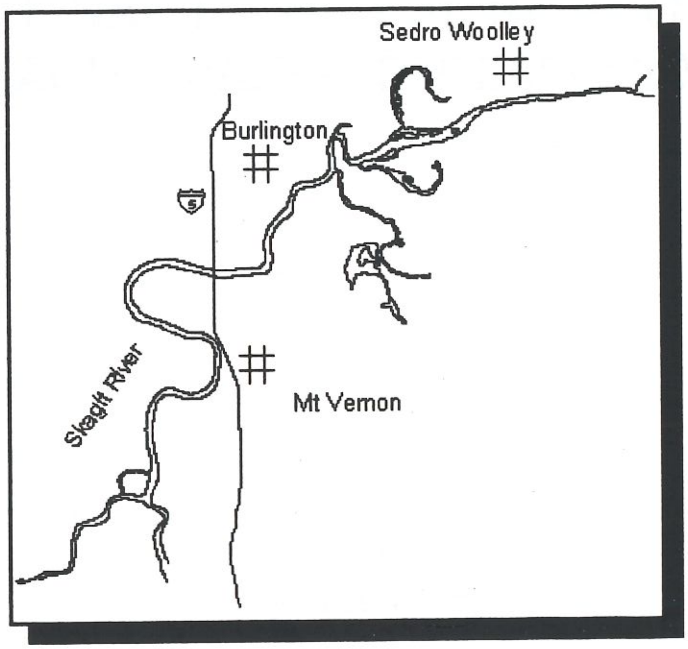
FINAL TECHNICAL REPORT
LOWER SKAGIT RIVER INSTREAM FLOW STUDIES



Prepared for

Public Utility District No. 1 of Skagit County
and
City of Anacortes

Prepared by

Duke Engineering & Services, Inc
Bellingham, Washington

June 1999

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ACKNOWLEDGMENTS

Funding for this project was provided by the City of Anacortes and Public Utility District No. 1 of Skagit County. Members of the Skagit River Instream Flow Committee provided valuable time, input and decisions throughout the duration of this study.

A special thanks is due to the people who assisted in various ways on this study. There are many and it would not be possible to list all of them.

EXECUTIVE SUMMARY

In order to assist Washington Department of Ecology in expediting the water right decision-making process in the Lower Skagit River, Duke Engineering & Services, Inc. (DE&S) conducted an instream flow study in the Skagit River segment downstream of river mile 24.3 (RM 24.3). The requirement to conduct instream flow studies in the Lower Skagit River is stipulated in the *Memorandum of Agreement Regarding Utilization of Skagit River Basin Water Resources for Instream and Out of Stream Purposes* (MOA), 1996. The parties to this MOA include Public Utility District No. 1 of Skagit County, City of Anacortes, Skagit County, Washington Department of Ecology, the Washington Department of Fish and Wildlife, and the Swinomish, Upper Skagit, and Sauk-Suiattle Tribes, represented by the Skagit System Cooperative.

A Skagit River Instream Flow Committee (Committee) was formed consisting of representatives of the parties to the MOA and consultants involved in conducting the studies.
The Committee was actively involved throughout the process. Responsibilities included jointly agreeing on the scope, reviewing methods, and making final instream flow recommendations.

This study focused on the habitat, hydrologic and instream flow needs of anadromous salmonids. Fisheries resources of primary concern in the Lower Skagit River are commercial and game fish including four salmon species, steelhead trout, cutthroat trout, and bull trout. Salmonid populations are from native stocks and consist of healthy populations as well as populations in decline.

The study area was subdivided into the a Main Skagit River Instream Flow Study Area and an Estuary Study Area; the study designs and results were distinct for each area. The Main Skagit River Instream Flow Study Area encompassed the mainstem river from RM 24.3 near Sedro Woolley, to RM 8.1 at the bifurcation of the North and South Forks. The Estuary Study Area continued downstream from RM 8.1 and encompassed the Skagit estuary.

The Main Skagit River Instream Flow Study was conducted using the US Fish and Wildlife Service Instream Flow Incremental Method (IFIM). Study method for the Estuary Study Area consisted of measuring streamflow and tidal effects on a variety of estuary habitats.

The Main Skagit River Instream Flow Study computed Weighted Usable Area (WUA), which is a quantifiable index of habitat value, relative to flows ranging between 2,900 cfs and 72,000 cfs. This document reports WUA results for rearing salmonids including chinook salmon, coho salmon, steelhead trout, cutthroat trout, and bull trout. WUA results for spawning salmonids are reported for pink salmon, chum salmon, chinook salmon, and steelhead trout.

The Estuary Study computed the effects of tide and river discharge on selected estuarine habitats for both tidal and nontidal conditions. The analysis delineated areas primarily controlled by tidal influences and areas primarily controlled by river discharge. The frequency and duration of inundation of over-bank feeding areas are reported for a range of flows from 10,000 to 25,000 cfs.

The Committee reviewed the results of the studies and recommended instream flows and maximum out-of-stream allocations for the Lower Skagit River. Individual species and life stage needs were considered in developing instream flow recommendations. Instream flow recommendations vary by month and range from 10,000 cfs to 13,000 cfs. Recommendations for maximum allocation vary by month and range from 836 cfs to 1610 cfs.

This report is organized into five main sections, Introduction (1.0), Main Skagit River Instream Flow Study (2.0), Estuary Study (3.0), Hydrology (4.0), and Discussion and Recommendations (5.0). The methodology, results and discussion are contained in the main body of the text and supporting technical data is located in the Appendices.

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1.0 INTRODUCTION

1.1 Authority

In order to meet future water supply needs, Public Utility District No. 1 of Skagit County (District) and the City of Anacortes (City) studied the option of water withdrawal from the Skagit River. In order to exercise this option, the District and the City were required to conduct instream flow studies on the Skagit River down stream of the District pipeline crossing at located at River Mile (RM) 24.3. This requirement is stipulated under Section IV-B of the *Memorandum of Agreement Regarding Utilization of Skagit River Basin Water Resources for Instream and Out of Stream Purposes* (MOA), 1996. The parties (Parties) to this MOA include the District, the City, Skagit County (County), Washington Department of Ecology (WDOE), the Washington Department of Fish and Wildlife (WDFW), and the Swinomish, Upper Skagit, and Sauk-Suiattle Tribes, represented by the Skagit System Cooperative (SSC).

This report is organized into four main sections, the Main Skagit River Instream Flow Study, the Estuary Study, Hydrology of the Lower Skagit River and Discussion of the results and recommendations. The methodology and implementation of the results of these three main components are each distinct and each addresses particular aspects of the overall instream flow issue.

1.2 Background

In the Lower Skagit River basin, instream flow issues have not been addressed in sufficient detail to determine adequate stream flows to protect fish and other important aquatic resources. This lack of established instream flows has caused the Washington Department of Ecology to suspend actions that are necessary to issue new water rights and process proposed changes in of point of diversion and place of use, for out-of-stream water needs. The Parties to the MOA decided that to avoid litigation they would assist in expediting the WDOE's water right decision-making. All involved parties agreed to a process structured to resolve the Lower Skagit River instream flow issue.

The primary purpose of the MOA is to 1) to ensure the establishment of instream flows to protect fisheries resources; and 2) provide a mechanism for coordinated water resources management between the parties for out-of-stream needs, including resolution of public purveyors water rights issues. This report presents the study methodology, results, and recommendations for the establishment of instream flows for the Lower Skagit River.

Fisheries resources of primary concern in the Lower Skagit River are commercial and game fish including 4 salmon species, steelhead trout, cutthroat trout, and bull trout. Salmonid populations are from native stocks and consist of healthy populations as well as populations in decline. Factors such as habitat degradation and over fishing have contributed to the decline of wild stocks in the Skagit Basin.

1.3 Skagit River Instream Flow Committee

In order to facilitate the study process and review information a Skagit River Instream Flow Committee (Committee) was formed of representatives of the Parties to the MOA and consultants involved in conducting the studies. The Committee includes the following representatives. (Table 1.3-1).

Table 1.3-1 Skagit River Instream Flow Committee

Organization	Representative
Public Utility District No. 1 of Skagit County (District)	Mr. Robert Powell
City of Anacortes (City)	Mr. Jim Pemberton
Skagit System Cooperative (SSC)	Mr. Larry Wasserman Mr. Eric Beamer (Technical)
Duke Engineering & Services, Inc. (DE&S)	Mr. Pete Rittmueller Mr. Michael Barclay Mr. John Blum
Skagit County	Mr. Tom Karsh
Washington Department of Ecology (WDOE)	Mr. Jeff Marti Mr. Brad Caldwell
Washington Department of Fish and Wildlife (WDFW)	Dr. Hal Beecher

1.4 Study Objectives

The objectives of this study were to provide instream flow technical data to the Parties for use in the discussion and establishment of Lower Skagit River instream flow recommendations downstream of River Mile 24.3 (Figure 1.1-1). *The study primarily focused on the habitat needs of important salmonid species that use the Lower Skagit River for all or part of their fresh water life cycle. Both spawning and rearing habitat requirements were addressed as appropriate.*

Lower Skagit River Instream Flow Study Area

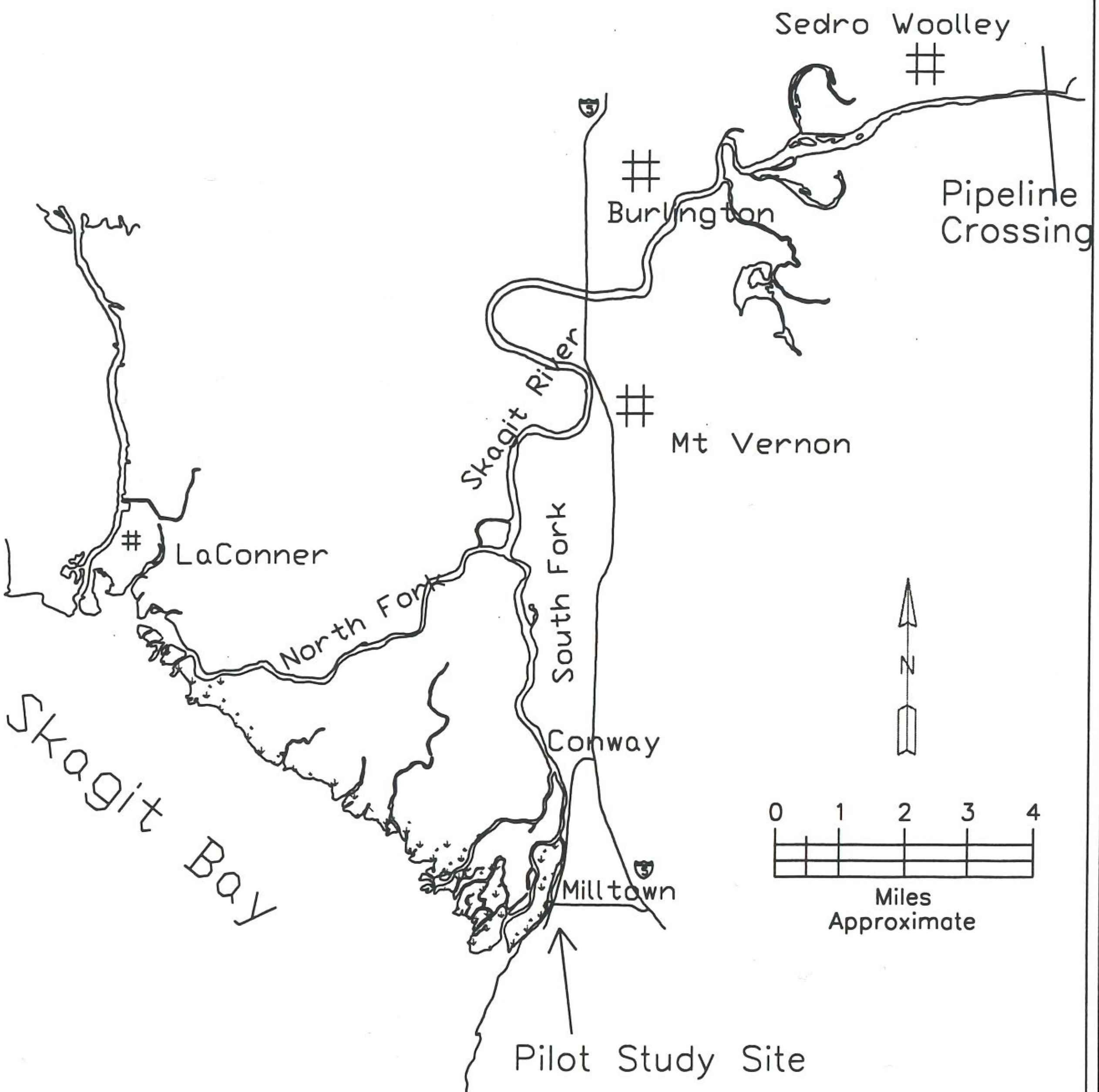


Figure 1.1-1

1.5 Skagit River Watershed

The Skagit River originates as rainfall and snowmelt in the North Cascades Mountains of Washington and Coast Mountains of southern British Columbia. The Skagit river flows to the southwest 162 miles and empties into Skagit Bay, in Skagit County, Washington. The Skagit River basin is the largest of the Puget Sound drainages. The Skagit River watershed above the pipeline crossing at RM 24.3 is approximately 3,015 square miles.

The topography, hydrology and land uses of the Skagit watershed is diverse. In the mountainous headwaters, much of the area is managed park and forest land with glaciers and snow fields on the higher peaks and dense coniferous forests covering the mid elevation slopes.

The headwater streams are generally steep continuous cascades with boulder and cobble substrate. The mid and upper river segments generally wind through constricted valley floors and flow over cobble and gravel riffles interspersed with short, boulder strewn cascades.

The study area is in the lower section of the Skagit River between the pipeline crossing at RM 24.3 and the mouth of the river at Skagit Bay (Figure 1.1-1). The Lower Skagit River flows through a broad valley of fertile, cultivated fields, with small towns at intervals along the river. The banks of the river are mainly covered with rip rap and in some areas dikes have been constructed on both banks. Stream gradient is extremely low, with an averaging just 0.003% (Hayman et al. 1996).]

