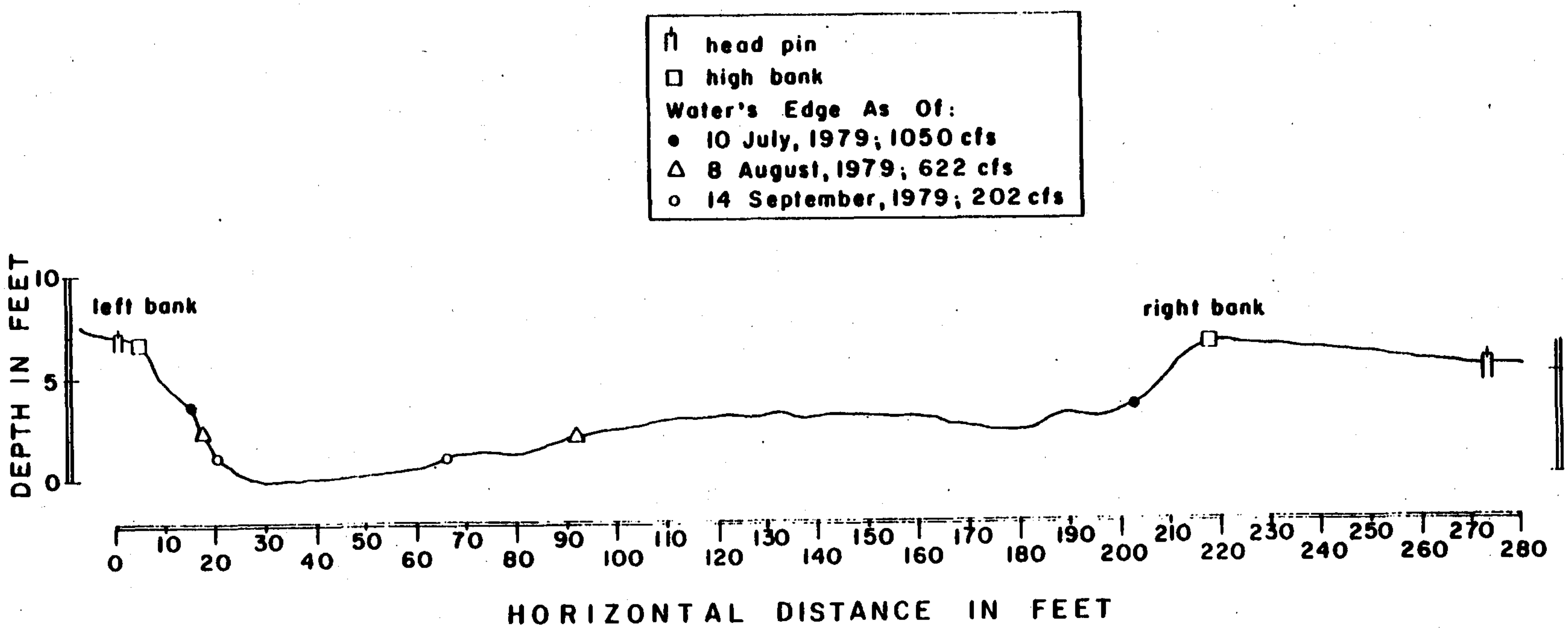
CROSS-SECTIONAL PROFILE OF WILLOW CREEK LOWER REACH, TRANSECT #3B.
(1 vertical foot equals 4 horizontal feet)

Figure 6

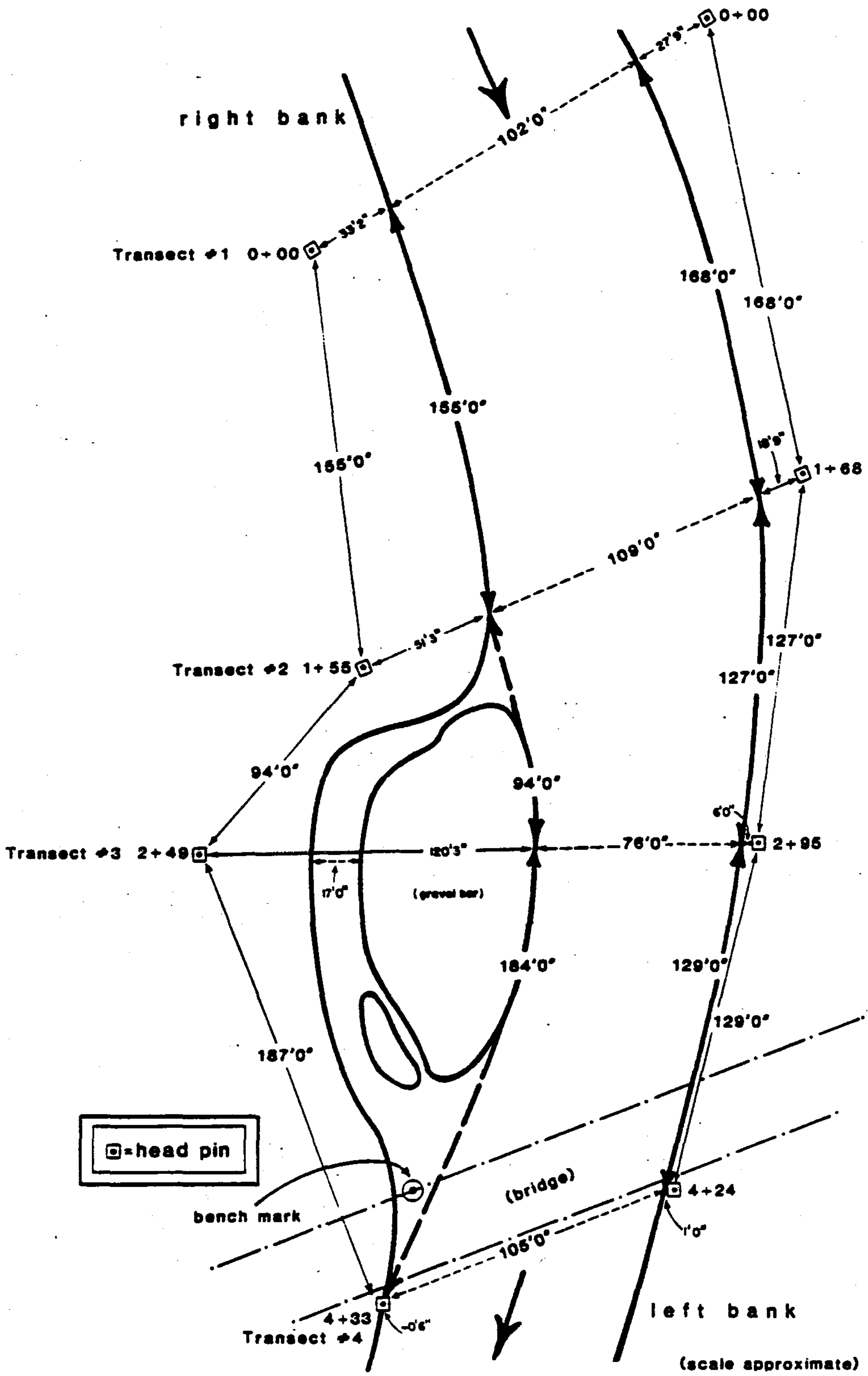


CROSS-SECTIONAL PROFILE OF WILLOW CREEK LOWER REACH, TRANSECT #4.
(1 vertical foot equals 4 horizontal feet)

Figure 7

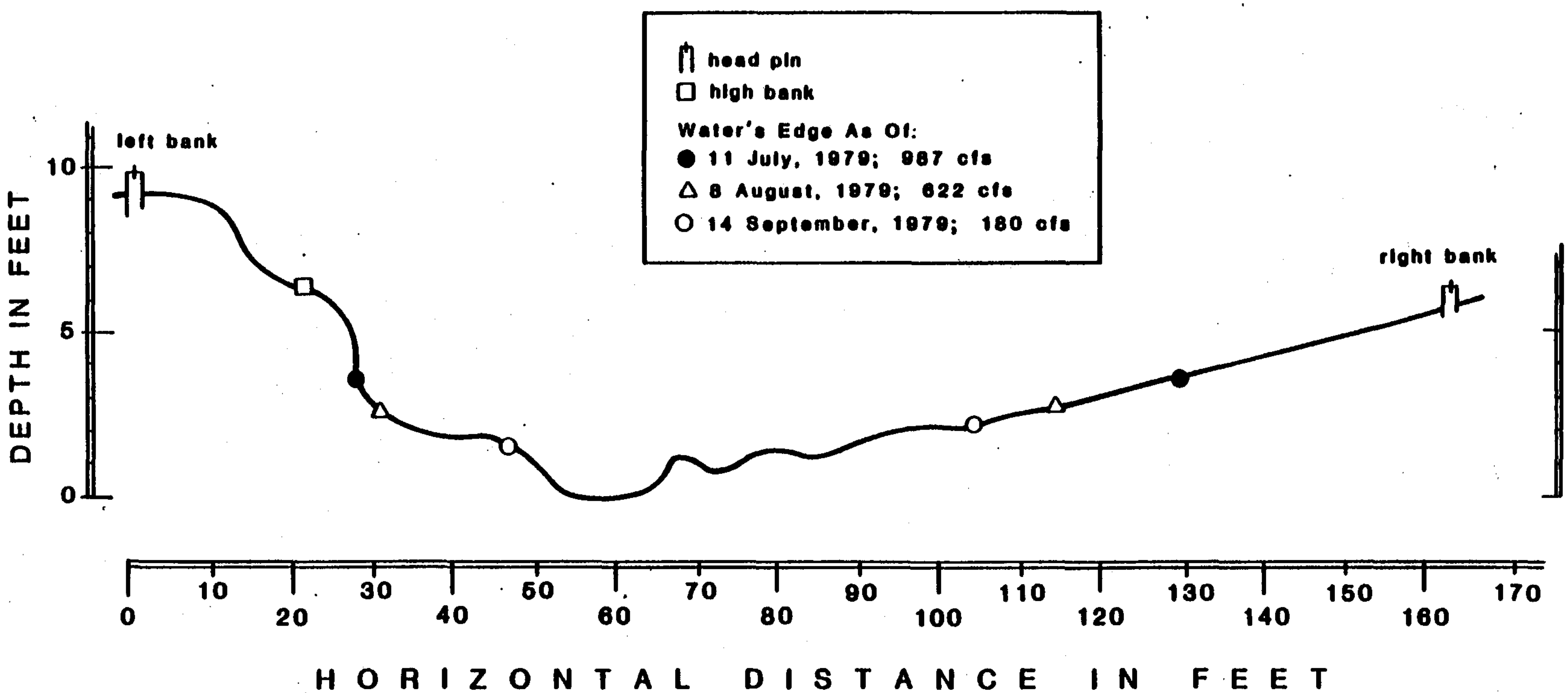


CROSS-SECTIONAL PROFILE OF WILLOW CREEK LOWER REACH, TRANSECT #5
(1 vertical foot equals 4 horizontal feet)