2.0 MAIN RIVER INSTREAM FLOW STUDY

2.1 Methodology and Approach

2.1.1 Overview of IFIM Methodology

The Instream Flow Incremental Methodology (IFIM) is based on the premise that stream-dwelling fishes prefer a certain range of depths, velocities, substrates, and cover types, depending upon the species and life stage, and that the availability of these preferred habitat conditions varies with stream flow. The IFIM is designed to quantify potential physical habitat available for each life stage of interest for a target fish species at various levels of stream discharge, using a series of computer programs developed by the US Fish and Wildlife Service. Major components of the IFIM methodology include: (1) study site and transect selection; (2) transect weighting; (3) field collection of hydraulic data; (4) development or verification of habitat suitability criteria; (5) hydraulic simulation to determine the spatial distribution of combinations of depths and velocities with respect to substrate and cover under a variety of discharges, and (6) habitat simulation, using habitat suitability criteria, to generate an index of change in habitat relative to change in discharge. The product of the habitat simulation is expressed as Weighted Usable Area (WUA) for a range of simulated stream discharges.

It is important for the water manager to recognize that the result of the IFIM is not a set value but a range of values to be used as a tool for determining the appropriate stream flow or set of stream flows.

2.1.2 Stream Reach Description

Within the Main River Study Area, the Skagit River is primarily contained within a single channel. River banks have been substantially modified for most of this reach, with dikes positioned along one or both banks of the river for significant lengths. In many instances the banks have been extensively hydro-modified with rip-rap, the primary material offering bank protection.

As part of a program to evaluate chinook restoration strategies for the Skagit River, the Skagit System Cooperative (SSC) conducted extensive studies to calculate the area of chinook rearing habitat and estimate the chinook population in the Skagit River mainstem and estuary (Hayman et al. 1996). Based on these studies, the Main River Study Area was divided into three separate reaches, described as the Lower Skagit River Reach in the SSC report. Reach numbers in parenthesis are those assigned in the above-referenced document. River miles listed are the Washington River Index Area (WRIA) designations.

> **Reach 1 (SK030):** A single-channel, hydromodified reach extending from RM 8.1 (the North Fork/South Fork junction) upstream to RM 18.6. The downstream end of Reach 1 (from the Forks upstream to approximately RM 11.1) is tidally-influenced at times.

Reach 2 (SK040): Both single and multi-channel, containing predominantly natural banks and extending from RM 18.6 (downstream of the confluence of Nookachamps Creek) upstream to RM 22.3.

Reach 3 (SK050): A single-channel, hydromodified reach extending from RM 22.3 upstream to the pipeline crossing at RM 24.3.

Table 2.1-1 Lower Skagit Mainstem Study Reaches

	River Mile				
Reach	Lower	Upper	Length	Location	Description
1 - SK0	8.1	18.6	10.5	Forks [of North and South Skagit to Nookachamps Cr.	Single channel; extensive hydromodification
2 - SK2	18.6	22.3	3.7	Nookachamps Cr. to HWY 9 Bridge	Braided Channel islands, natural banks, some hydromodification
3 - SK3	22.3	24.3	2	HWY 9 Bridge to Pipeline Crossing	Single channel; some hydromodification

2.1.3 Transect Selection

Study sites and transects were selected to best represent the variety of habitat types within the Lower Skagit River. DE&S chose 10 IFIM transects within the study reach between RM 8.1 and 24.3 The study sites and transects were approved by resource agency representatives during a site visit on April 22, 1997 (Figure2.1-1).

Since much of the lower Skagit river is low gradient and confined within defined banks, differentiation of habitat types is limited. Minor differences in Lower Skagit River habitat primarily stem from constraints on channel width, presence of gravel or sand bars and single or multi-channel configuration.

The habitat in the Lower Skagit mainstem is dominated by moderately deep glides with rip rap confining the channel on one or both banks. Natural banks with a wide river channel are associated with sand and gravel bars. Transects that represent these variations of moderately deep glides include T2, T4, T9 and T10. Transects with gravel or sand bars on one bank include T1, T3 and T5 (Table 2.1-3).

Lower Skagit River
Study Reaches and Transects

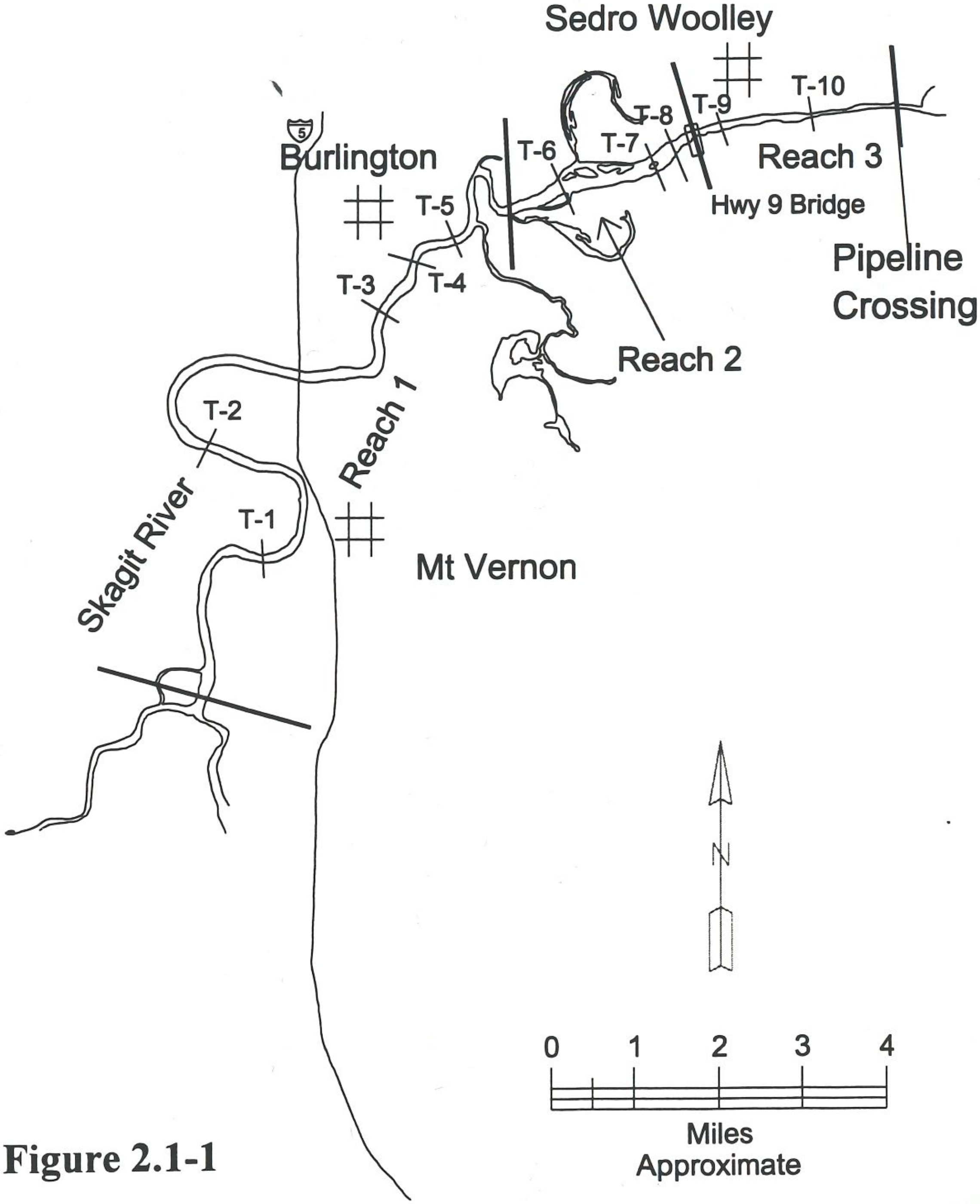


Figure 2.1-1

Approximately 10% of the lower mainstem study reach contains some type of split channel or island habitat. Virtually all of the multi channel habitat is found in Study Site 2. Transects that represent the split channel habitat includes T6 and T7 (Table 2.1-2).

Spawning habitat within the mainstem Skagit study reach is limited primarily to a gravel bar and island habitat just below the Highway 9 bridge. Spawning habitat is represented by T7 and T8.

2.1.4 Transect Weighting

Weighting for each transect was accomplished in basically two steps. The first involved classification of the various habitat types present in the study reach. These classifications were derived from study of the low altitude aerial video, river inspection, and ground truthing.

The second step involved a frequency analysis to determine the proportion of each habitat type in the study reach. Frequencies for the Lower Skagit River were calculated from the low-elevation aerial video. DE&S analyzed the low-altitude videotape using the following procedures. Viewing the aerial video in an upstream direction, the tape image was "frozen" on the screen exactly every 5 seconds according to a screen-generated stop watch. The habitat type that lined up with an index marker drawn horizontally across the center of the monitor screen was tallied according to the established habitat classifications. A total of 178 observations were made of the video tape.

Transect weighting (Table 2.1-2) is based on the frequency of habitat types in the Lower Skagit River that are represented by the selected transects. Transects were weighted empirically, using professional judgement, after several thorough reviews of the aerial videotape and ground truthing efforts. Study site and transect weighting were approved by Dr. Hal Beecher, WDFW, on August 11, 1998. The transect weighting report is included as Appendix A.

Table 2.1-2 Main Channel Skagit River Study Area Final Transect Selection and Transect Weighting

Study Site	Trans No.	Description	River Mile	Weighting Percent
1	1	Bar below bridge; wide, fast, shallow	10.6	12.61%
	2	Wide, steep sided glide; rip rap	12.9	25.22%
	3	Wide glide on river bend; bar/island; rip rap	17.8	10.21%
	4	Wider glide; rip rap on one bank	17.9	15.61%
1 / 2	5	Narrow glide; natural, wooded; gravel bar one bank/rip rap one bank	18.6	13.52%
2	6	Split channel, island, slough	20.9	6.61%
	7	Island; split channel; gravelly spawning bar; rip rap one bank	22.1	2.40%
	8	Very wide glide; shallow, rip rap one bank	22.4	2.40%
3	9	Wider glide, natural and rip rap vegetated banks	22.8	3.00%
	10	Narrower glide; natural vegetated/woody /rip rap banks	23.5	8.41%

October 29, 1998

2.1.5 Field Methods

Physical habitat and hydraulic parameters were measured using standard techniques of the USFWS Instream Flow Incremental Methodology (IFIM) (Trihey and Wegner, 1981; Bovee, 1982; and, WDFW, 1989). DE&S obtained a high, middle and low flow set of hydraulic calibration measurements at each transect. Measurements included depths and velocities at close intervals across the transect, stage of zero flow, hydraulic slope, and water surface elevation.

Mid-channel depth and velocity distributions at the calibration flow were measured from a boat using an acoustic doppler current profiler (ADCP). This device uses acoustic pulses to measure water velocities and depths across the channel. According to an extensive evaluation conducted by the USGS, "ADCP's can be used successfully for data collection under a variety field conditions" (USGS 1996). ADCP hydraulic measurements are made from a boat by moving the ADCP across the channel while it collects vertical-velocity profile and channel-depth data. The ADCP tracks the distance traveled form the point of origin so each depth and velocity measurement is coordinated with a horizontal distance on the transect. Measurements are taken at close intervals across the transect and at multiple levels in the water column. The ADCP is connected by cable to a power source and to a laptop computer. The computer is used to program the instrument, monitor its operation, and collect and store the data.

Because the ADCP will not measure in depths less than approximately 1.5 feet, shallow measurements near shore and at other locations were taken manually using a digital, Swoffer brand, propeller-type velocity meter mounted on a standard top-set USGS wading rod. Manually measured velocities were taken at sixth tenths of the depth when depths were less than 2.5 feet and at two tenths and eight tenths of the depth when depths equaled or exceeded 2.5 feet or when the expected velocity profile was altered by an obstruction immediately upstream.

A Pentax brand electronic total station was used to measure headpin elevations, water surface elevations (WSE), hydraulic controls, above water bed elevations and distances along each transect. All measurements were made relative to a temporary benchmark. Bed elevations below the water surface were obtained by subtracting measured depths taken during velocity calibration from the water surface elevations for that particular transect. Except when surveying the bed profile, the surveyor attempted to measure elevations to the nearest .01 feet.

Substrate and cover were measured visually in shallow water. In the deeper portions of each transect substrate was measured on each transect using a remote video camera towed under a boat. The camera was suspended on a cable with an attached weight that kept the camera directly under the boat. The camera was raised and lowered with the bottom profile to provide a clear view of the bottom and substrate. The width of the camera view was about 1.5 feet and a ruler attached to the camera housing provided a scale to measure substrate size. Horizontal distance along the transect was measured using an ADCP and changes of substrate type was recorded with the location along the transect. This method provided a measurement of horizontal length along each transect with uniform substrate type and location of substrate changes. A recording of the video with an audio description was kept for reference. Observations were coded according to the revised Washington State Resource Agency Substrate and Cover Codes (Appendix G).

2.1.6 Affected Species

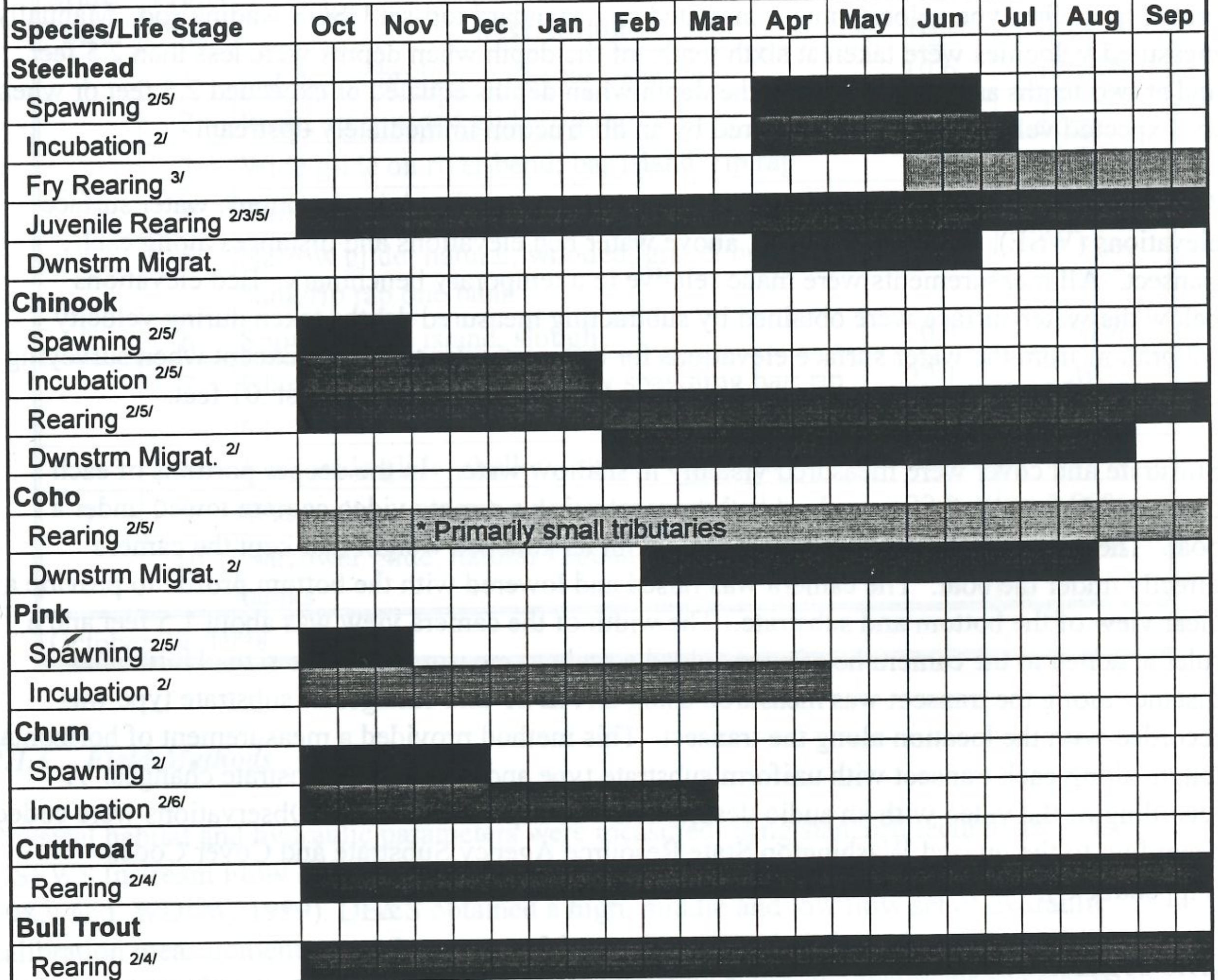
Fisheries resources of primary concern in the Lower Skagit River are commercial and game fish that include 4 salmon species, steelhead trout, cutthroat trout, and bull trout. All of these species utilize the study area during some part of their life cycle. Figure (2.1-2) presents the life stage timing of the Lower Skagit River salmonids.

2.1.6.1 Affected Life Stages

Anadromous fish use the Skagit River in a variety of ways. Adults of all species use the lower river as an upstream migration corridor to the rich spawning grounds of the upper Skagit. Salmonid fry and smolts also use the river as a downstream migration corridor on their journey towards the sea. Due to the nature of the river, migration of salmonids is unimpaired by stream flow and therefore was not an issue for this study.

FIGURE 2.1-2 LOWER SKAGIT MAINSTEM RIVER SALMONID LIFE STAGE PERIODICITY. [1/]

Revised February 12, 1999



1/ Includes all species, not just target species

2/ Pete Castle, WDFW February 12, 1999/ June 1999

3/ Skagit R. Hydroelectric Project FERC NO. 553. Fisheries Settlement Agreement April 1991.

4/ Curt Kraemer, WDFW, pers. comm., Oct. 28, 1996.

5/ SSC staff, January 10, 1997/ February 5,1998

6/ Estimated

The Lower Skagit River also provides spawning and rearing habitat important to the fresh water survival of the affected salmonids. Spawning steelhead trout, chinook salmon, chum salmon, and pink salmon can often be found in mainstem river reaches that offer good habitat. Although some coho salmon spawn in the mainstem Skagit River, the majority of spawning coho are found in smaller tributaries. Analysis of spawning habitat in this study targeted steelhead trout, chinook salmon, chum salmon, and pink salmon. Spawning habitat for coho was not investigated since they don't often utilize the mainstem Skagit as spawning habitat.

Spawning in the mainstem study area is largely limited to a section of the river at approximately RM 22, just below the Highway 9 bridge (Figure 2.1-1). Chinook salmon, chum salmon, pink salmon, and steelhead trout have been observed spawning in this area (Pete Castle, WDFW; Eric Beamer, SSC; personal communication). Downstream of this section stream gradient lessens and suitable spawning substrate is sparse.

Rearing salmonid species in the Lower Skagit River include steelhead trout, cutthroat trout, bull trout, chinook salmon, and coho salmon. All of these species can be found year round in the Lower Skagit River but some species are found in greater abundance than others.

Successful rearing (feeding and predator avoidance) by fry and smolts occurs as they reside in the river and move downstream to salt water. Residence time of out migrating fry in the mainstem study area is likely less than a month but some fry and juveniles can be found throughout the study area during all months of the year.

2.1.7 Preference Criteria

Salmonid fish species are not found randomly in streams and rivers but rather have an affinity for a particular ranges of depth, velocity, cover and substrate. Selection for these habitat parameters varies with species and life stage. In IFIM studies the range of each of these parameters are commonly referred to as fish preference criteria.

In Washington, fisheries agency representatives recommend that IFIM studies include efforts to obtain site-specific observations for development of habitat preference criteria for the target species. In this study, extensive data was collected from observations of rearing salmonids throughout the study area. Attempts at collecting data for spawning salmonids was not successful. Therefore, only the rearing preference curves were updated from new site-specific data.

2.1.7.1 Rearing Life Stage

Field Studies

During the period from February 27 through May 29, 1998, DE&S biologists conducted 8 days of surveys throughout the study reach for verification of depth and velocity preferences for rearing chinook salmon and steelhead trout. Habitat utilized by juvenile salmonids in the river margin was identified either by snorkeling or by electrofishing.

Snorkeling was done where water depth precluded use of the electrofisher. Two biologists swam upstream and made observations of behavior, substrate, cover, velocity, and depth. Where normal behavior was observed, such as feeding or territorial defense, flagging was set to mark the location. After a section of uniform habitat type was observed, mean column velocity and depth was measured at each flagged location.

Electrofishing was conducted in the shallow river margins for a length of 300 to 600 feet of uniform habitat type. Because fish could not be observed prior to electrofishing, it was assumed that where a stunned fish was observed, was the location of the fish's microhabitat. At these locations, mean column velocity, depth, cover and substrate was recorded. Stunned fish were identified to species.

Locations for snorkeling or electroshocking were chosen to represent the habitat found within the mainstem area. That is, if a substantial length of a uniform habitat type was present within the reach, a section of that unit or similar habitat was observed. Areas of high velocity were avoided for safety reasons.

In Reach 1 snorkeling was conducted along both banks of the river near Transect 1, along the left bank of Transect 4, and both banks of Transect 5. In Reach 2 snorkeling and electrofishing was conducted below Transect 6, and along Transects 6, 7 and 8. In Reach 3 snorkeling and electrofishing was conducted near Transects 9 and 10.

At each location where snorkeling or electrofishing surveys were completed, length of section, depth, velocity, substrate, and cover measurements were sampled in the entire section surveyed. These habitat parameters were the basis of calculations for determining available habitat in the sections where the fish surveys were conducted.

Depths and velocities for 473 salmonids were measured. Depth and velocity distributions of fish observations was compared to depth and velocity distributions of available habitat from the field surveys. Data were reduced and then compiled to calculate the number of fish observed (OBS), expected (EXP) and OBS/EXP ratios for each velocity and depth bin. Results from each observation set were combined per methods described in Beecher (1994) and compared to the composite WDFW preference curves. Final preference curves for chinook salmon and steelhead trout rearing were primarily based on analysis of site specific observations with WDFW curves used in areas where sufficient direct observations were available.

Literature Review

Insufficient observations of rearing were made to generate a site specific preference curve for coho salmon. The WDFW fallback curve was compared to data presented by Hampton (1997). Minor changes to the WDFW curve were made.

No new information was available for the rearing life stage of cutthroat trout or bull trout. WDFW fallback rearing curves for these species were used.

Preference curves for substrate and cover were based on WDFW fallback curves and modified based on Skagit River data collected by SSC biologists (Haymen, et al, 1996).

2.1.7.2 Spawning Life Stage

Attempts to gather site specific field observations for spawning chum salmon and steelhead trout were unsuccessful due to the low number of spawning fish in the vicinity of the study area. A literature review of current data was completed and where appropriate WDFW fallback preference curves were modified from the new data source.

The steelhead spawning fallback curve was appropriate for velocity. However, due to the nature of the Skagit River in the study area, the depth curve was modified to include slightly deeper water.

The WDFW "large river" fallback preference curves for chinook salmon spawning were partially based on observations by Kurko (1977) in the Skagit River and were deemed appropriate to use.

The WDFW "large river" fallback preference curves for chum salmon spawning were reviewed and modified slightly for lower velocities based on Skagit River observations made by Kurko (1977).

The WDFW "large river" fallback preference curves for pink salmon spawning and were appropriate for depth. Minor adjustments were made to the velocity curve based on Skagit River data from Kurko (1977).

2.1.7.3 Agency Consultation

Committee members representing the WDFW and WDOE reviewed and approved all WDFW fallback preference curves including modifications. Committee members representing the WDFW and WDOE and SSC reviewed and approved all preference curves that were primarily based on direct observations for this study.

Preference curves adopted for the Lower Skagit River Instream flow study are shown in Appendix C.

2.1.8 Data Compilation Methods

The ADCP interfaces directly with a laptop computer when collecting data. Software provided by the manufacturer of the ADCP is used to record and display the data as it is being collected while traversing the river. This same program is used to output a text file containing all the detail of a transect including the depth, velocity, distance, and error checking values for each vertical and bin along the transect. Verticals are columns looking straight down from the water elevation to the river bottom. Velocity data taken at incremental depths are called bins.

A conversion utility from RHABSIM (Riverine Habitat Simulation) reads the text file from the ADCP software and converts it into a format that was imported into a spreadsheet. This utility screens out errors and converts bins of velocities into mean column velocities (average velocity for the one vertical). Three summary columns are created; distance, depth, and velocity. Since the ADCP and the boat were incapable of taking readings in very shallow depths, manual depth and velocity data were manually entered into the spreadsheet. The summary ADCP data was integrated between the left and right banks of the manual data. The substrate & cover codes were entered alongside the depth & velocity data. Using a true water surface elevation entered by the user, depths were converted into elevations. A total discharge for the transect is generated. At this point the data for each transect was subjected to a final check for errors and corrected. The corrected data file was then converted into a format readable by RHABSIM. RHABSIM read the file, and the completed data deck was ready for hydraulic modeling.

2.2 Data Analysis

2.2.1 Hydraulic Modeling

Analysis and integration of physical stream measurements and habitat preference criteria require the use of a group of the PHABSIM computer programs. There are two main programs in the PHABSIM library: the hydraulic model (called IFG-4) and the habitat model (called HABTAT). The IFG-4 hydraulic simulation model predicts depth of flow and mean column velocities across the stream transect as a function of discharge. A log-log regression analysis is used to develop stage-discharge relationships at each transect and to predict velocity/discharge relationships at each habitat cell. Interpolation and extrapolation with the regression equations allows modeling of flows between and beyond the measured discharges. The resulting simulated hydraulic information is then input to the HABTAT program.

The HABTAT program integrates the simulated hydraulic information from IFG-4 with habitat suitability criteria (i.e, preference curves) and quantifies habitat availability over a range of flows for the specified target species and life stages. Habitat quantification is expressed as an index called Weighted Useable Area (WUA), and is given in square ft of habitat per 1,000 linear ft of stream.

Riverine Habitat Simulation (RHABSIM), a series of programs developed by Thomas R. Payne and Associates of Arcata, California, allows direct input of Acoustic Doppler Current Profiler (ADCP) data, and is an extensive conversion of the PHABSIM hydraulic and habitat simulation system developed by the USFWS. RHABSIM was used by DE&S for the Lower Skagit River modeling.

2.2.2 Hydraulic Modeling Procedures

The Lower Skagit River IFIM data input files (decks) were compiled by DE&S and calibrated using methods prescribed by the USF&WS Instream Flow Group, Fort Collins, Colorado. All of the input decks were initially processed using the Problem Report subroutine of the Field Data Entry Module of RHABSIM. This program looks for errors in data placement and produces hard copy of the pertinent information needed to run the model, including transect weighting factors, slopes, stage of zero flow and Water Surface Elevation (WSE). DE&S collected three sets of velocity calibration measurements at each transect. RHABSIM was used for model calibration and generation of Weighted Usable Area (WUA) tables. In addition to WSE associated with the three calibration measurements, an additional WSE and the related discharge were added to the model to improve the stage-discharge relationship (i.e., minimize the mean error of the predictions). Three one-velocity set models were developed for each transect. Model extrapolation range was 2,900 to 72,000 cfs.

In Washington State, a standard "three velocity set" regression model is normally used on all transects except where special circumstances required the use of alternate modeling methods. The three-velocity set models require that "verticals" (i.e., stations) be placed in exactly the same locations along the stream bed and that velocity measurements be taken at these stations at all the calibration flows. It is not possible to do this when using the ADCP, since the placement of "verticals" is determined by boat speed, boat direction, and beginning point along the transect. As a result, "one velocity set" models were used. The "one velocity set" models use the velocities from one of the calibration flows for velocity modeling and employ the WSEs from the other calibration flows to develop the stage/discharge relationship. An additional high flow water surface elevation was taken at a flow of approximately 41,000 cfs. This WSE was added to the high flow calibration deck to more accurately develop a stage/discharge relationship at the highest modeled flows (i.e., from 29,000 cfs to 72,000 cfs).

One of the goals of the hydraulic simulation is to have the model simulation accurately reflect measured velocities and depths at calibration flows, while minimizing changes to the data. In this regard, only minor changes were made to the IFIM decks in order for the model to more accurately predict cell velocities at the simulated flow. When calibrating one velocity set data decks, normally, two types of corrections can be made directly or indirectly to velocity data: 1) changes in the measured velocity; and, 2) changes in the Manning's N for given cells. Changes were kept to a minimum and the decks were revised only when specific changes improved model performance.