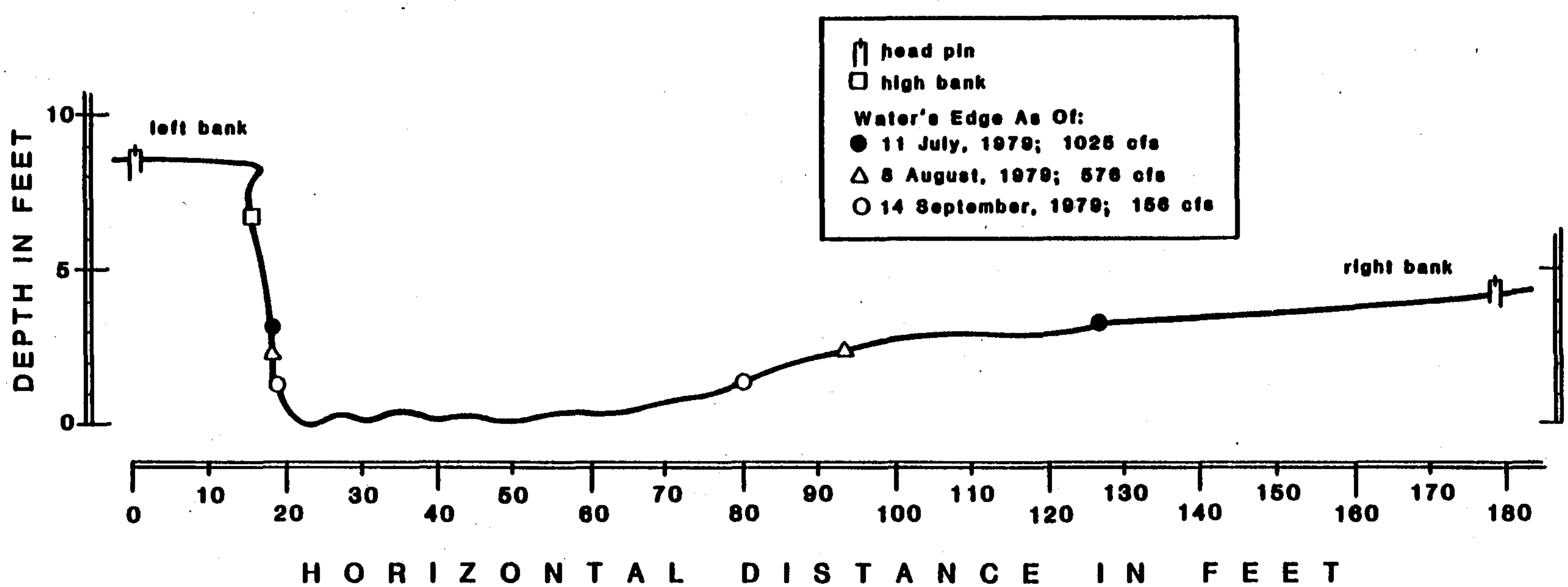
MIDDLE WILLOW CREEK WATER'S EDGE & HEAD PIN STATIONING MAP
11 July, 1979
Average discharge 990 cfs
Figure 8

Figure 9



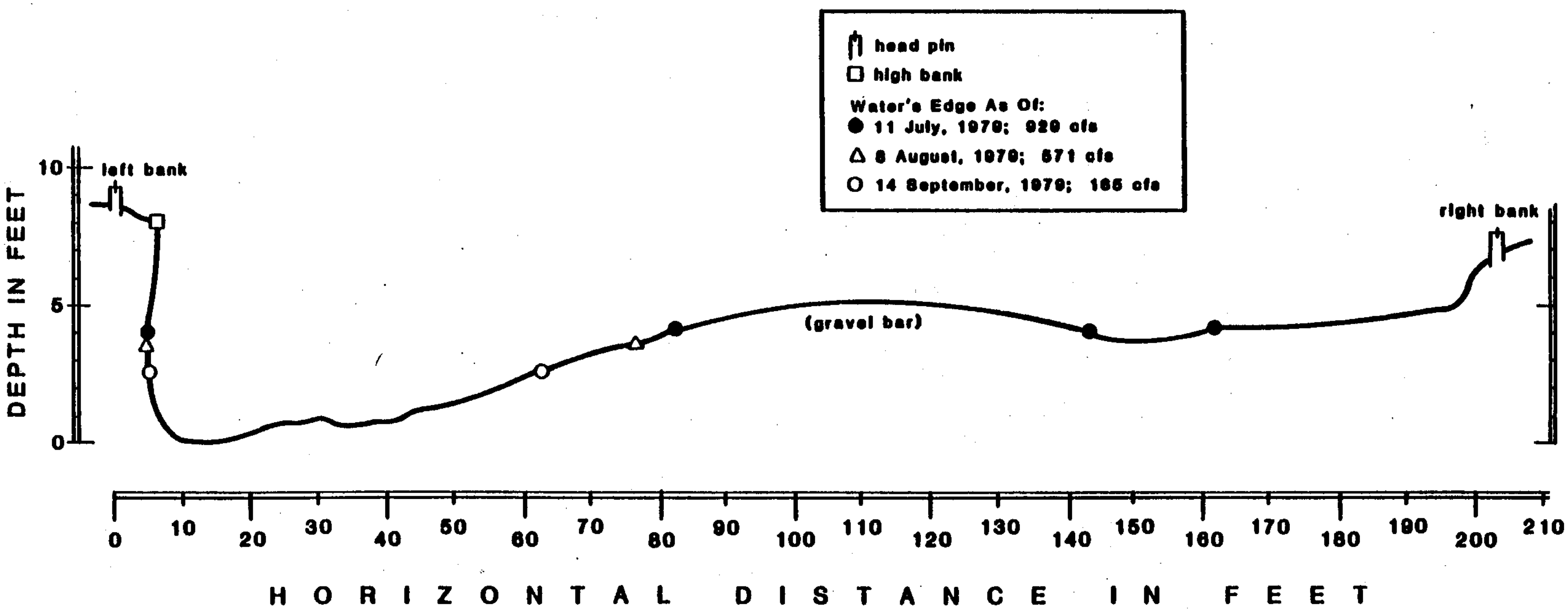
CROSS-SECTIONAL PROFILE OF WILLOW CREEK MIDDLE REACH, TRANSECT #1.
(1 vertical foot equals 4 horizontal feet)

Figure 10



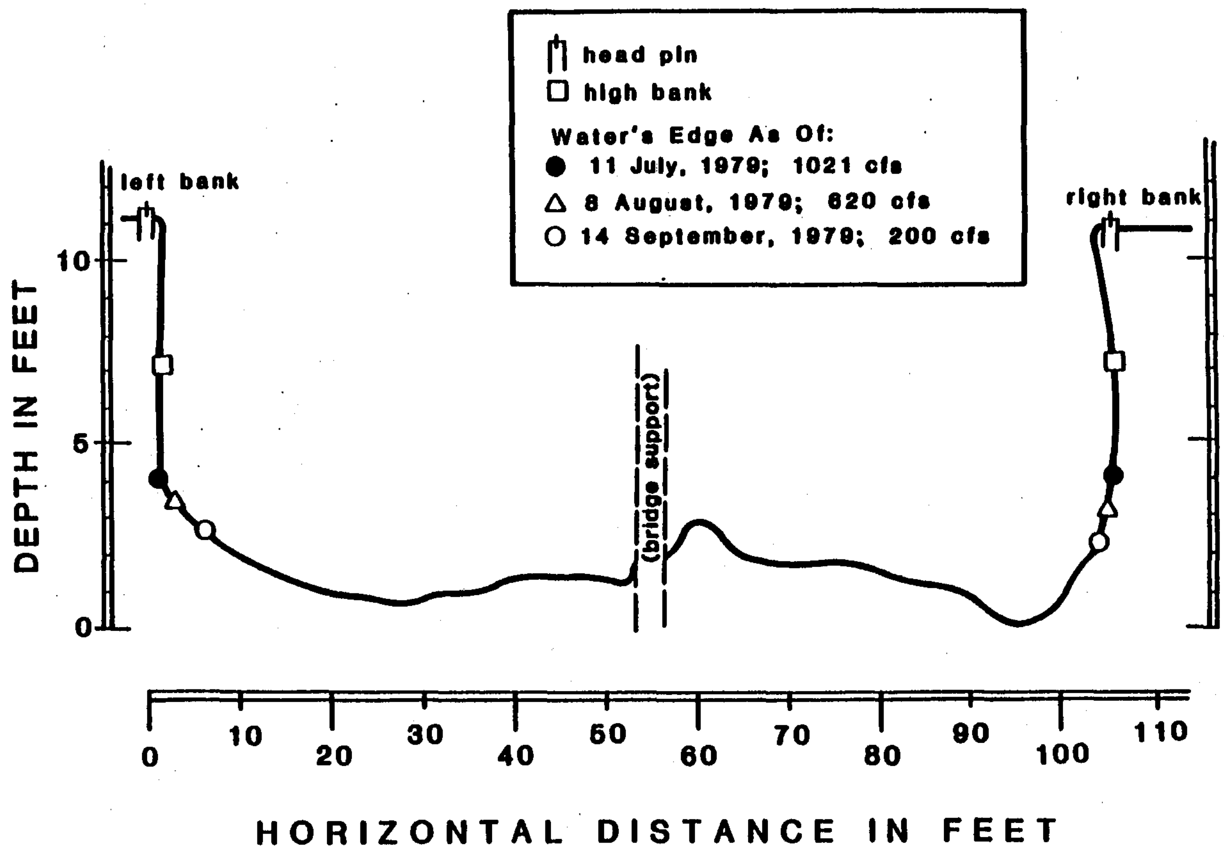
CROSS-SECTIONAL PROFILE OF WILLOW CREEK MIDDLE REACH, TRANSECT #2.
(1 vertical foot equals 4 horizontal feet)