One type of data change was a minor velocity adjustment (0.01 - 0.10 ft/sec) in some cells where there was depth but no measured velocity. The model "sees" a measured zero velocity as a blank and will attempt to fill that cell with a velocity based on a mass balance equation for the transect, taking into consideration slope, adjacent velocities, and calculated Manning's N values. Replacing a measured 0.00 with a velocity of 0.01 or 0.1 often corrects this problem. In addition, edge cells are often assigned high Manning's N values (i.e., the roughness coefficient) by the model. The high N values slow the velocity through these cells, giving an unrealistic simulation of velocities. In these instances the N values were manually reduced.

The range of extrapolation for simulated depths and velocities depends on the hydraulics of the channel and the accuracy of the velocity simulation, slope and Manning's N values in the case of one velocity set calibrations. Generally, all flows of interest were within the limits of acceptable extrapolation.

The range of extrapolation for simulated depths and velocities depends on the hydraulics of the channel and the spread between calibration flows. Velocity Adjustment Factors (VAF) are a measure of how well a three-flow regression model simulates velocities. A VAF between 0.90 and 1.10 is considered good. A VAF between 0.85 and 0.90 or between 1.10 and 1.15 is considered to be fair. A VAF between .80 and .85 or 1.15 and 1.20 is marginal, while a VAF below 0.80 or above 1.20 is considered poor. In the case of one velocity set models, the VAFs are actually adjustment factors of discharge, not velocities, and a wider range of values (between 0.10 and 10.0) is acceptable. A summary of VAFs and calibration details are presented in Tables 2 and 4 of Appendix B.

DE&S elected to use the "discontinuous" transect approach for the Lower Skagit River IFIM. This method allows more flexibility in selecting transects to best represent all habitat types in the study reach. Using this approach requires that the model be "tricked" since the model assumes that there are no other habitat types between sequential transects. The following procedures were used to model the discontinuous transects. Each transect was given a weight of 1.0. Study site length was established at 1,000 feet. Actual weight for each transect was converted proportionally to the study site length and input as "distance to next transect". Because PHABSIM "looks" downstream for transect distance regardless of the weighting method, assigned transect distances must be shifted upstream one transect. Since the model "looks" upstream for transect weight and each transect has received a full weight of one, a "dummy" transect must be placed as the upper transect. These dummy transects do not affect WUA since they are given a weight of 0.0. Additional IFIM calibration details are provided in Appendix B.

2.2.2.1 Measured Flows for Lower Skagit River

The goal of the modeling effort is to be able to model predicted habitat between 0.4 of the low flow calibration measurement and 2.5 times the high flow calibration measurement, using the "one-velocity set" models to predict velocities.

Three sets of calibration flow data were developed from the field measurements. Actual measured flows for each transect are shown in Table 2.2-1. An additional WSE was taken at a flow of approximately 41,300 cfs.

Table 2.2-1 Calibration Flows (CFS) And Water Surface Elevations (Ft), Lower Skagit River Instream Flow Study

	Low Calibration		Middle Calibration		High Calibration		Extra-High Calibration*	
Transect	Flow	WSE	Flow	WSE	Flow	WSE	Flow	WSE
1	7,385	85.64	18,582	90.37	29,018	93.47	41,307	97.43
2	7,624	66.48	19,401	70.02	28,940	75.68	41,625	83.14
3	7,632	74.20	19,490	79.19	30,110	82.35	41,426	85.80
4	7,835	77.31	18,732	82.34	30,041	85.58	41,387	88.55
5	7,593	81.44	18,585	86.71	28,965	90.12	41,148	93.35
6	8,392	81.13	18,912	84.16	29,517	86.47	41,386	90.70
7A	6,911	86.76	16,178	89.2	23,621	91.66	33,509	94.67
7B	342	87.92	2,546	89.68	5,107	91.55	7,758	94.35
8	8,349	86.44	19,249	89.15	29,122	91.63	41,188	94.51
9	8,136	79.68	18,118	82.44	27,879	84.97	41,148	88.24
10	8,519	82.41	18,518	84.95	28,488	87.19	41,346	90.26

* Water surface elevation only

Transect 7 modeled an island in the upper portion of the study reach. Regression analysis was used to apportion flows between the left and right channels for modeling purposes. Table 2.2-2 shows the division of streamflow for Transect 7 (left and right channels) throughout the range of modeled flows.

Table 2.2-2 Apportionment of Flows Through Transect 7, Skagit River Instream Flow Study

Skagit R. Flow (cfs)	Transect 7	
	Left Channel	Right Channel
2,900	2,823	77
8,000	7,539	461
19,000	16,626	2,374
29,000	23,955	5,045
72,000	57,445	14,555

2.2.2.2 *Model Performance*

Only minor changes were made to the original input decks. Most revisions fell into three categories: 1) replacing a measured velocity of 0.0 ft/second with a velocity of 0.1 ft/second; 2) changing the Manning's N value to either reduce or increase the velocities in the given cell: and 3) adjusting the bed elevations the stream margin cells slightly. Table 4 in Appendix B presents the summary of calibration details for this reach. Mean error (for both given and predicted discharges), ratio of measured vs. predicted discharges, and B coefficients were all within the acceptable limits for IFIM calibration.

A total of 33 data decks were developed and calibrated for the Lower Skagit Instream Flow Study (low, middle and high calibration decks for Transects 1 - 6, and 8 - 10). Transect 7, which traversed an island, required a total of 6 data decks (high, middle, and low calibration decks for both the left and right channels) for modeling purposes.

2.2.3 Habitat Modeling Procedures

The Lower Skagit River Instream Flow Committee (Committee) requested additional transect delineation and analysis for the spawning and juvenile rearing life stages of the target salmonid species in the Lower Skagit Instream Flow Study Area (from the pipeline crossing downstream to approximately the confluence of the North and South Forks of the Skagit River). These refinements to modeling are given below.

2.2.4 Spawning Analysis

The Committee requested that only Transects 7 (both channels) and 8 be included in the spawning analysis for steelhead trout and chinook, coho and chum salmon. Spawning in limited in the Lower Skagit River; that spawning which does occur in the study reach is located on or near these transects. The Committee determined that transect weighting for Transects 7 and 8 would be 40% and 60%, respectively. A total of 9 data decks were used to model spawning life stages in the Lower Skagit River:

1. Transect 7 Left Channel: low flow calibration deck (2,823 - 16,626 cfs)
2. Transect 7 Left Channel: middle flow calibration deck (7,539 - 23,955 cfs)
3. Transect 7 Left Channel: high flow calibration deck (16,626 - 57445 cfs)
4. Transect 7 Right Channel: low flow calibration deck (77 - 2,374 cfs)
5. Transect 7 Right Channel: middle flow calibration deck (461 - 5,045 cfs)
6. Transect 7 Right Channel: high flow calibration deck (2,374 - 14,555 cfs)
7. Transect 8: low flow calibration deck (2,900 - 19,000 cfs)
8. Transect 8: middle flow calibration deck (8,000 - 29,000 cfs)
9. Transect 8: high flow calibration deck (19,000 - 72,000 cfs)

2.2.5 Juvenile Rearing Analysis

The Committee requested that DE&S determine a preliminary delineation of the "shear zones" for each transect in the Instream Flow Study. Shear zones were defined as those zones separating more slowly-flowing waters near the shorelines (the "rearing zone") from the swifter waters found in the main channel.

DE&S submitted a draft shear zone delineation to the Committee for review and comment. Table 2.2-2 shows the final delineation after input from the Committee:

In order to "remove" the center of the channel (i.e., those areas outside of the shear zone), the following steps were taken:

1. The outside edge of the "rearing zone" (i.e, that end farthest from the bank) in the high and middle flow decks was given the same station value as the low flow deck. Bed elevations and velocities were calculated as a linear interpolation of existing stations to either side of the determined shear zone in the low flow deck and these values were inserted into the middle and high flow decks.

2. In addition, a cell was placed 1.0 feet outside the "rearing zone" on all decks. The HABTAT model, which produces Weighted Usable Area (WUA), uses the midpoints between adjacent cells as the cell boundary. By inserting "rearing zone" stations and an additional station 1.0 feet to the center of the channel, stationing for determination of WUA is consistent among the three decks (high, middle, and low calibration decks).

3. Stations outside the shear zone were given a substrate/cover value of 99.9

4. In each rearing preference curve, a substrate/cover value of 0.00 was assigned to the substrate code 99.9 (i.e, bedrock). Bedrock was not found at any of the transect locations used in this study.

5. Transect weighting was not changed and remained consistent with Table 2.1- 2.

A total of 9 data decks were used to model spawning life stages in the Lower Skagit River:

1. Transect 7 Left Channel: low flow calibration deck (2,823 - 16,626 cfs)
2. Transect 7 Left Channel: middle flow calibration deck (7,539 - 23,955 cfs)
3. Transect 7 Left Channel: high flow calibration deck (16,626 - 57445 cfs)
4. Transect 7 Right Channel: low flow calibration deck (77 - 2,374 cfs)
5. Transect 7 Right Channel: middle flow calibration deck (461 - 5,045 cfs)
6. Transect 7 Right Channel: high flow calibration deck (2,374 - 14,555 cfs)
7. Transects 1-6; 8 - 10: low flow calibration deck (2,900 - 19,000 cfs)
8. Transects 1-6; 8 - 10: middle flow calibration deck (8,000 - 29,000 cfs)
9. Transects 1-6; 8 - 10: high flow calibration deck (19,000 - 72,000 cfs)

Table 2.2-3. Stations Used in Shear Zone Analysis, Lower Skagit Ifim Study

Transect	Zones Modeled
1	0.0 - 75.7; 332.0 - 775.5 (end)
2	0.0 - 64.3; 486.7 - 605.2 (end)
3	0.0 - 407.1; 689.4 - 726.0 (end)
4	0.0 - 149.0; 408.6 - 533.6 (end)
5	0.0 - 262.1; 585.1 - 618.6 (end)
6	0.0 - 248.2; 86.5 - 1123.0 (end)
7 Left C.	590.5 - 1088 (end)
7 Right C.	0.0 - 136.1
8	0.0 - 329.3; 878.5 - 936.8 (end)
9	0.0 - 41.6; 561.9 - 728.3 (end)
10	0.0 - 67.4; 672.1 - 716.1 (end)

Output from the hydraulic models was then used to determine changes in the Lower Skagit River water depths, velocities, surface area, and fish habitat throughout a range of flows from 2,900 cfs to 72,000 cfs.

After the hydraulic models were calibrated, transect weighting was added as shown in Table 2.1-2 for the rearing life stages, and weighted 40% and 60% for Transects 7 and 8, respectively, for the spawning life stages. Final hydraulic model runs were made to produce input for the HABTAT habitat model. The HABTAT program integrates the simulated hydraulic information from the IFG-4 with habitat suitability criteria and quantifies habitat availability over a range of flows for the specified target species and life stages. Habitat quantification is expressed as Weighted Useable Area (WUA), or square feet of habitat per 1000 linear feet of stream.

2.3 Weighted Useable Area Results

2.3.1 Combining Results of Calibration Deck WUA

As stated earlier, Transects 1-6 and 8 - 10, Transect 7 Left Channel, and Transect 7 Right Channel were run independently and WUA was calculated for the range of flows modeled for each deck. WUA results were then combined to arrive at a single WUA for each group of transects. For example, for Transects 1 - 6 and 8-10, the following procedure was used:

For flows modeled below the low flow calibration (i.e, from 2,900 cfs - 8,000 cfs), the low flow deck was exclusively used to calculate WUA. For modeled flows between the low and middle calibration flows (8,000 and 19,000 cfs, respectively), the results from the two modeling efforts were combined and weighted according to the proximity of the given flow to the calibration flow. For modeled flows between the middle and high calibration flows (i.e., 19,000 cfs and 29,000 cfs) the results from the two modeling efforts were combined and weighted according to the proximity of the given flow to the calibration flow. Flows above 19,000 cfs used the WUA from the high flow calibration deck exclusively. A similar method was used to calculate WUA for Transect 7, left and right channels.

Figure 2.3-1 shows the range of flows and models used to calculate final WUA. Table 2.3-1 shows how the WUA results from the calibration decks were combined to calculate WUA.

Figure 2.3-1 Range of Flows and Models Used to Calculate WUA.

	Skagit River Flows (cfs)				
High Flow Decks					
Middle Flow Decks					
Low Flow Decks					
	2,900	**8,000**	**19,000**	**29,000**	**75,000**

Table 2.3-1 Final WUA, Skagit River IFIM			
	Calibration Deck Utilization		
Flow	**Low**	**Middle**	**High**
2,900	100%		
8,000	91%	9%	
9,000	82%	18%	
10,000	73%	27%	
11,000	64%	36%	
12,000	55%	45%	
13,000	45%	55%	
14,000	36%	64%	
15,000	27%	73%	
16,000	18%	82%	
17,000	9%	91%	
18,000	0%	100%	
19,000		90%	10%
20,000		80%	20%
21,000		70%	30%
22,000		60%	40%
23,000		50%	50%
24,000		40%	60%
25,000		30%	70%
26,000		20%	80%
27,000		10%	90%
28,000		0%	100%
29,000			100%
72,000			100%

2.3.2 Weighted Usable Area Results

Within the HABTAT program, output from the hydraulic modeling is combined with preference curves for depth, velocity, and substrate/cover for the target species life stages. The output from this model is expressed as Weighted Usable Area (WUA) v. Flow (Q), which is an index of available habitat (in square ft) per 1,000 lineal ft of stream for each species and life stage modeled.

Details of individual model outputs for the Lower Skagit River IFIM Study are included in Appendix D. The WUA for Transect 7 was determined by adding the WUA for both left and right channels. Final WUA was calculated by using transect weighting. For example, the WUA results from Transects 1-6 and 8-10 were multiplied by 0.976 while Transect 7 WUA results were multiplied by 0.024 (their respective weightings). Table 2.3-2 and 2.3-3 and Figures 2.3.2 and 2.3.3 show final WUA for rearing and spawning life stages, respectively, of the target species.

The flows where Weighted Usable Area for the target species and life stages are maximized are shown below:

Table 2.3-2 Lower Skagit River Rearing Weighted Useable Area, Juvenile Life Stage [1/]

Flow	Total Area	Bull Trout	Chinook	Coho	Cutthroat	Steelhead
2,900	368,196	8,412	19,117	11,586	6,601	10,488
3,000	369,184	8,644	19,347	11,651	6,880	10,689
3,500	378,070	10,008	20,803	11,332	7,933	11,892
4,000	381,271	11,855	21,777	10,689	9,339	13,029
4,500	385,578	13,232	22,504	9,916	10,274	14,149
5,000	389,611	14,682	22,946	9,163	10,978	15,130
5,500	393,121	16,070	23,295	8,771	11,731	15,927
6,000	397,411	17,193	23,821	8,482	12,576	16,767
6,500	400,903	18,109	24,400	8,228	13,468	17,779
7,000	404,869	19,301	24,616	8,078	14,005	18,754
7,500	409,728	20,604	24,909	7,938	14,300	19,571
8,000	420,592	22,109	24,839	7,766	14,626	20,559
9,000	434,575	24,563	24,796	7,489	15,330	22,632
10,000	443,727	26,653	24,380	7,056	16,027	23,387
11,000	451,795	27,985	23,200	6,842	16,499	23,915
12,000	460,570	29,149	21,819	6,442	16,289	24,334
13,000	471,225	30,022	20,335	6,114	15,874	24,543
14,000	480,057	30,902	19,440	5,644	15,371	25,193
15,000	490,766	32,062	18,156	5,126	14,975	25,326
16,000	498,314	32,588	16,911	4,689	14,525	25,279
17,000	506,438	32,972	15,629	4,233	14,367	25,076
18,000	514,988	33,214	14,436	3,869	13,660	24,772
19,000	530,544	34,310	14,812	4,070	13,263	25,248

Table 2.3-2 Lower Skagit River Rearing Weighted Useable Area, Juvenile Life Stage [1/]

Flow	Total Area	Bull Trout	Chinook	Coho	Cutthroat	Steelhead
20,000	542,238	35,399	15,443	4,241	12,959	25,799
21,000	551,343	36,749	15,981	4,282	12,793	26,126
22,000	560,304	37,907	16,726	4,345	12,776	26,597
23,000	570,043	39,172	17,236	4,701	12,914	26,732
24,000	581,621	40,169	18,005	5,298	13,230	26,978
25,000	593,669	41,265	18,789	5,977	13,471	27,054
26,000	603,048	42,285	19,845	6,616	13,507	27,211
27,000	611,373	43,425	20,473	7,198	13,343	27,169
28,000	624,595	44,308	21,014	7,793	13,215	26,896
29,000	626,082	44,243	20,818	7,766	12,954	26,361
30,000	627,569	44,192	21,215	7,860	12,736	26,266
32,500	631,792	44,500	20,613	7,674	12,030	25,187
35,000	635,803	43,845	20,341	7,457	11,517	24,213
37,500	640,075	43,129	20,362	7,179	11,049	23,344
40,000	657,373	42,338	20,357	6,981	10,543	22,406
42,500	661,296	41,679	21,541	7,488	10,298	21,949
45,000	667,787	41,201	21,458	7,879	9,999	21,251
47,500	670,032	40,129	21,616	8,458	9,778	20,874
50,000	671,792	39,135	21,493	8,636	9,533	20,449
52,500	673,222	37,583	21,406	8,270	9,288	20,032
55,000	675,772	36,208	21,332	7,943	8,993	19,619
57,500	676,933	34,948	21,393	7,441	8,813	19,264
60,000	678,118	33,786	21,373	6,846	8,693	18,895
62,500	679,602	32,689	21,373	6,309	8,564	18,617
65,000	680,677	31,549	21,389	5,917	8,473	18,416
67,500	683,061	30,520	21,405	5,960	8,390	18,206
70,000	684,030	29,597	21,501	6,005	8,337	18,038
72,000	684,601	28,912	21,507	6,020	8,327	17,895

[1/] WUA calculated as $feet^2$/1,000 linear feet of stream

Table 2.3-3 Lower Skagit River Spawning Weighted Useable Area 1/					
	Total	Spawning			
Flow	Area	Chum	Chinook	Pink	Steelhead
2,900	341,828	25,912	61,769	10,232	30,671
3,000	344,590	26,222	62,315	10,248	31,255
3,500	384,074	26,624	64,906	10,351	34,682
4,000	409,999	28,809	66,791	11,561	38,172
4,500	440,591	37,178	66,818	20,076	41,638
5,000	483,970	48,876	71,651	28,213	47,206
5,500	517,515	56,519	80,785	34,810	52,992
6,000	561,953	72,062	88,531	48,394	58,236
6,500	580,432	83,472	95,222	59,066	67,251
7,000	592,422	94,741	103,761	71,391	74,493
7,500	605,098	99,857	112,005	78,217	78,998
8,000	637,116	104,451	121,626	82,068	86,871
9,000	691,657	117,731	137,651	90,232	95,419
10,000	696,139	131,087	153,846	100,096	109,992
11,000	700,286	134,693	169,514	107,048	124,141
12,000	705,571	130,682	178,697	103,304	126,715
13,000	710,477	124,802	182,854	93,162	125,296
14,000	713,405	117,385	183,129	78,968	121,631
15,000	716,694	108,799	182,449	62,638	118,774
16,000	721,178	98,123	181,210	47,557	115,244
17,000	725,729	87,102	179,638	34,654	106,374
18,000	728,974	76,158	178,244	24,253	92,473
19,000	732,587	66,904	169,747	19,330	81,529
20,000	738,813	58,864	160,551	16,727	74,649
21,000	743,898	51,608	152,124	14,995	67,867
22,000	755,097	45,875	146,449	14,479	64,538
23,000	762,919	40,813	143,523	13,610	62,127
24,000	772,162	37,024	142,156	13,414	61,047
25,000	780,320	34,104	141,577	13,281	60,132
26,000	788,851	32,814	142,148	13,454	58,895
27,000	795,302	31,431	143,515	14,368	58,630
28,000	806,892	29,555	145,896	15,786	59,134
29,000	816,714	28,089	147,029	14,658	58,557
30,000	823,973	26,259	147,661	13,515	58,199

Table 2.3-3 Lower Skagit River Spawning Weighted Useable Area [1/]					
	Total	Spawning			
Flow	Area	Chum	Chinook	Pink	Steelhead
32,500	841,183	22,751	146,232	9,657	55,485
35,000	858,070	20,523	142,509	6,421	52,688
37,500	869,917	19,658	139,210	3,669	50,701
40,000	881,655	20,122	136,183	2,341	49,762
42,500	894,125	20,193	134,150	1,569	49,463
45,000	913,911	20,386	132,628	1,163	49,088
47,500	926,513	20,703	131,518	972	49,282
50,000	934,742	20,691	130,688	784	48,986
52,500	940,800	20,721	129,871	613	48,692
55,000	947,189	20,591	129,152	444	48,401
57,500	953,332	20,467	128,436	355	48,095
60,000	961,950	19,488	127,703	344	47,725
62,500	976,944	18,802	126,910	350	47,240
65,000	985,485	18,136	126,155	354	46,811
67,500	1,001,692	19,004	125,510	364	46,539
70,000	1,006,065	19,820	124,886	373	46,286
72,000	1,007,485	19,867	124,390	360	46,023

[1/] WUA calculated as feet^2/1,000 linear feet of stream

Table 2.3-4 Lower Skagit River Maximum WUA and Associated Flow by Species.			
Species	Life Stage	Flow (cfs)	Max. WUA
Chum	Spawning	11,000	134,693
Chinook	Spawning	14,000	183,129
	Juv. Rearing	7,500	24,909
Pink	Spawning	11,000	107,048
Steelhead	Spawning	12,000	126,715
	Juv. Rearing	26,000	27,211
Bull Trout	Juv. Rearing	32,500	44,500
Coho	Juv. Rearing	3,000	11,651
Cutthroat Trout	Juv. Rearing	11,000	16,499

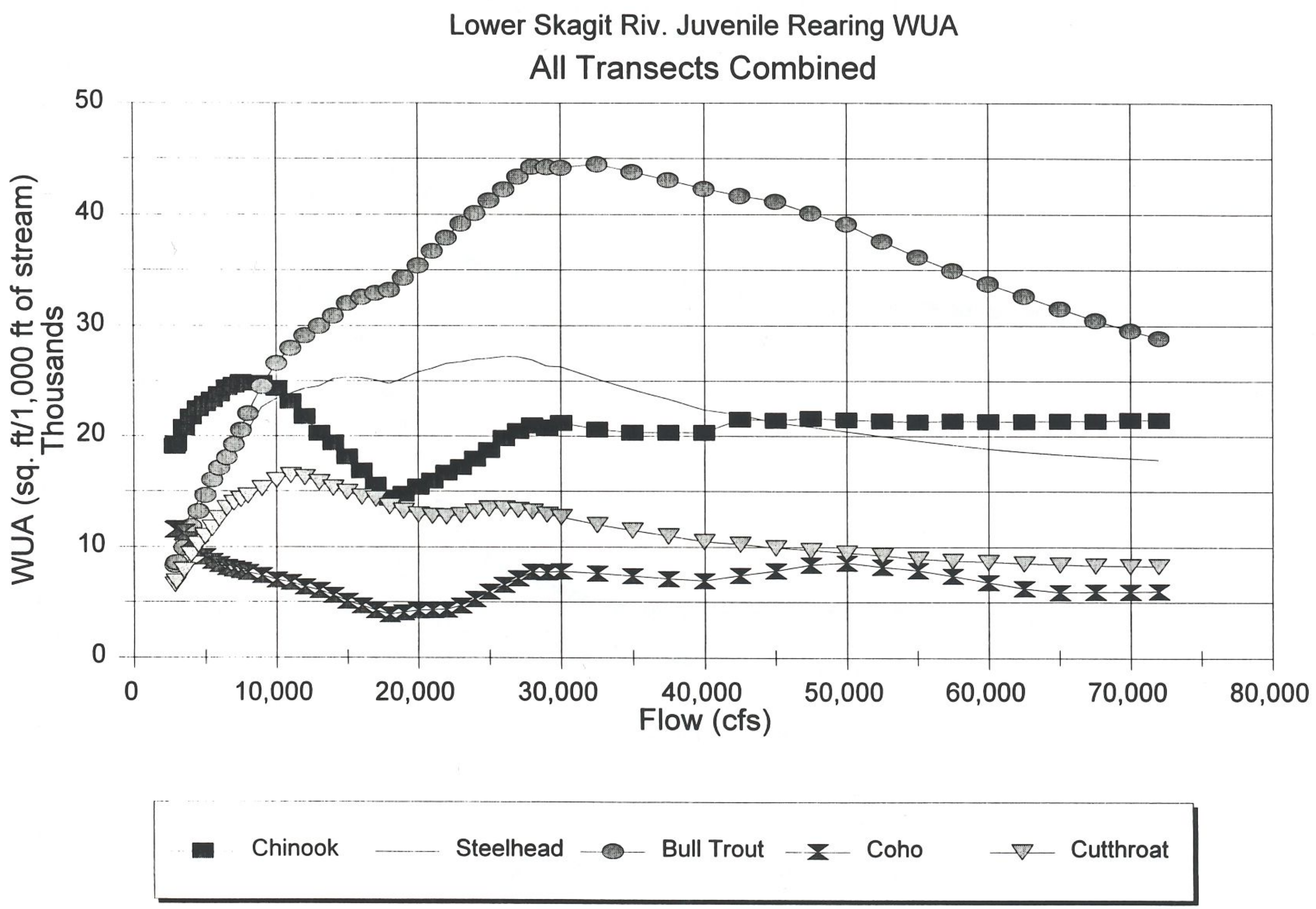
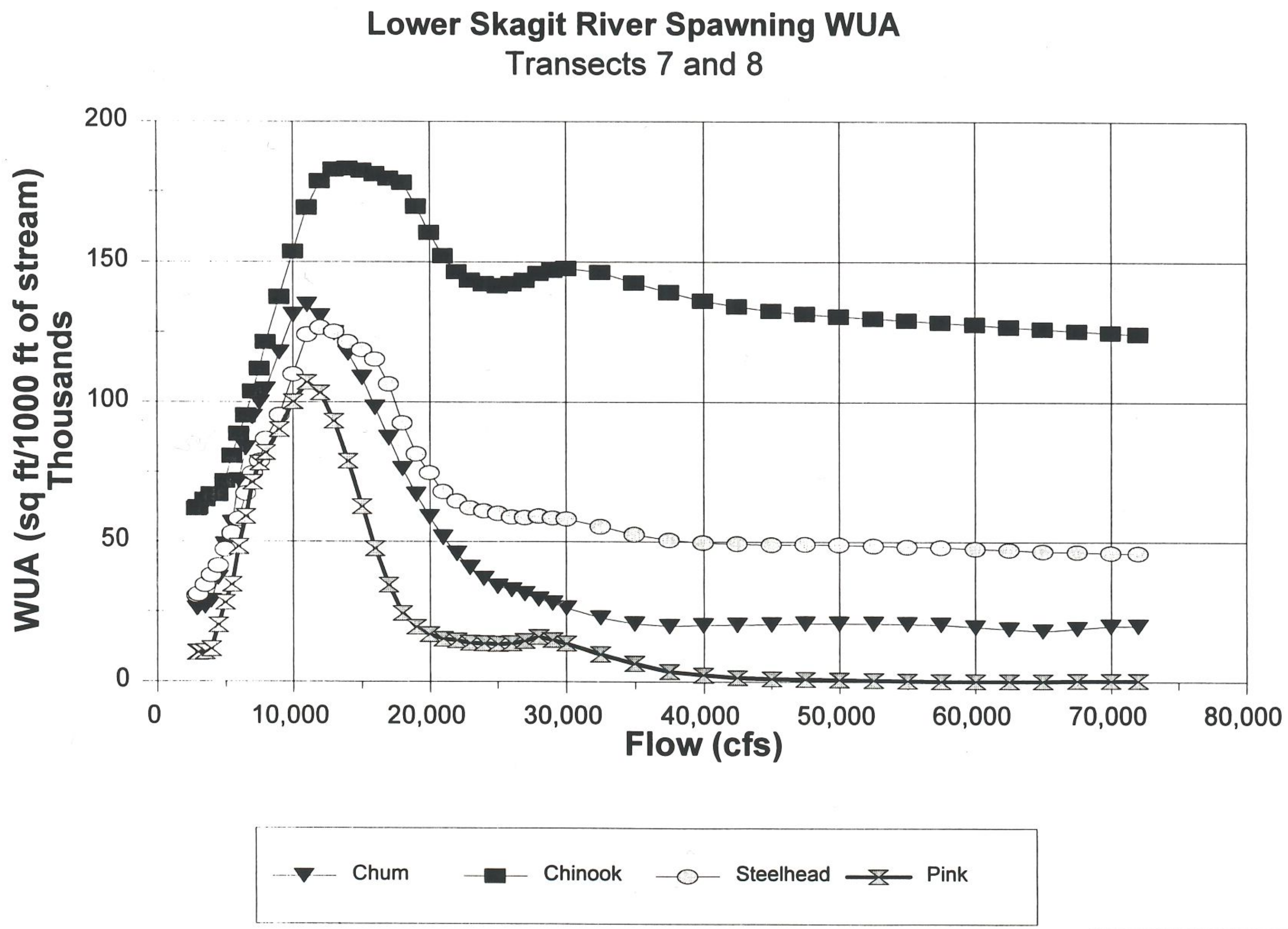

Lower Skagit Riv. Juvenile Rearing WUA
All Transects Combined
WUA (sq. ft/1,000 ft of stream)
Thousands
50
40
30
20
10
0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Flow (cfs)
Chinook
Steelhead
Bull Trout
Coho
Cutthroat

Figure 2.3-2



Lower Skagit River Spawning WUA
Transects 7 and 8
WUA (sq ft/1000 ft of stream)
Thousands
200
150
100
50
0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Flow (cfs)
Chum
Chinook
Steelhead
Pink

Figure 2.3-3

3.0 SKAGIT RIVER ESTUARY STUDY

3.1 General Overview

Unlike the upper riverine study area where a conventional instream flow incremental methodology (IFIM) was applied, there are no standard instream flow study methods for estuaries. Therefore, a method to assess the effect of alternative instream flows on the estuary environment was developed by DE&S in consultation with the Committee.