Figure II



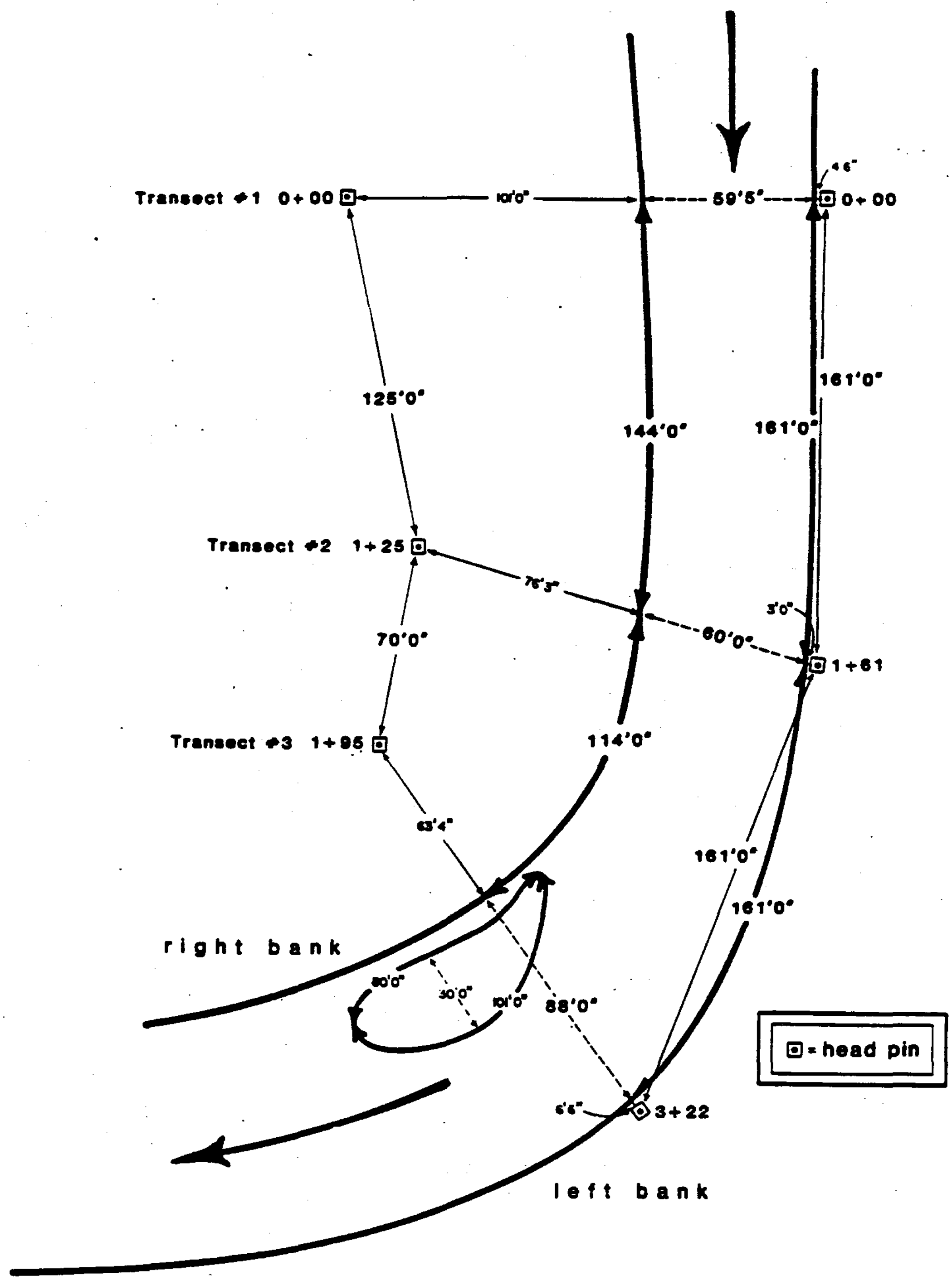
CROSS-SECTIONAL PROFILE OF WILLOW CREEK MIDDLE REACH, TRANSECT #3.
(1 vertical foot equals 4 horizontal feet)

Figure 12



CROSS-SECTIONAL PROFILE OF WILLOW CREEK MIDDLE REACH, TRANSECT #4.

(1 vertical foot equals 4 horizontal feet)

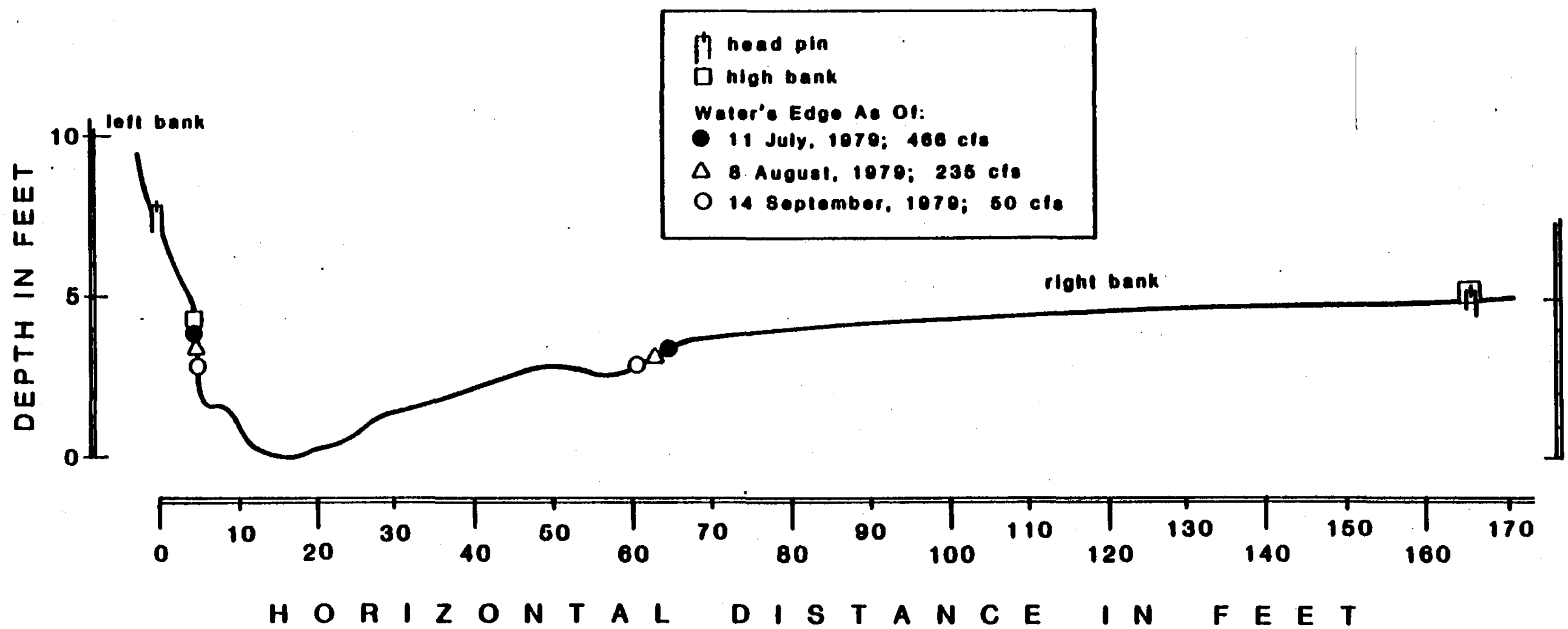


(scale approximate)

UPPER WILLOW CREEK WATER'S EDGE & HEAD PIN STATIONING MAP
11 July 1979
Average discharge 476 cfs

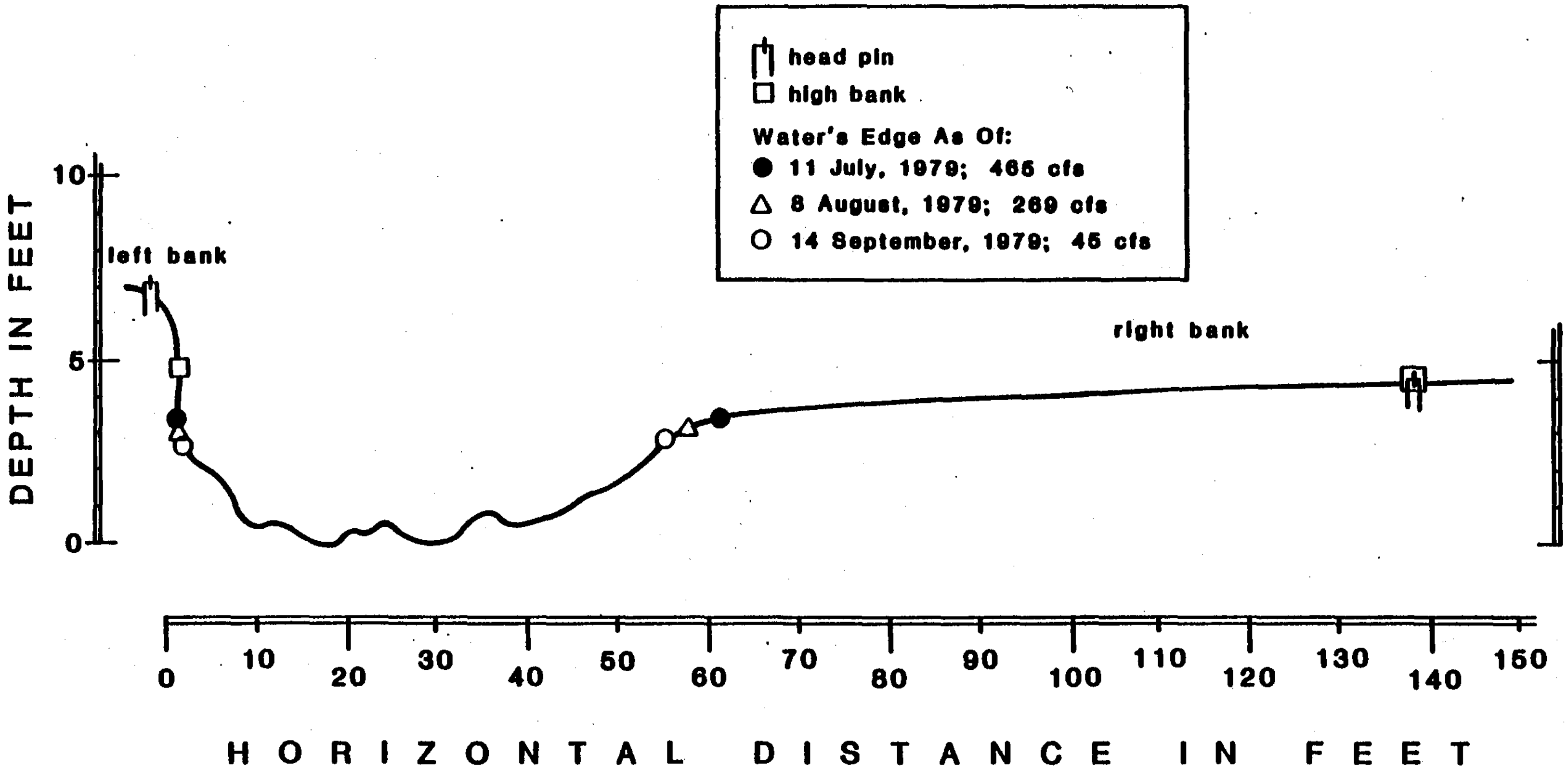
Figure 13

Figure 14



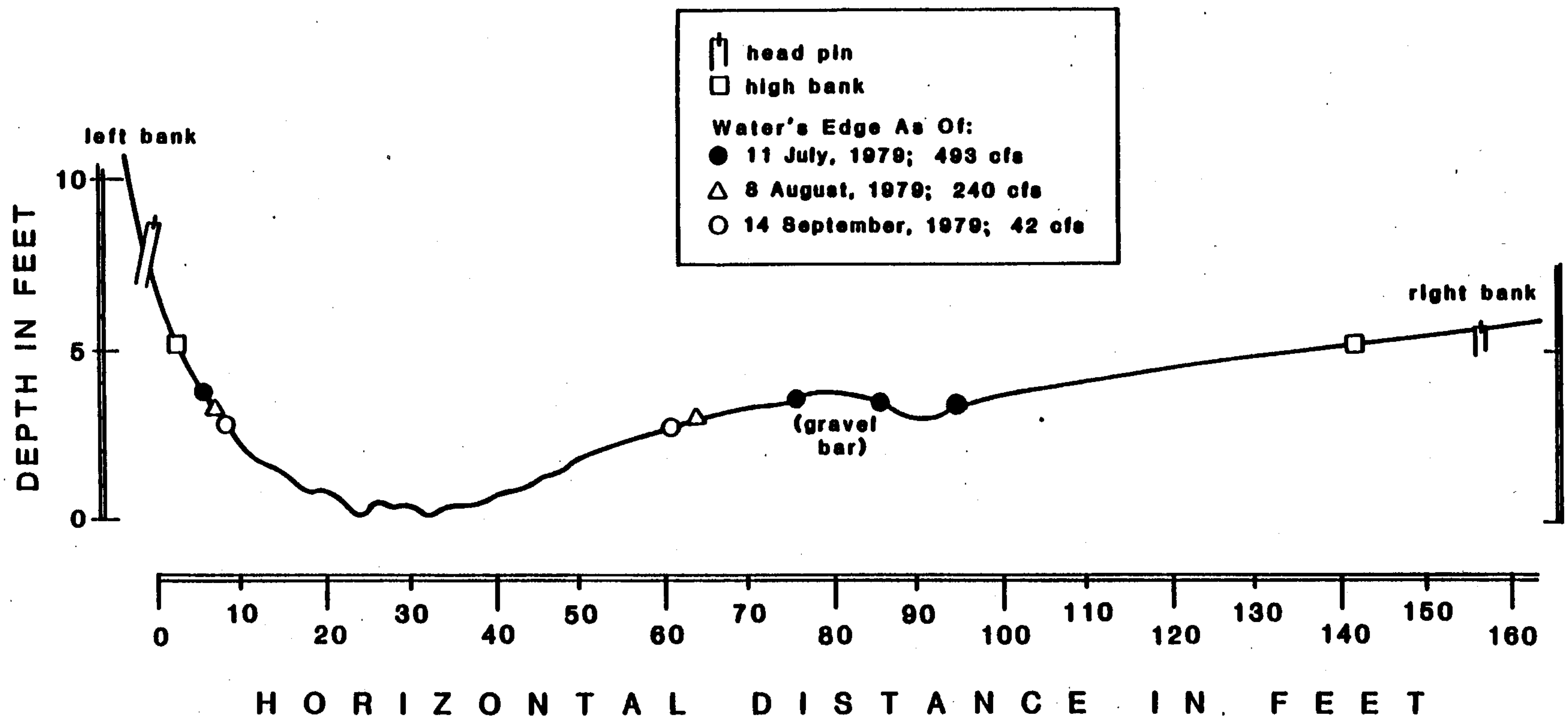
CROSS-SECTIONAL PROFILE OF WILLOW CREEK UPPER REACH, TRANSECT #1.
(1 vertical foot equals 4 horizontal feet)

Figure 15



CROSS-SECTIONAL PROFILE OF WILLOW CREEK UPPER REACH, TRANSECT #2.
(1 vertical foot equals 4 horizontal feet)

Figure 16



CROSS-SECTIONAL PROFILE OF WILLOW CREEK UPPER REACH, TRANSECT #3.
(1 vertical foot equals 4 horizontal feet)

APPENDIX B

HABITAT MEASUREMENTS OF CHINOOK AND PINK SALMON REDDS IN WILLOW CREEK

Appendix B. Table 1. Redd measurements for chinook salmon in Willow Creek, August 1979.*

Depth (Ft.	Velocity (ft./sec.)	Substrate Classification
1.10	1.92	IV
1.70	2.39	III-IV
0.95	0.28	II
1.30	4.75	III-IV
2.00	5.20	III-IV
1.50	3.21	III
1.60	1.23	III
1.40	2.34	IV
3.00	4.28	III
2.70	2.50	III-IV
2.10	2.80	III
2.20	0.99	III
1.60	0.99	III
1.10	0.84	III-IV
2.00	2.10	III
2.40	2.99	III
2.00	4.75	IV
1.50	2.44	IV
2.20	3.13	III
1.70	3.06	III
1.40	3.28	III-IV
2.00	2.69	III
2.50	3.21	III
2.60	3.28	III
1.80	2.99	III
2.10	1.16	III-IV
2.00	2.20	III-IV
1.60	2.29	III
1.10	2.10	III
1.60	2.10	III
1.50	2.74	III-IV
1.50	1.88	III
1.70	3.80	III

*Not recommended for application to other watersheds.

Appendix B. Table 2. Redd measurements for chinook salmon in Willow Creek, August 1978 (adapted from Watsjold and Engel 1978).*

Depth (ft.)	Velocity (ft./sec.)	Substrate (in.)	Classification**
1.7	3.72	2.0-6.0	IV-V
1.3	3.06	2.0-6.0	IV-V
1.0	2.39	1.5-6.0	IV
1.3	3.28	2.0-7.0	IV-V
1.9	1.54	2.0-6.0	IV-V
1.8	1.76	1.5-7.0	IV
1.5	1.76	2.0-7.0	IV-V
1.7	2.44	1.5-7.0	IV
1.4	4.46	1.5-7.0	IV
1.3	3.57	1.5-7.0	IV
2.2	3.21	2.0-7.0	IV-V
1.8	2.61	2.0-6.0	IV-V
2.0	3.50	2.0-5.0	IV
1.4	3.80	2.0-6.0	IV-V
2.1	3.43	3.0-6.0	V
1.4	3.28	1.0-5.0	III-IV
1.4	3.21	3.0-6.0	V
1.0	3.89	3.0-6.0	V
1.3	2.92	2.0-5.0	IV
1.4	2.50	2.0-4.0	IV
1.2	1.51	1.0-4.0	III-IV
1.6	3.43	1.0-6.0	III-IV
1.2	3.80	2.0-6.0	IV-V
2.0	3.37	3.0-7.0	V
1.6	2.29	1.5-4.0	III-IV
1.3	2.55	1.5-4.0	III-IV
1.8	2.99	2.0-5.0	IV
1.8	3.80	1.5-4.0	III-IV
1.8	3.28	2.0-6.0	IV-V
1.6	3.98	1.5-6.0	IV
1.7	2.55	3.0-6.0	V
1.3	1.58	1.5-3.0	III-IV
1.9	2.74	2.0-6.0	IV-V
2.1	2.50	- -	- -
2.0	1.65	3.0-6.0	V

*Not recommended for application to other watersheds.

**Substrate data collected in 1978 and classified using the method described in this report.

Appendix B. Table 2 (continued)

Depth (ft.)	Velocity (ft./sec.)	Substrate (in.)	Classification*
1.9	3.43	3.0-5.0	V
1.7	3.50	2.0-6.0	IV-V
2.1	4.75	2.0-6.0	IV-V
2.0	4.16	- -	- -
2.2	3.56	- -	- -
2.2	3.28	- -	- -
1.8	4.37	1.5-4.0	III-IV
1.7	4.55	1.5-4.0	IV
1.7	3.80	2.0-6.0	IV-V
1.5	2.29	1.5-3.0	III-IV
1.9	2.92	1.5-4.0	III-IV
1.4	2.99	1.5-3.0	III-IV
1.4	4.16	4.0-6.0	V-VI
1.7	4.07	3.0-5.0	V
1.5	3.89	2.0-5.0	V

*Substrate data collected in 1978 and classified using the method described in this report.