The Skagit River estuary begins where the Skagit River splits into the North and South Forks (RM 8.1) and extends downstream to the lower river delta (Hayman et al. 1996). This is the section of the Skagit River regularly influenced by the tide and which is characterized by a pattern of progressive channel splitting in a downstream direction. The estuary covers roughly 27 square miles and consists of over 100 channels or channel segments (Figure 3.1-1).

The Skagit River estuary is a "freshwater" or salt-wedge estuary (Thomson 1981; E. Beamer, SSC, pers. comm, October, 1996) where river runoff is large relative to tidal current and little mixing takes place between fresh and salt water. The elevated sandbar that extends up to two miles into Skagit Bay appears to substantially restrict the intrusion of saltwater into the estuary proper.

One of the most important aspects of estuaries is that they act as nutrient traps where river-born organic and inorganic materials collect in concentrated amounts. This makes estuaries biologically active areas that support complex food webs of large assemblages of plants and animals from primary producers (plants) to higher level consumers (mammals). The area in the immediate vicinity of the river mouth is particularly rich with plant and animal life (Thompson 1981; Thom 1987). According to Healy (1982 as cited in Thom 1987) all five species of Pacific salmonids use estuaries of their natal stream. Healy found that chinook were most dependent upon estuaries as a feeding ground. Sockeye and pink salmon utilize estuaries primarily as an area for acclimatization to higher salinities. There is considerable variation in the habitats used by each species due to the food that they eat. For example, chum salmon are able to use freshwater, estuarine, and marine food resources. Chum will spend extended periods of time foraging on invertebrates within marshes (Mason 1974; Congleton et al. 1982 cited by Thom 1987). Besides its importance as a nursery habitat for the early life histories of anadromous salmonids, estuaries are also important foraging habitat for sea-run trout. Studies by the Skagit System Cooperative (SSC) have demonstrated the importance of the Skagit River estuary for rearing of sub-yearling chinook (Hayman et al. 1996). Fish species known to occur in the Skagit River estuary include the 5 Pacific salmon species and the char and trout species Dolly Varden, rainbow, and cutthroat. Whitefish, cottids, suckers, chub, peamouth, perch, smelt, sticklebacks, and flounder also inhabit the estuary (Hayman et al. 1996).

Considerable fisheries research is being conducted in the Skagit River estuary by the SSC under the auspices of the Northwest Indian Fisheries Commission which sponsored the Skagit River

Chinook Restoration Research Program. This research has focused on chinook juvenile life history and habitat utilization in the estuary, estuary habitat restoration studies, and historical reconstruction of estuarine habitats in the Skagit Delta.

Hayman et al. (1996) have identified three basic channel types within the Skagit River estuary: a) main channels; b) subsidiary channels; and, c) blind channels (Figure 3.1-2). Channels range in size from the main forks over 200 feet wide to channels less than two feet wide. Smaller channels are critical for chinook juvenile rearing (E. Beamer, October 1996, pers. comm.). Moving upriver from the saltwater, the estuary can be classified into three parallel zones (Figure 3.1-3): the estuarine emergent marsh zone (closest to the saltwater); the emergent/forested transition zone; and the forested riverine/tidal zone (Hayman et al. 1996).

Channel splitting and the backwater effect of the tide on the river create a complex and dynamic pattern of flow in the estuary. Volume and direction of flow through the estuary channels is constantly changing with the ebb and flood of the tide and with fluctuations in river discharge due to upstream hydro regulation and variations in natural runoff. An estuary channel may never de-water or de-water daily during low tide, depending on its type and elevation.

3.2 Study Approach and Objective

As stated previously, the backwater effect of the tide on river discharge and complex channel splitting in the estuary precluded the application of conventional hydraulic/fish habitat models, such as IFIM, that predict the habitat value of depth and velocity in relation to substrate and cover as a function of discharge. Because of the hydraulic complexity created by the tidal backwater effect and multiple channels, DE&S developed and applied an alternate methodology for assessing the effects of alternative instream flows on the magnitude, duration, and frequency of inundation of the estuary environment and fish habitat. A hydrodynamic/habitat model was the primary tool used in the assessment. The basis for this approach is explained below.

An estuary forms and functions around its basin hydrology and tidal regime and these two factors (hydrology and tidal regime) largely determine the magnitude, duration, and frequency of inundation of the estuary. Although there are many other important physical, chemical, and biological components, for the most part, they are subordinate to the hydrodynamics of freshwater discharge and tidal flow in the form and function of the estuary ecosystem. Because of the dependence of estuary ecology on hydrodynamics, the Committee determined that the effect of alternative instream flows on estuary hydrodynamics would be the primary focus of the estuary study. Secondarily, the study would focus on the effects of alternative instream flows on the estuary life stages and habitats of certain salmonids.

For most of the time throughout the estuary, the level of tidal channel and tidal marsh inundation is a function of both tide and freshwater discharge. However, below a certain tide elevation water level in the estuary is a function of river discharge only and perhaps some residual tidal drainage.

In this report, the periods when estuary hydrodynamics are a function of river discharge (and perhaps tidal drainage) only and the periods when estuary hydrodynamics are a function of discharge and tide are referred to as non-tidal and tidal, respectively. Modeling hydrodynamics and habitat under non-tidal conditions is important since this daily occurring period may be when habitat is most sensitive to reductions in discharge and fish seek refuge in low elevation areas. Modeling hydrodynamics and habitat under tidal conditions is important since this daily occurring period is when the most productive feeding areas are inundated and when salmonids move to food rich channel margins and over-bank tidal marsh areas.

The Committee identified three basic objectives to better understand and analyze the effects of alternative instream flows on the Skagit River estuary. The primary objectives were:

a) to spatially and temporally isolate the tidal from the non-tidal periods;
b) to establish a relationship between freshwater discharge and Water Surface Elevation (WSE) for selected estuary channels and associated tidal marshes during both tidal and non-tidal periods; and,
c) using WSE as the link, to model estuary hydrodynamics and potential salmonid habitat availability as a function river discharge.

To accomplish these objectives DE&S chose water surface elevation at each study site as the fundamental tool for measuring and analyzing the effect of alternative instream flows on estuary hydrodynamics.

3.3 Field Study Methods

3.3.1 Overview

DE&S used miniature pressure transducer water level recorders to measure the effect of river discharge and tide on WSE in selected channels throughout the estuary. The study channels and WSE recording sites were selected in consultation with SSC, Washington Department of Wildlife (WDFW), and Department of Ecology (DOE) biologists and were generally representative of the mixture of channel types and sizes in the estuary. Known fish use and critical habitat features were also factored into the selection. The recorders were stationed at each site for a period of time and then rotated to another site. WSE was recorded at 10 minute intervals. Data recording periods at each site were scheduled through the year to capture the normal range and combinations of marine tide levels and river discharges. Skagit Bay tide level was obtained from a dedicated tide recorder and Skagit River discharge was obtained from the USGS recording gage at Mt. Vernon. Periods of rapidly fluctuating river discharge and tide level anomalies were factored out of the data set by selective use of the data record.

In addition to WSE readings, channel geometry and habitat features such as cover and substrate were surveyed at each study site. With channel geometry and the relationship between channel WSE, river discharge, and tide, the study method provided a tool that would predict the relationship between river discharge and a number of hydrodynamic and physical habitat parameters related to water surface elevation. In addition, this method provided a means of determining the tide level below which WSE is only a function of discharge (non-tidal period).

3.3.2 Geographic Extent of the Estuary Study Area

The estuary study area begins at the junction of the North Fork and South Fork at approximately RM 8.1 and extends downstream to near the lower extent of the emergent marsh zone. Although limited study occurred in the emergent marsh zone, the lower end of the study area is generally demarked by the boundary between the emergent/forested transition zone and the estuarine emergent marsh zone, an area largely formed and influenced by tidal action (Hayman, et al, 1996). All measurements were made in estuary channels and over-bank tidal marsh zones.

3.3.3 Target Species and Habitats of the Estuary Study

With the exception of the salmonid rearing life stage, the estuary study did not investigate the effects of alternative instream flows on individual species or life stages. Rather than target individual fish or wildlife species, the study focused on the effects of altered instream flows on the magnitude, frequency, and duration of inundation of the estuary channels and overflow zones. Magnitude, frequency, and duration of estuary inundation are directly affected by river discharge and are two primary factors driving estuary form and function.

The following are additional reasons why the estuary study did not target individual species.

a) Hydraulic habitat suitability indices (HSI) for individual species are not available for estuary environments;

b) Hydraulic HSI's that are available for river systems are not conducive to estuary environments;

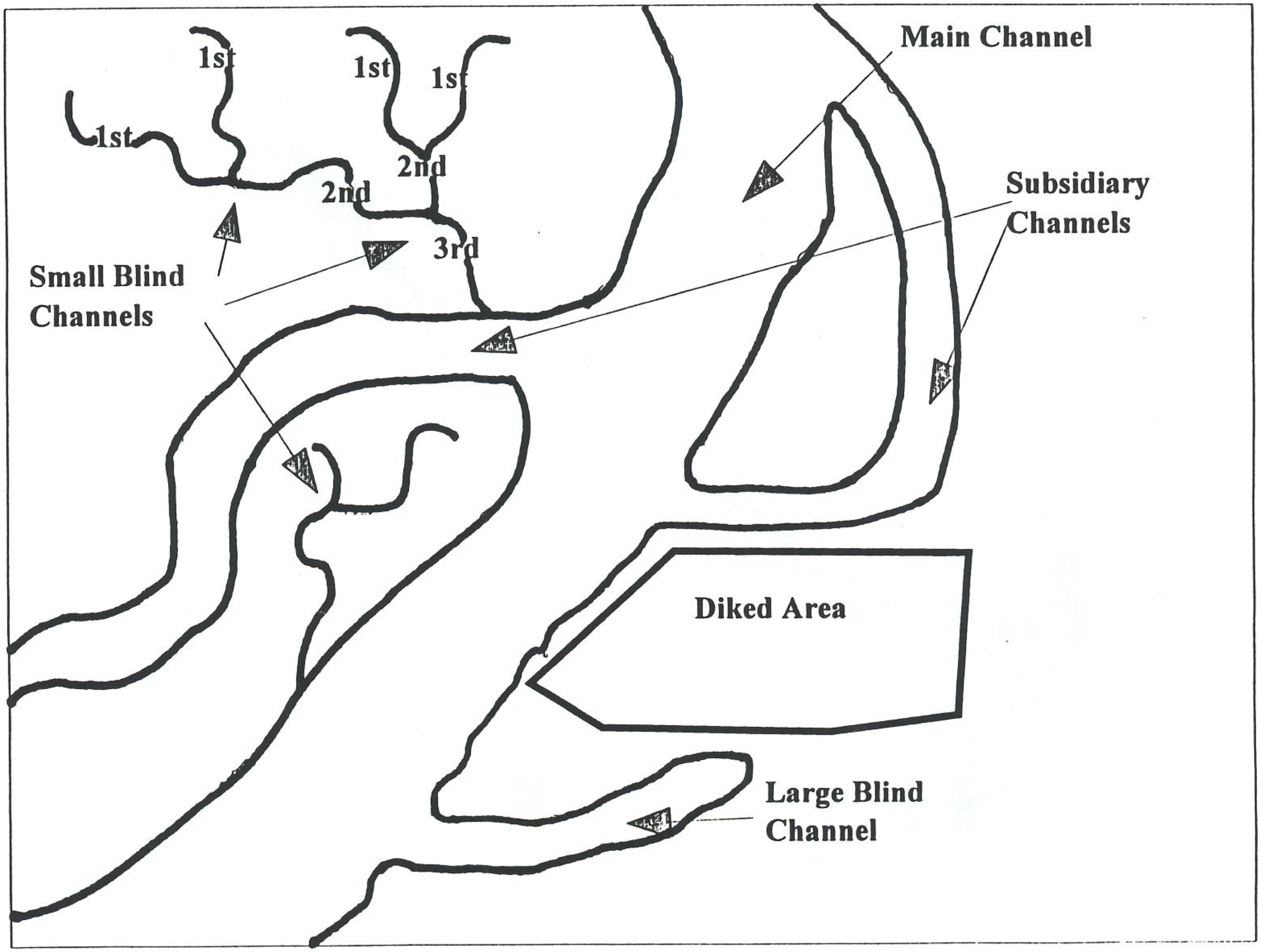
c) Instream flow decisions based on a few individual fish species or life stages ignores and would possibly compromise other estuary fauna and flora that have different habitat needs.