Appendix B. Table 3. Redd measurements for pink salmon in Willow Creek, August 1978 (adapted from Watsjold and Engel 1978).*

Depth (ft.)	Velocity (ft./sec.)	Substrate (in.)	Substrate Classification**
1.8	2.10	1.0-1.5	III-IV
1.8	2.29	1.0-2.0	III-IV
2.1	2.10	1.0-2.0	III-IV
1.4	1.01	1.0-2.0	III-IV
2.1	1.17	1.0-2.0	III-IV
2.4	2.20	1.0-2.0	III-IV
1.9	1.51	1.0-1.5	III-IV
2.1	3.28	0.5-2.0	III
2.0	2.55	1.0-2.0	III-IV
0.9	1.92	1.5-2.0	III-IV
1.7	3.28	2.0-3.0	IV
1.8	3.50	2.0-5.0	IV
1.4	1.76	1.0-1.5	III-IV
2.3	2.74	1.5-2.0	III-IV
1.6	2.00	1.0-2.0	III-IV
1.1	2.20	0.5-1.5	III
0.9	1.33	1.0-1.5	III-IV
0.6	1.25	0.5-1.0	III
2.1	2.74	0.5-1.5	III
0.8	2.02	1.0-1.5	III-IV
0.9	3.72	1.5-2.0	III-IV
1.1	1.58	0.5-1.5	III
1.0	2.00	0.5-1.5	III
0.8	3.11	0.5-1.0	III
1.5	2.74	0.5-1.5	III
0.5	1.84	1.0-1.5	III-IV
0.8	2.44	1.0-1.5	III-IV
1.5	3.28	1.5-3.0	III-IV
1.7	3.65	1.0-2.0	III-IV
0.6	1.25	1.0-1.5	III-IV

*Not recommended for application to other watersheds.

**Substrate data collected in 1978 and classified using the method described in this report.

Appendix B. Table 3 (continued)

Depth (ft.)	Velocity (ft./sec.)	Substrate (in.)	Substrate Classification*
0.7	1.96	0.5-1.5	III
0.7	2.34	1.0-1.5	III-IV
0.8	1.58	0.5-1.0	III
1.4	2.20	1.0-2.0	III-IV
1.4	2.50	- -	- -
0.7	2.50	1.0-2.0	III-IV
1.7	2.50	1.0-2.0	III-IV
1.5	2.38	1.0-2.0	III-IV
0.7	1.96	0.5-1.5	III
1.5	2.55	1.0-1.5	III-IV
1.5	2.10	0.5-1.5	III
1.7	2.29	1.0-1.5	III-IV
1.1	1.47	0.5-0.8	II-III
1.7	1.92	0.5-1.0	III
1.8	2.29	0.5-1.5	III
2.0	2.74	1.0-2.0	III-IV
1.8	2.55	0.5-1.0	III
0.6	1.35	0.5-1.0	III
0.9	1.88	0.5-1.0	III
1.5	2.20	1.0-1.5	III-IV
0.7	1.63	f**-0.8	II
1.3	1.96	1.0-2.0	III-IV
1.5	2.99	1.0-2.0	III-IV
1.0	1.28	f**-2.0	II-III
1.2	2.20	1.0-2.0	III-IV
1.3	2.39	1.0-2.0	III-IV
0.8	1.65	0.5-1.5	III
1.3	2.44	1.0-3.0	III-IV
1.1	3.50	1.0-2.0	III-IV
1.6	2.34	1.0-1.5	III-IV
1.4	3.13	1.0-2.0	III-IV
1.2	2.44	0.5-1.5	III
1.7	2.74	0.8-2.0	III
1.5	2.55	0.5-1.5	III
1.3	2.74	1.5-2.0	III-IV

*Substrate data collected in 1978 and classified using the method described in this report.

**f = fines

Appendix B. Table 3 (continued)

Depth (ft.)	Velocity (ft./sec.)	Substrate (in.)	Substrate Classification*
1.4	2.99	1.5-2.0	III-IV
1.1	2.61	0.5-1.5	III
1.1	2.29	1.0-2.0	III-IV
1.3	3.37	1.0-1.5	III-IV
1.1	3.37	1.0-2.0	III-IV
0.9	2.05	1.0-1.5	III-IV
1.7	2.10	f**-1.0	II-III
1.1	1.88	0.3-6.0	III
1.2	2.74	1.0-6.0	III-IV
1.6	2.50	0.5-5.0	III
1.0	2.55	0.5-5.0	III
1.1	2.74	0.5-5.0	III
1.6	2.99	1.0-6.0	III-IV
2.0	4.01	1.0-6.0	III-IV
1.2	2.20	0.5-4.0	III
1.9	2.74	0.5-5.0	III
1.6	3.80	1.0-4.0	III-IV
2.1	2.39	1.0-4.0	III-IV
1.0	3.21	0.8-5.0	III
1.2	2.72	0.5-3.0	III
1.5	2.98	1.0-6.0	III-IV
1.9	3.89	1.0-6.0	III-IV
0.9	2.05	f**-1.0	II-III
1.1	2.05	0.5-3.0	III
1.6	3.13	1.0-6.0	III-IV
1.5	1.84	f**-3.0	II-III
1.3	2.29	0.5-5.0	III
1.5	3.07	1.0-5.0	III-IV
1.6	1.65	0.5-3.0	III
2.4	2.00	0.5-4.0	III
1.7	3.80	0.8-4.0	III
0.9	2.50	0.5-2.5	III
1.5	2.55	0.5-4.0	III
2.3	2.61	0.5-4.0	III
1.2	1.88	0.5-2.5	III

*Substrate data collected in 1978 and classified using the method described in this report.

**f = fines

Appendix B. Table 3 (continued)

Depth (ft.)	Velocity (ft./sec.)	Substrate (in.)	Substrate Classification*
1.8	2.98	0.5-7.0	III
1.0	2.68	0.8-3.0	III
1.6	3.24	0.5-3.0	III
1.0	1.62	0.5-2.5	III
1.2	2.10	0.5-3.0	III
0.6	1.84	0.5-4.0	III
1.3	1.65	0.5-3.0	III
1.4	2.15	0.5-2.5	III
0.9	1.92	0.5-3.0	III
1.5	2.44	0.8-4.0	III
1.7	2.61	1.0-5.0	III-IV
1.5	3.65	0.8-5.0	III
1.0	3.43	0.8-4.0	III
1.0	2.61	0.5-2.5	III

*Substrate data collected in 1978 and classified using the method described in this report.

**f = fines

APPENDIX C

CHINOOK AND PINK SALMON UTILIZATION CURVES

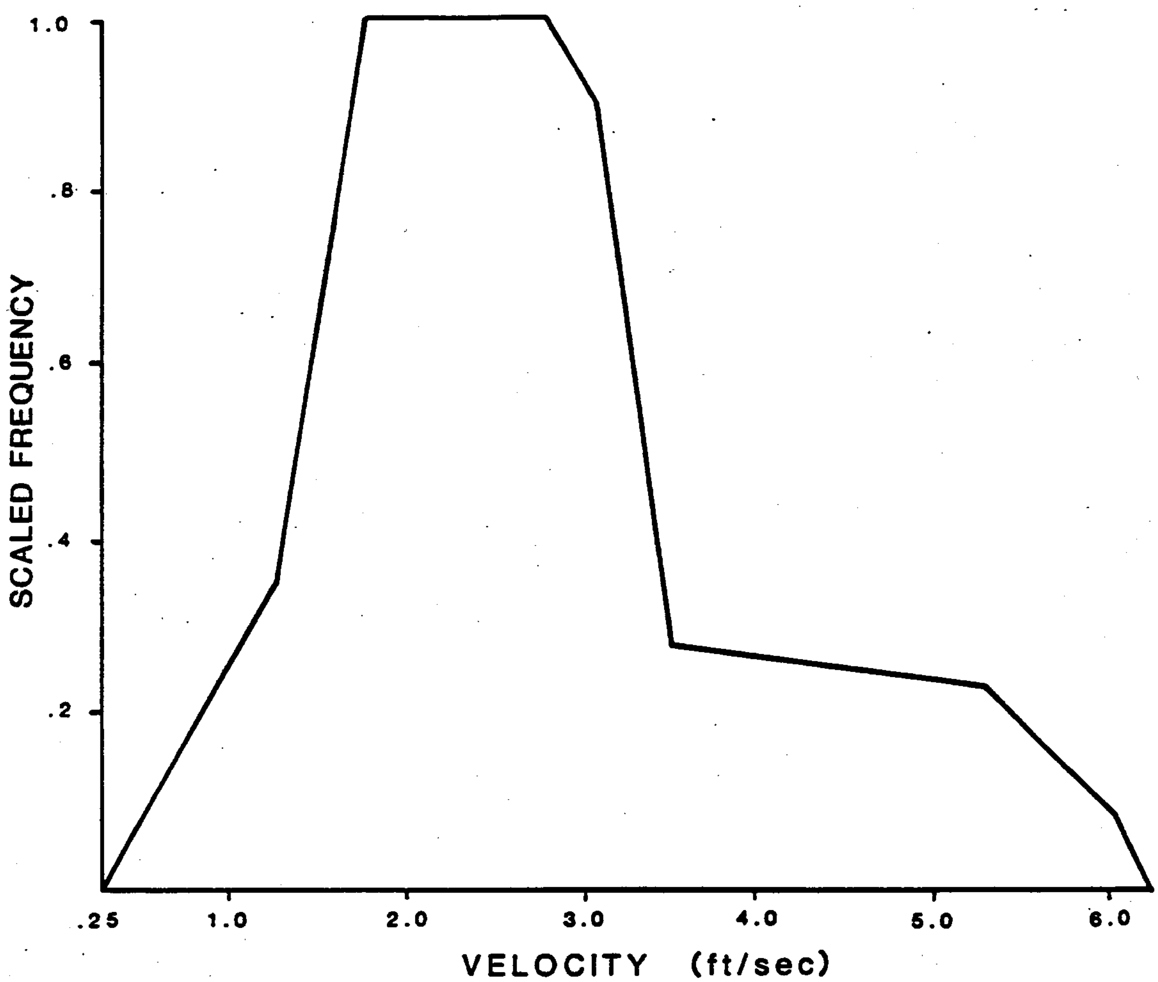


Figure 1 Velocity utilization curve for spawning chinook salmon in Willow Creek Alaska, Summer 1979.

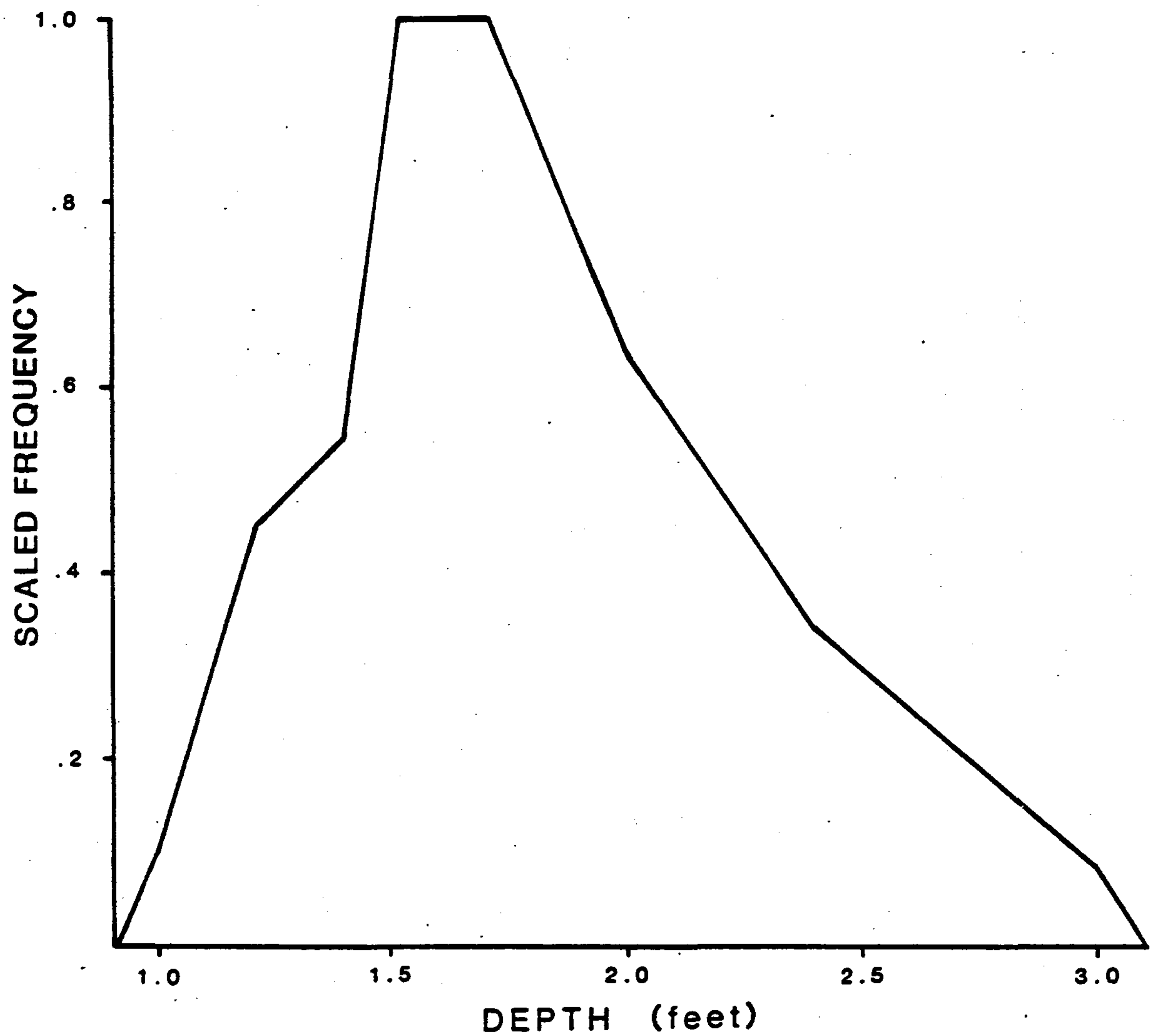


Figure 2 Depth utilization curve for spawning chinook salmon in Willow Creek, Alaska, Summer 1979.

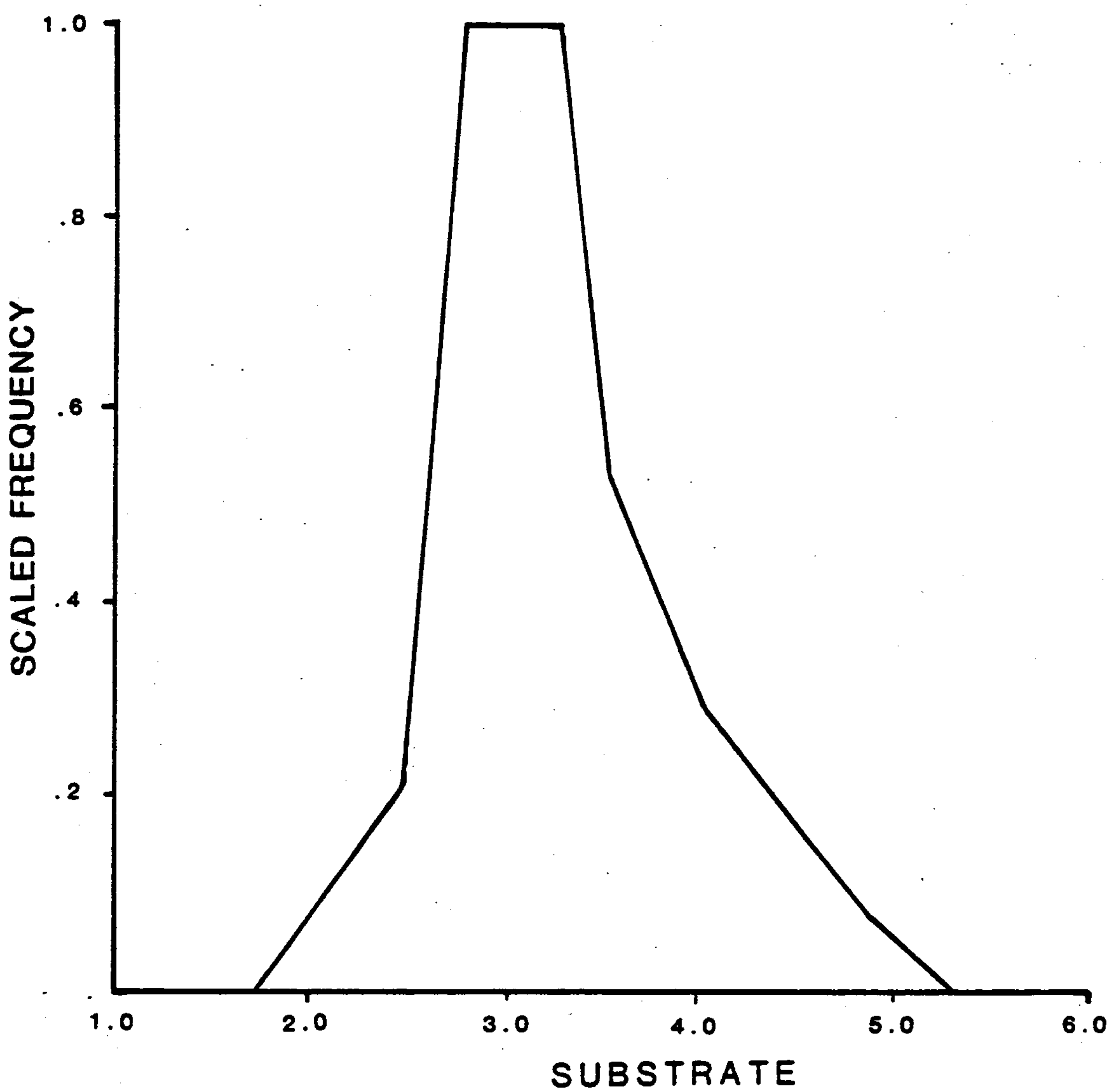


Figure 3 Substrate utilization curve for spawning chinook salmon in Willow Creek, Alaska, Summer 1979.

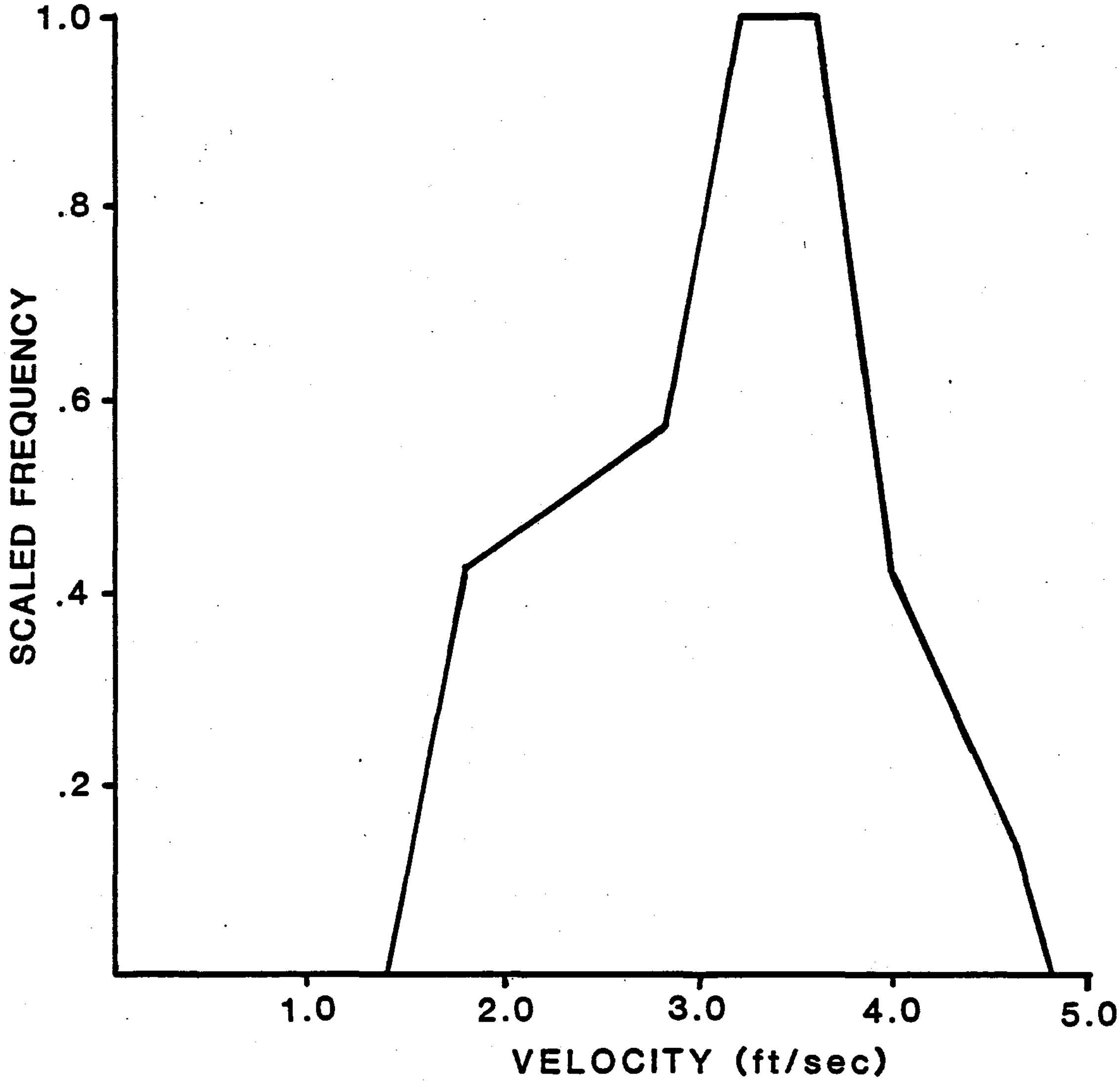


Figure 4 Velocity utilization curve for spawning chinook salmon in Willow Creek, Alaska, Summer 1979. (adapted from Watsjold and Engel 1978)