Effects of altered instream flows on salmonid rearing habitat were evaluated through the hydrodynamic and habitat models described below.

3.3.4 Habitat/Discharge Model Selection

Prior to developing the estuary hydrodynamic/habitat method eventually used in this study, DE&S reviewed numerous instream flow methods to determine if any were appropriate for modeling estuaries. The following is a summary of the literature review findings that led to the selection of the model used.

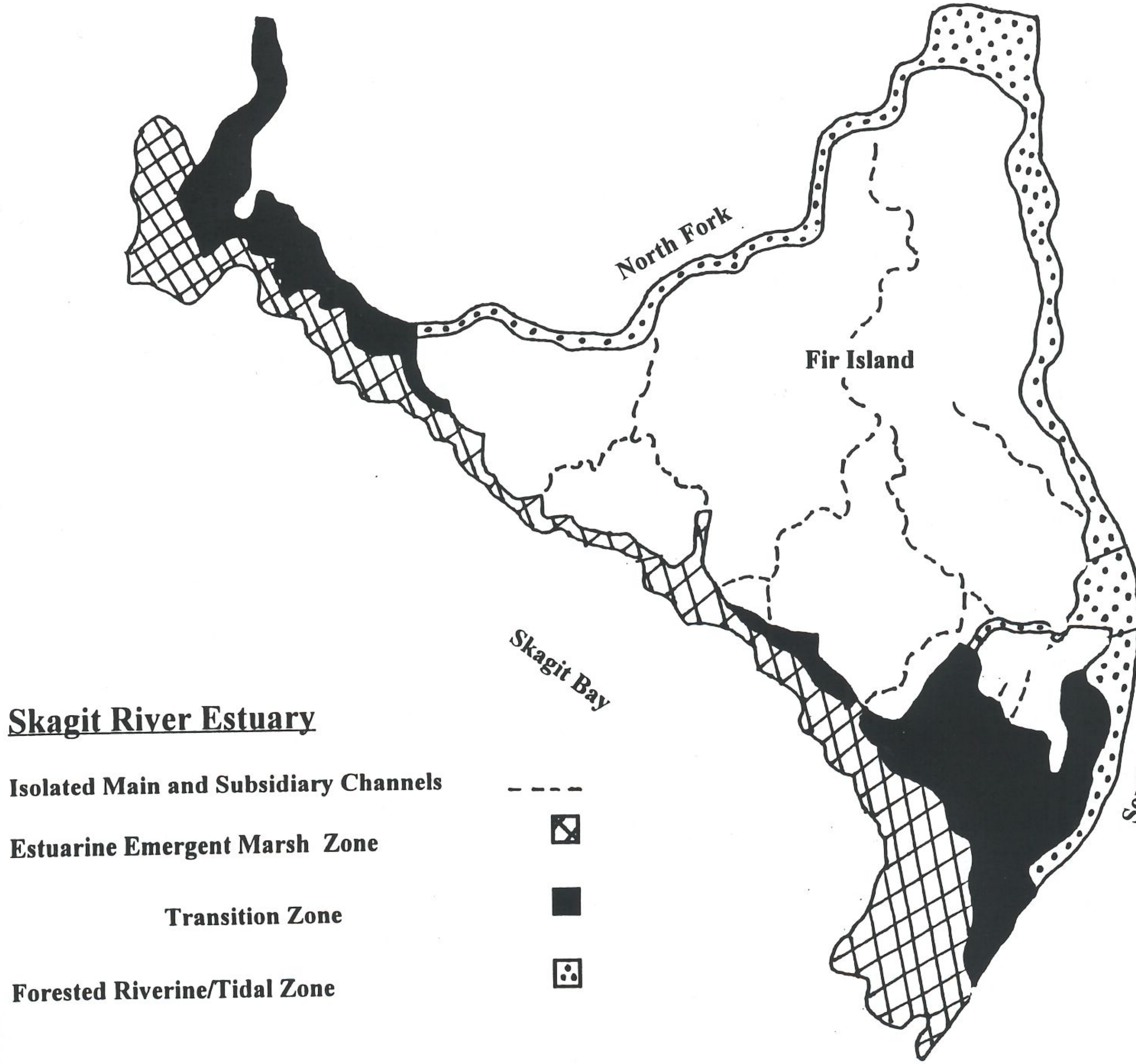
FIGURE 2.1-2



Estuary channel types. After Simenstad (1983). **Figure 3.1-2**

Reported by Hayman et al. (1996)

Figure 3.1-3



After Hayman et al., (1996)

Figure 3.1-3

Over 30 instream flow methods or variations have been designed since 1963 to determine the amount of water required in a stream to protect fisheries resources. All of these methods use one or more input (independent) variables to determine the value of one output (dependent) variable.

Based on the type and number of input variables used, Morhardt (1986) has grouped all of the methods into two basic categories, each with three subcategories. The "Traditional Methods" category uses input variables that are easily obtained from existing information but are not necessarily correlated with any biologically beneficial features of the stream. Common input variables in this category include river basin variables, average discharge variables, and discharge exceedence variables. Morhardt (1986) states that instream flow recommendations based on the relationship between these variables and fish habitat/standing crop are essentially arbitrary. Methods in the traditional category were not recommended for the Skagit River estuary study.

The "Incremental/Habitat Quality Methods" category uses one or more input variables that are more closely correlated to habitat specific parameters. Common input variables include hydraulic, structural, and biological parameters. Methods in this category permit the evaluation of incremental changes in habitat quantity as a function of discharge.

Evaluation and selection of a habitat model for the Skagit River estuary study had to consider that flow dependent input variables change as a function of river discharge ***and*** tide. This three dimensional aspect presented modeling, data aggregation, output presentation, and decision making complexities that are not encountered in standard instream flow studies. Because the number and type of input variables are the primary determinant of model complexity, the least complex model in the Incremental/Habitat Quality Methods category uses "untransformed" hydraulic variables for which biological benefits can be ascribed. Some standard untransformed hydraulic variables for instream flow determination include wetted perimeter, wetted width, depth, and velocity. Because of hydraulic complexities posed by tide, velocity was not considered a useable variable in the estuary study.

The next level of model complexity in the Incremental/Habitat Quality Methods category uses one or more "transformed" variables. Data transformation is the process of ascribing an index of biological value to a habitat constituent. Index's are often non-dimensional suitability indices based on an observed preference for a habitat constituent by a species or life stage. Transformed variables include, among others, depth, velocity, cover, and substrate. The variables are aggregated into a single index and plotted against flow. The recommended flow is derived in part from a point on the curve that retains a certain quantity of habitat for a selected species or life stage. The most common method that uses biologically transformed hydraulic and structural variables is the USFWS IFIM where the aggregated suitability index is weighted useable area (WUA). The IFIM is the method used by DE&S for the mainstem portion of this study.

The most complex models in the Incremental/Habitat Quality Methods category use multiple biologically transformed variables aggregated into an index of habitat quality. The index of habitat quality is then plotted against flow and the recommended flow is determined from the inflection point on the curve. The most notable of these methods is Binn's Habitat Quality Index.

DE&S advocated and the Committee agreed to use an "Incremental/Habitat Quality Method" that used ***untransformed*** hydraulic variables. A number of untransformed hydraulic variables could be modeled using WSE as the primary link between discharge and flow dependent habitat variables. The primary dependent variables that would be obtainable from such a model are listed below in Table 3.3-1.

Table 3.3-1. Habitat related hydraulic parameters measurable using the proposed WSE simulation models.
• Water surface elevation. • Wetted perimeter and wetted area. • Channel volume. • Toe-of-bank width. • Maximum, minimum, and mean channel depth and width. • Percent area that meets a certain depth criteria. • Depth or surface area in a specified section of the channel, ie near bank. • Proximity of wetted edge to bank cover and structure. • Thalweg depth. • Magnitude, duration, and frequency of estuary inundation.

3.3.5 Description of Hydrodynamic/Habitat Model Selected

The selected discharge/habitat model is based on development of two separate WSE simulation sub-models (regression equations). The non-tidal period was modeled using a multiple regression equation between channel WSE and the combination of discharge and tidal drainage potential.

The tidal period was modeled with a multiple regression between channel WSE and the combination of discharge and tide level in Skagit Bay. Both predicted WSE as a function of discharge for any selected estuary study channel(s). The hydrodynamic model and equations are described in more detail in section 3.5, Data Analysis.

3.3.6 Study Site and Transect Description

The study channels and transects were selected in consultation with SSC, WDFW, and DOE biologists and were selected to be generally representative of the mixture of channel types and sizes in the estuary. Known fish use from SSC studies and critical habitat features were also factored into the selection. Study sites are listed in Table 3.3-2 and locations are shown in Figure 3.3-1.

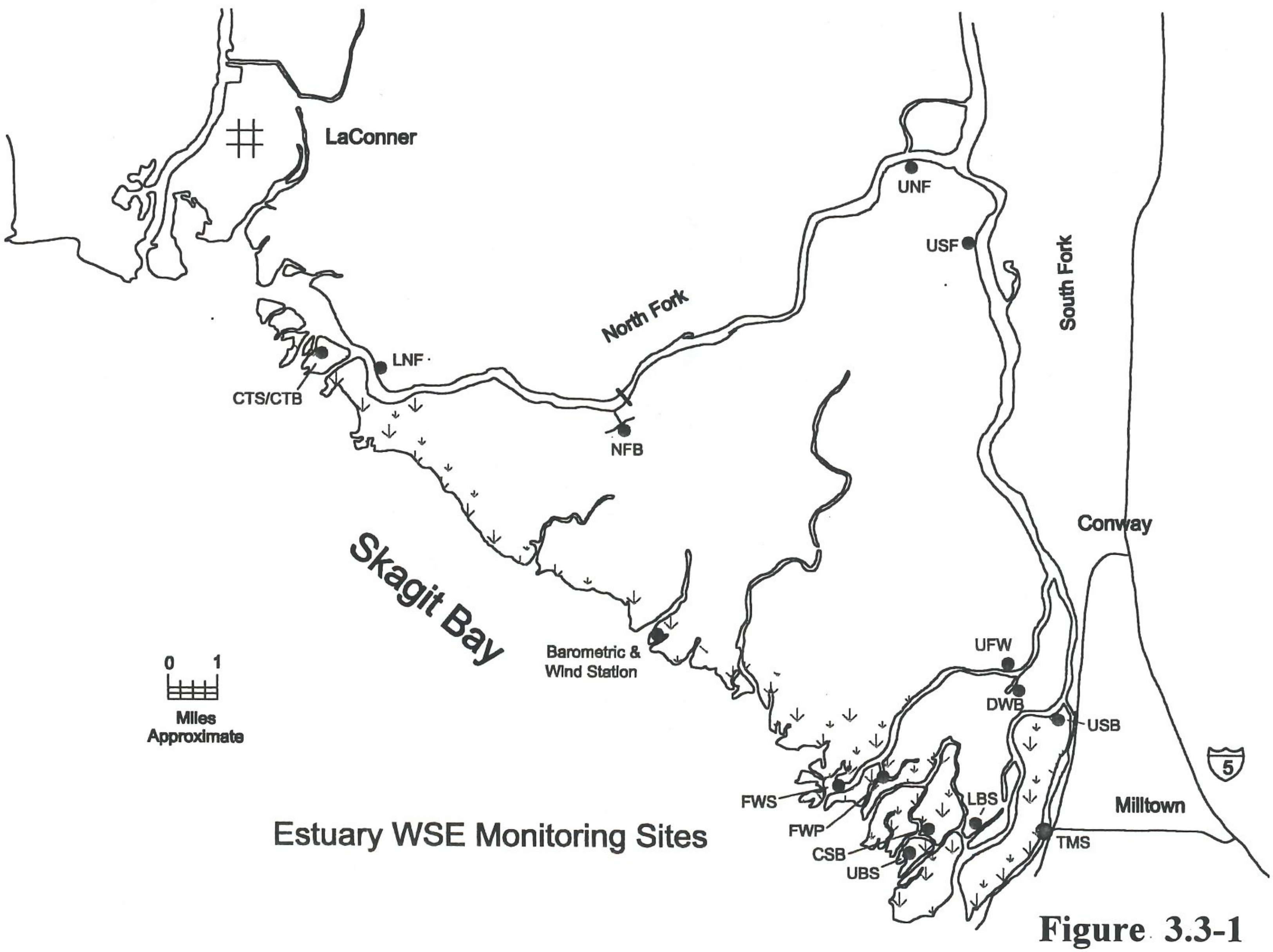
Each study site included a semi-permanent benchmark (8 foot steel fence post sunk 7 feet into the ground) at least one transect at a right angle across the selected study channel, and a continuous water level recorder located in the channel in close proximity (within 300 feet) of the transect.

Table 3.3-2. Skagit Estuary Study Site Locations and Descriptions				
Channel Name	Acronym	Channel Type	Estuary Zone	Number of Transects
Tom Moore Slough	TMS	Open channel - mid-size	Transition	1
Upper Steam Boat Slough	USB	Open channel - mid-size		1
Lower Brandstedt Slough	LBS	Blind channel - large- w/o pool		2
Upper Boom Slough	UBS	Open channel - small	Forested/Riparian	1
Crooked Slough Blind	CSB	Blind channel - small		2
Lower Freshwater Slough	LFS	Open channel - mid-size		1
Freshwater Pond	FWP	Blind channel - small w/ pool		2
Deepwater Blind Channel	DWB	Blind channel - small w/ pool		2
Upper Freshwater Slough	UFS	Open channel - mid-size		1
Upper North Fork	UNF	Open channel - large		1
Upper South Fork	USF	Open channel - large		1
North Fork Blind	NFB	Blind channel - small w/ pool		1
Lower North Fork	LNF	Open channel - large		1
Cattail Slough	CTS	Open channel - mid-size		1
Cattail Blind	CTB	Blind channel - small w/o pool		1

Study sites varied from wide and single main channels with steep and high banks in the upper estuary to study sites with multiple low profile channels cutting across the wide flat tidal plain in the lower estuary. Transects in the upper estuary generally terminated at the top of the bank near the flood crest elevation. Transects in the lower estuary generally crossed multiple channels including small rivulets and traversed hundreds of feet into over-bank tidal marsh.