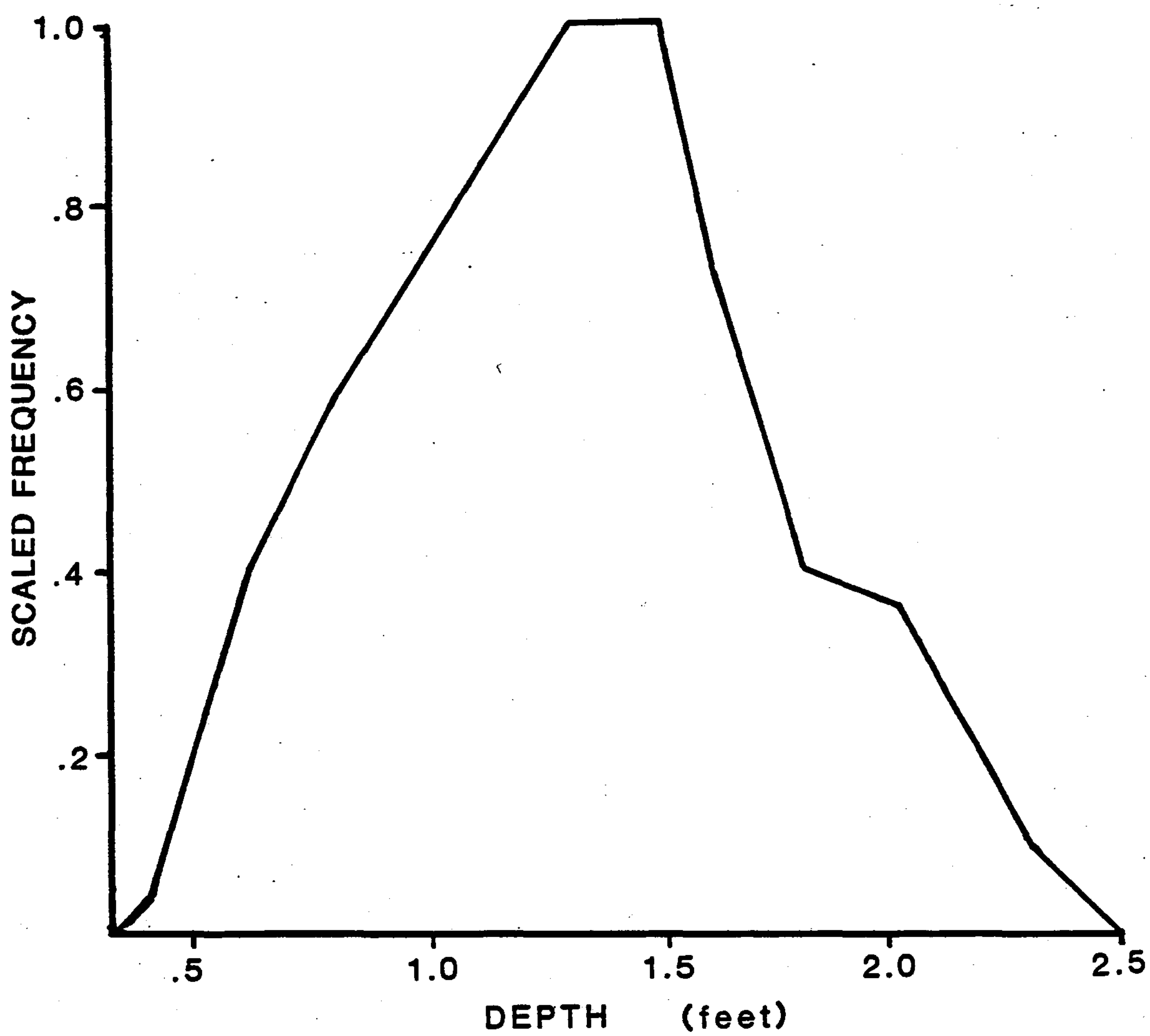


Figure 5 Depth utilization curve for spawning chinook salmon in Willow Creek, Alaska, Summer 1978. (adapted from Watsjold and Engel 1978)

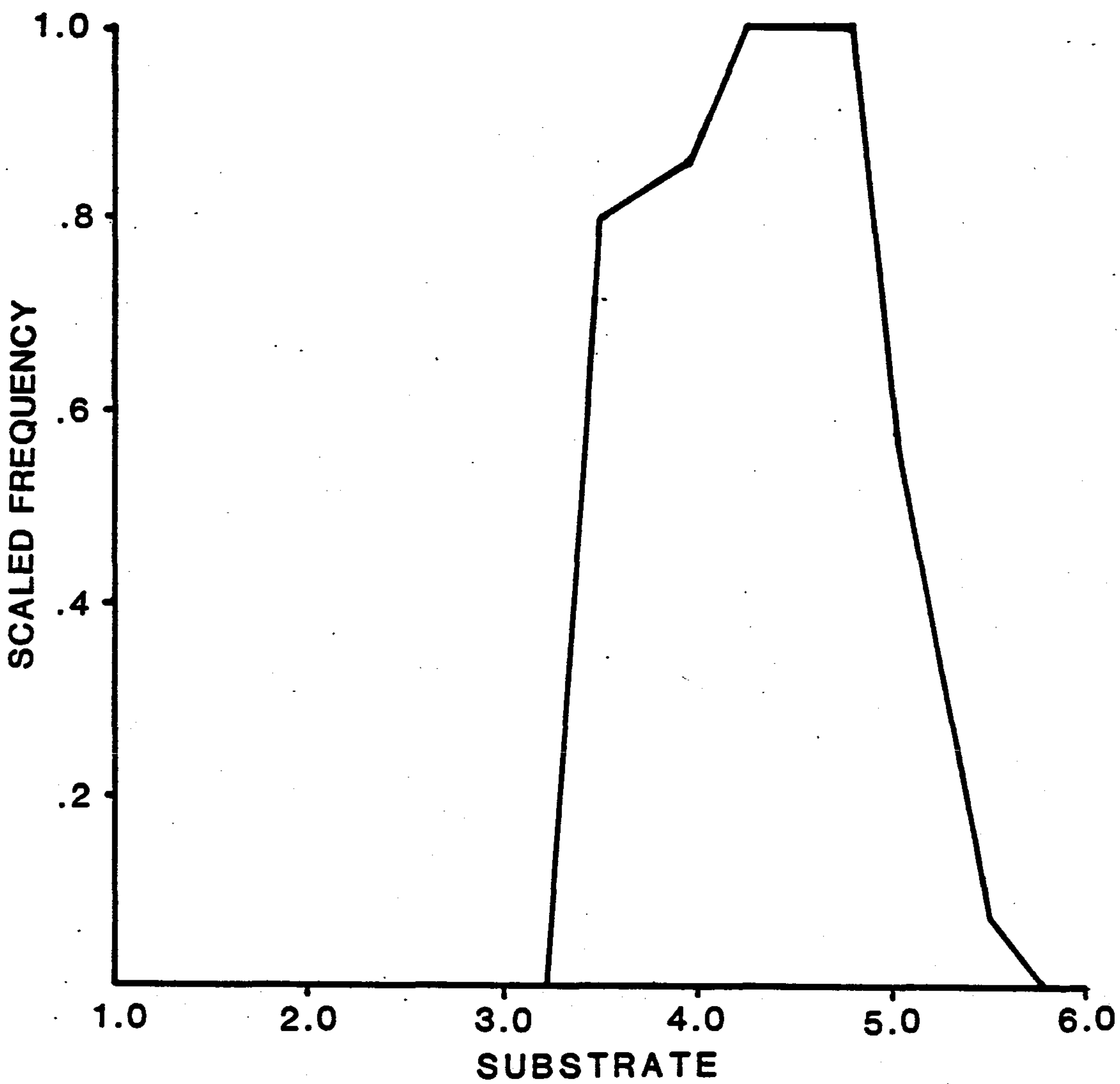


Figure 6 Substrate utilization curve for spawning chinook salmon in Willow Creek, Alaska, Summer 1978. (adapted from Watsjold and Engel 1978)

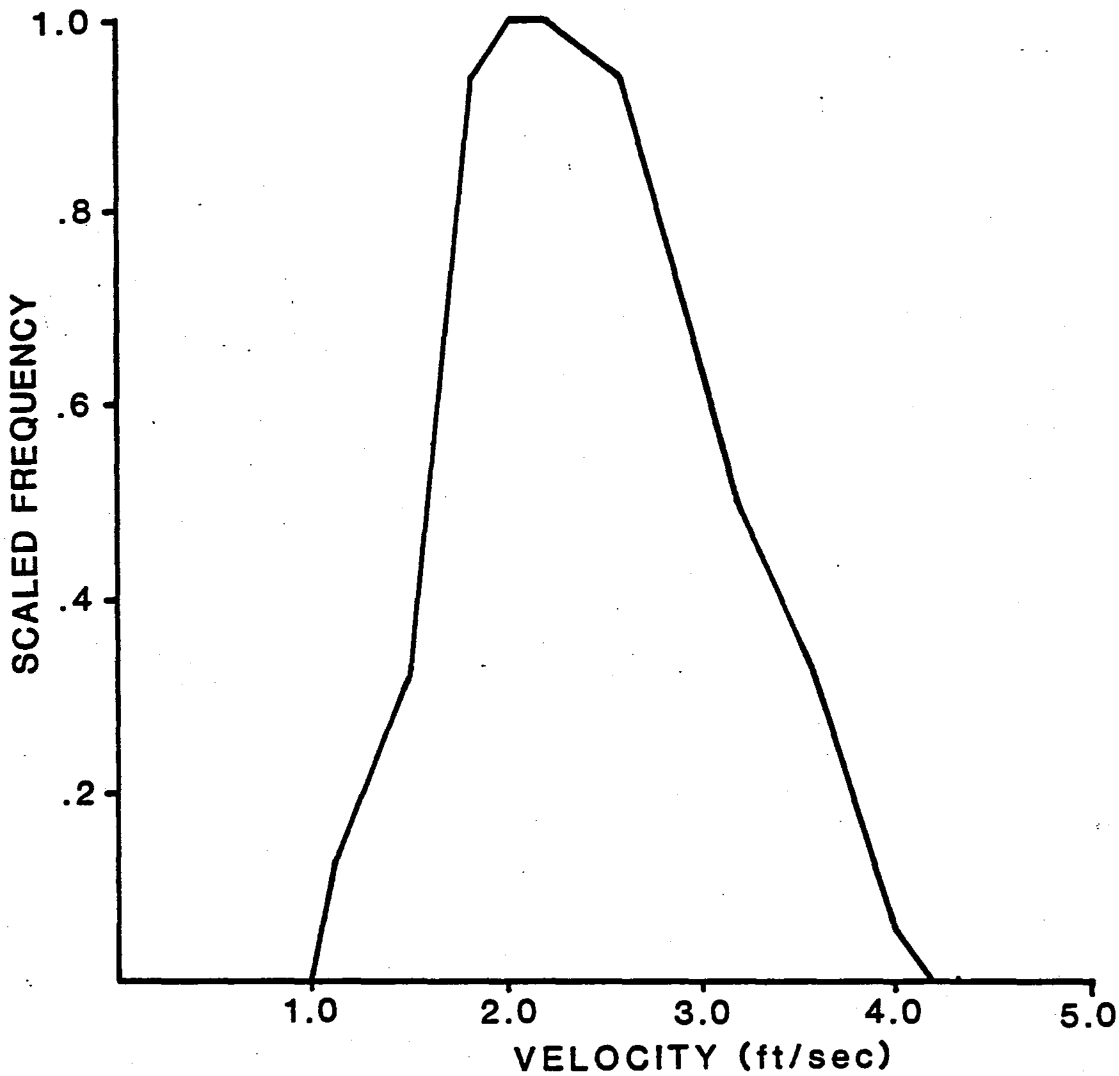


Figure 7 Velocity utilization curve for spawning pink salmon in Willow Creek, Alaska, Summer 1978. (adapted from Watsjold and Engel 1978)

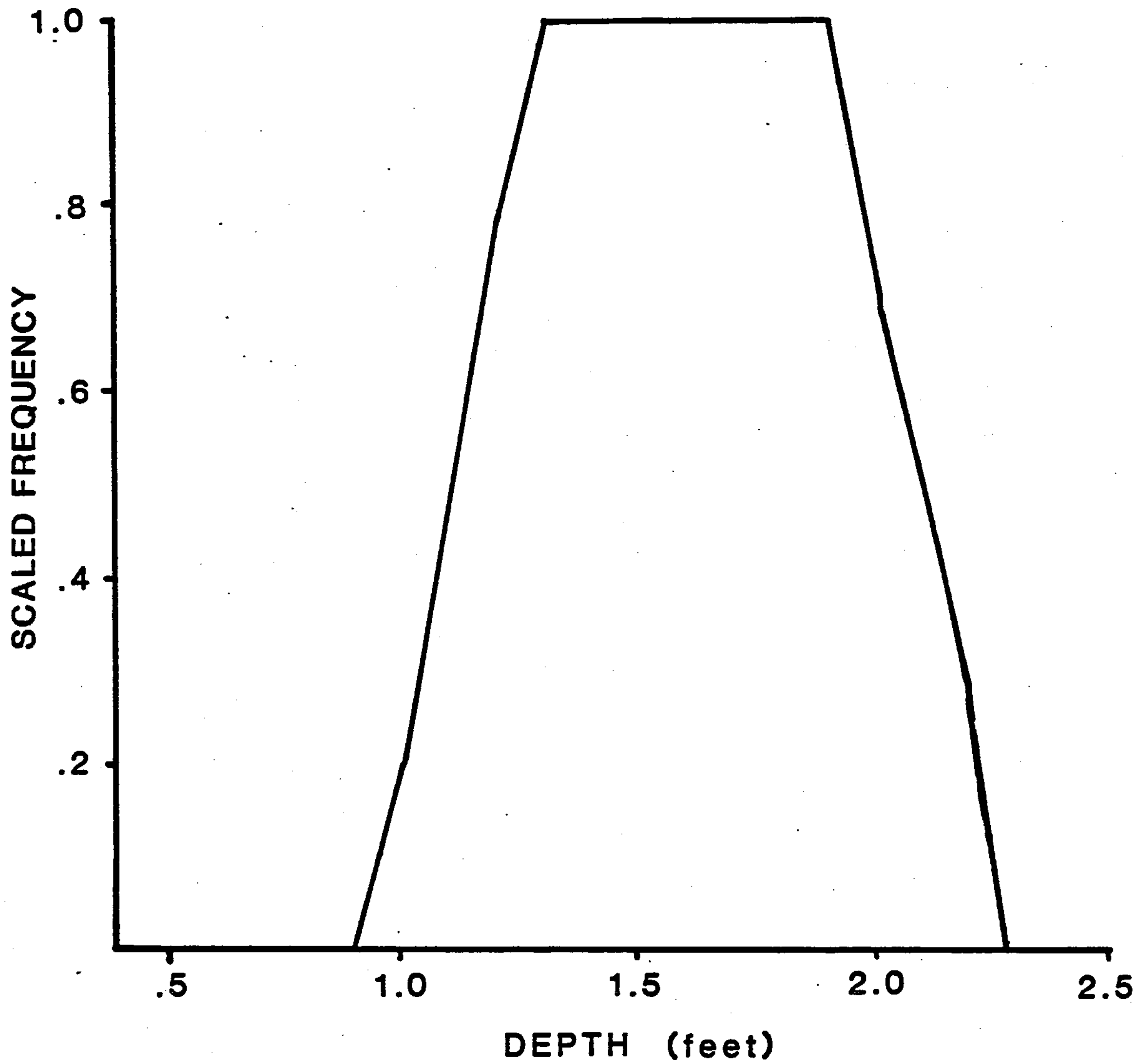


Figure 8 Depth utilization curve for spawning pink salmon in Willow Creek, Alaska, Summer 1978. (adapted from Watsjold and Engel 1978)

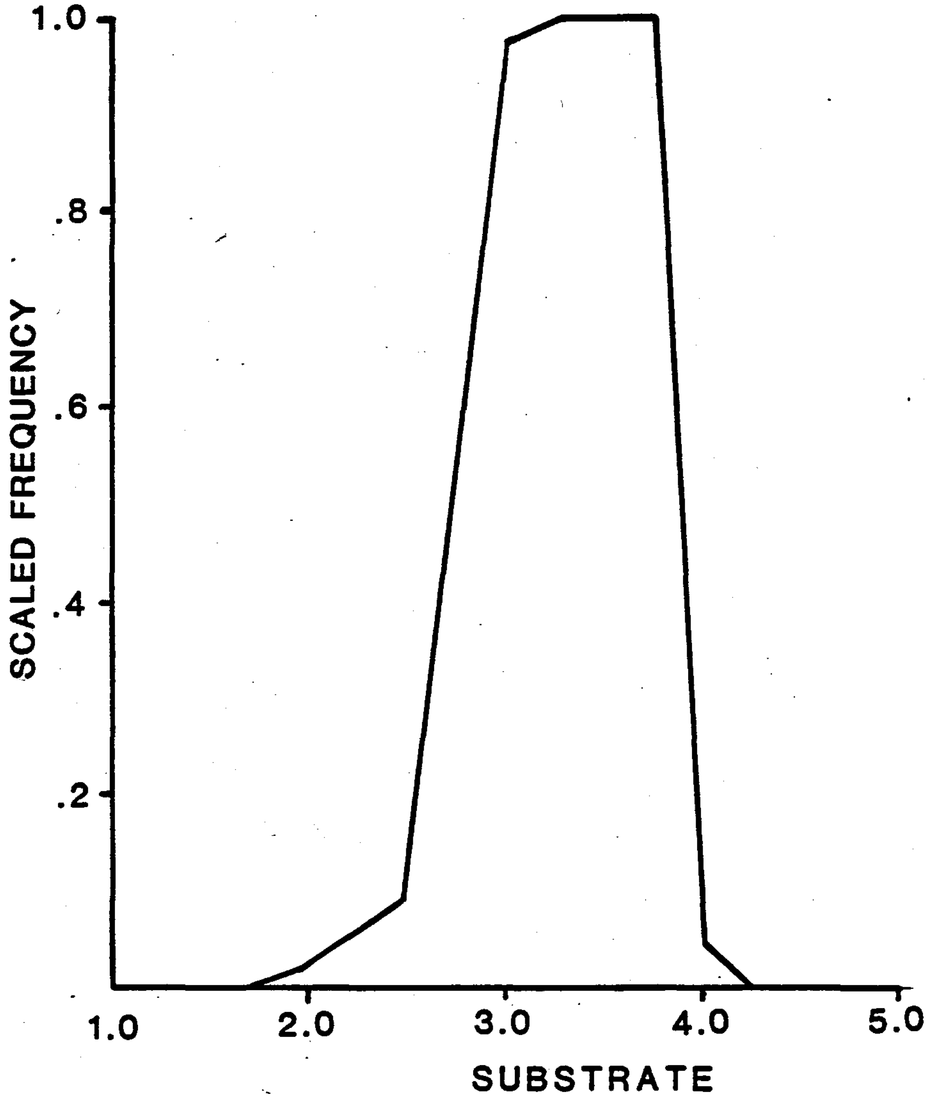


Figure 9 Substrate utilization curve for spawning pink salmon in Willow Creek, Alaska, Summer 1978. (adapted from Watsjold and Engel 1978)