Physical and habitat measurements collected at each transect included the following:

1) Cross sectional profile extending into the over-bank tidal marsh zone;
2) Distance between transect pairs;
3) Water surface slope;
4) A thalweg trace to determine the presence and elevation of hydraulic controls below each transect;
5) Cover including vegetation and structure along the transect.



Estuary WSE Monitoring Sites

Figure 3.3-1

The number of transects at each site varied depending on the diversity of channel configuration and habitat within the boundaries of each study site. Study sites on large and mid-size open channels, such as the main forks and sloughs only required one transect while some small open and blind channels required two transects.

3.3.7 Field Data Collection

The primary field study objective was the collection of accurate and simultaneous measurements of Skagit Bay tide level, river discharge, and channel WSE at each selected study site. Skagit Bay tide level and river discharge were the independent variables and site WSE were the dependent variable to be used in the model regressions. Accurate channel cross sectional profiles at the selected study sites was also a primary objective. Three data sets (tide level, site WSE, and channel profiles) all needed to be referenced to the common datum plane of mean lower low water (MLLW). The required data sets are listed below.

a) Time indexed WSE at each study site over a wide range of river discharges and tide levels.

b) Time indexed river discharge entering the estuary.

c) Time indexed tide level in Skagit Bay.

d) Cross sectional channel and associated tidal marsh profile at each estuary study site.

e) Reference of WSE, tide, cross section, and physical habitat features to the datum plane of MLLW.

Field data collection methods for each of these data sets is described below. Figure 3.3-2 is a graphic illustration of tide level and tidal channel WSE traces at three sites during a 36 hour period. This figure will be referenced several times in the remainder of this section.

3.3.7.1 Geodetic Elevation Survey

Semi-permanent benchmarks at each study channel were referenced to national vertical datum (NAVD 88) by Skagit County Public Works using high-accuracy (+/- .03 feet) GPS dual frequency receivers. National Vertical datum were converted to the datum plane of MLLW using the Polnell point tidal bench mark (Table 3.3-3).

Table 3.3-3 Relation Between Datum Planes at Polnell Point (COE - last revised March 9, 1996).

Datum Plane	Elevation Relative to Mean Lower Low Water
Mean Higher High Water	11.70
Mean High Water	10.80
Mean Tide Level	6.80
Mean Low Water	2.80
Mean Lower Low Water	0.00
NAV 88 Conversion to MLLW	-2.46

3.3.7.2 Cross Sectional Profile of Estuary Study Channels

Cross sectional profiles of each study channel were surveyed and referenced to its semi-permanent bench mark using methods adopted from the USFWS IFIM. Horizontal coordinates were spaced to define discrete changes in the bottom, bank, substrate, and vegetation profile and extended up to several hundred feet beyond the channel bank into the tidal mash zone. In-water bed elevations in deeper main channels were obtained using an ADCP. Direct cross sectional measurements were generally within 0.02 feet while measurements using an ADCP were within 0.10 feet.

3.3.7.3 Water Surface Elevations (WSE) in the Study Channel

Water surface elevations at each study site were continuously recorded using miniature, completely submersible data-logger/absolute pressure transducers. Accuracy of the units is +/- 0.04 feet. Because the sensor is not vented to the atmosphere, barometric pressure must be subtracted from the readings to obtain water pressure (depth) only.

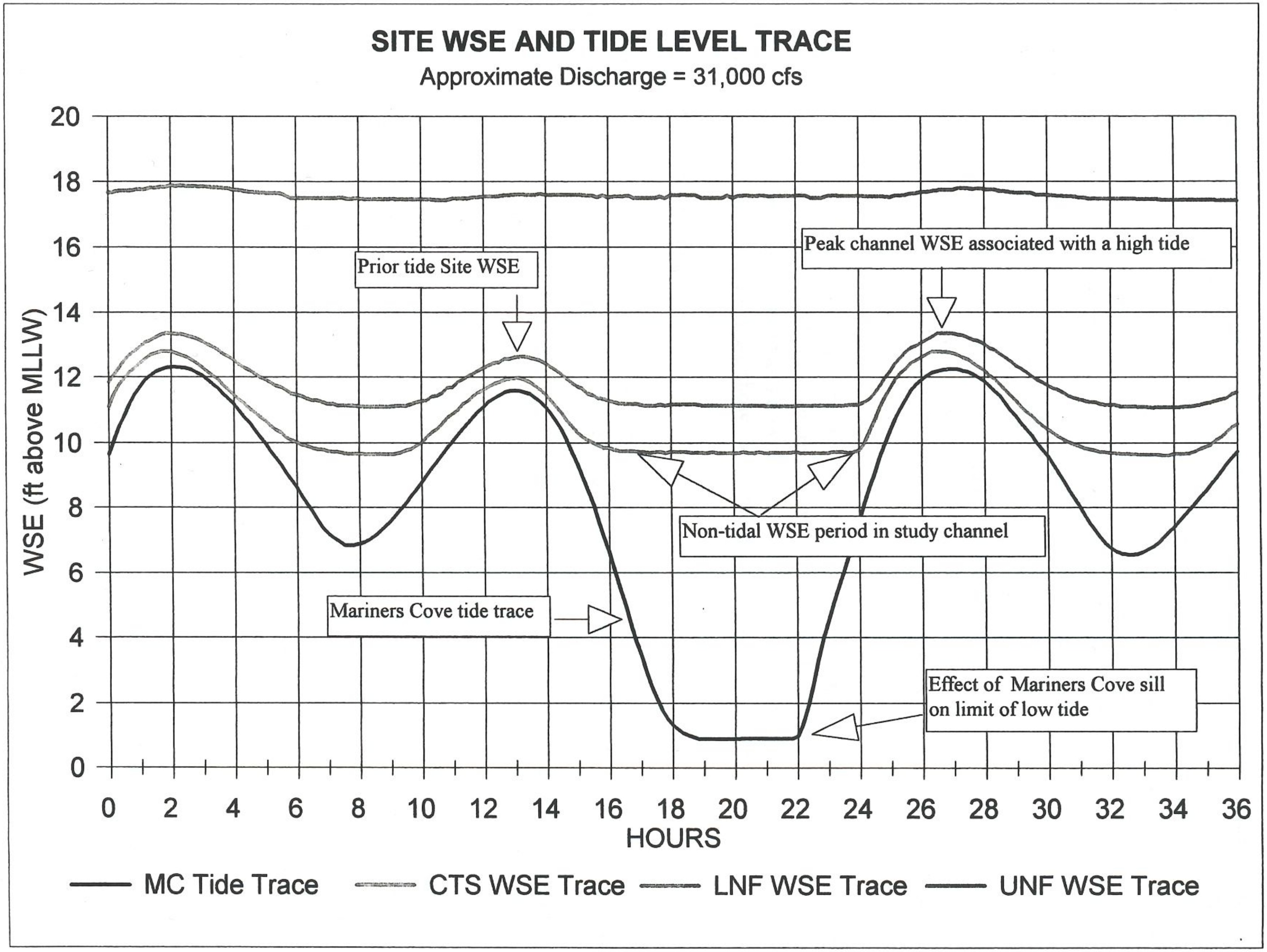

SITE WSE AND TIDE LEVEL TRACE
Approximate Discharge = 31,000 cfs
WSE (ft above MLLW)
20
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
HOURS
Prior tide Site WSE
Peak channel WSE associated with a high tide
Non-tidal WSE period in study channel
Mariners Cove tide trace
Effect of Mariners Cove sill on limit of low tide
MC Tide Trace
CTS WSE Trace
LNF WSE Trace
UNF WSE Trace

Figure 3.3-2

The pressure transducers were suspended from a small gage stainless steel cable inside a 2 inch diameter steel stand pipe with a vertical slot vent below water and a perforated cap at the top. Stand pipes ranged in height from three to fourteen feet depending on channel depth. In deeper channels, the stand pipe was secured to an existing structure such as a dock or remnant piling. In small and shallow channels, stand pipes were secured with cross members anchored to the channel bank. In both configurations the gages were very stable from horizontal or vertical movement. A staff gage was attached to the outside of the stand pipe. The elevation of the transducer sensor was surveyed to the site benchmark to the nearest 0.01 feet.

Because of the expense of the water level recorders, each was rotated from one study site to another study site every two to three weeks. This rotation permitted water level monitoring at twice as many study sites as there were water level recorders. Each recorder was always rotated between the same two study sites.

Recorded data was retrieved and units the were re-deployed using a lap-top computer. The water level recorded by the unit immediately before retrieval was checked against the external staff gage each time a unit was retrieved and downloaded. Recorded versus actual water levels were usually within .05 feet. Figure 3.3-2 shows WSE traces for three tidal channels.

3.3.7.4 River Discharge

River discharge entering the estuary was obtained from USGS stream gaging station #122005000 near Mt. Vernon. The stream gage is located at approximately RM 15.8 on the north bank of the Skagit River approximately 500 feet upstream of Interstate 5. Stage is recorded to 0.01 feet at 15 minute intervals. The gage is rated as "good" by the USGS. The 15 minute published gage record for the study period was obtained in electronic form from the USGS. Figure 3.3-3 is a mean monthly hydrograph for the Mt. Vernon USGS gage.

Compounding an already complicated hydrodynamic system is the high variability in Skagit River discharge due to upstream hydro regulation. The daily or twice daily peaking of Puget Power's Baker River Project and Seattle City Light's Skagit Projects cause diurnal flow fluctuations at Mt. Vernon that average from 2,000 to 5,000 cfs, depending on the time of year. Daily flow ranges of 8,000 to 10,000 cfs are not uncommon. These frequent fluctuations are generally unpredictable. Figure 3.3-4 shows an example period of rapid flow fluctuations due to upstream hydro regulation.

3.3.7.5 Tide Level in Skagit Bay

Actual tide level in Skagit Bay was continuously recorded at a dedicated tide gage installed by DE&S in Mariners Cove, across Skagit Bay on the east side of Whidbey Island. Mariners Cove is a small private community marina. The marina is well protected from wind and waves and has minimal boat traffic resulting in a near constant smooth water surface. The tide gage was a relative pressure type transducer water level recorder housed in a pvc pipe attached to the piling of a private dock located away from the main boat traffic lane.

Mean Monthly Flows - USGS Gage #12200500
Period of Record
(1/1/41 - 12/31/95)

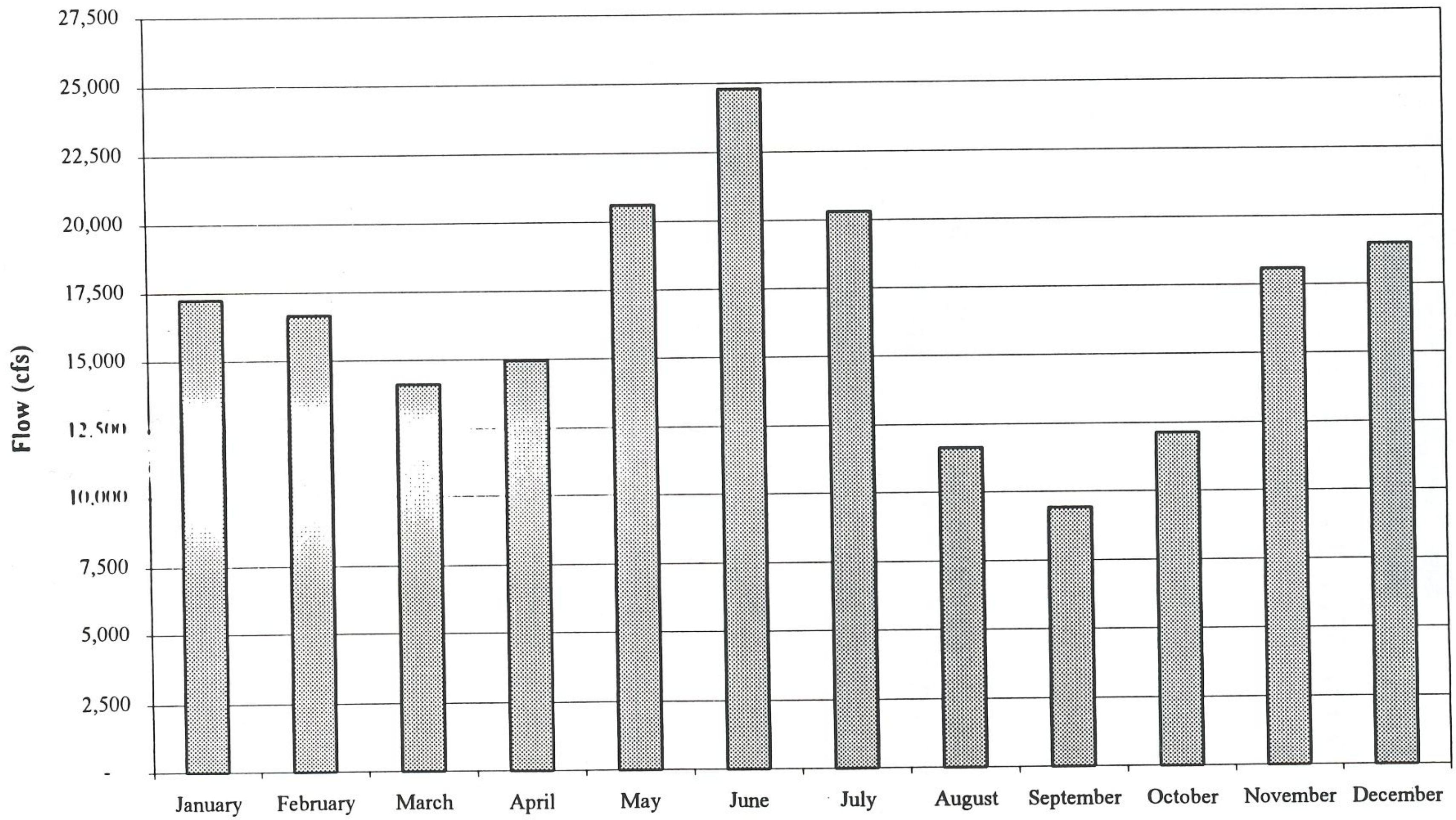
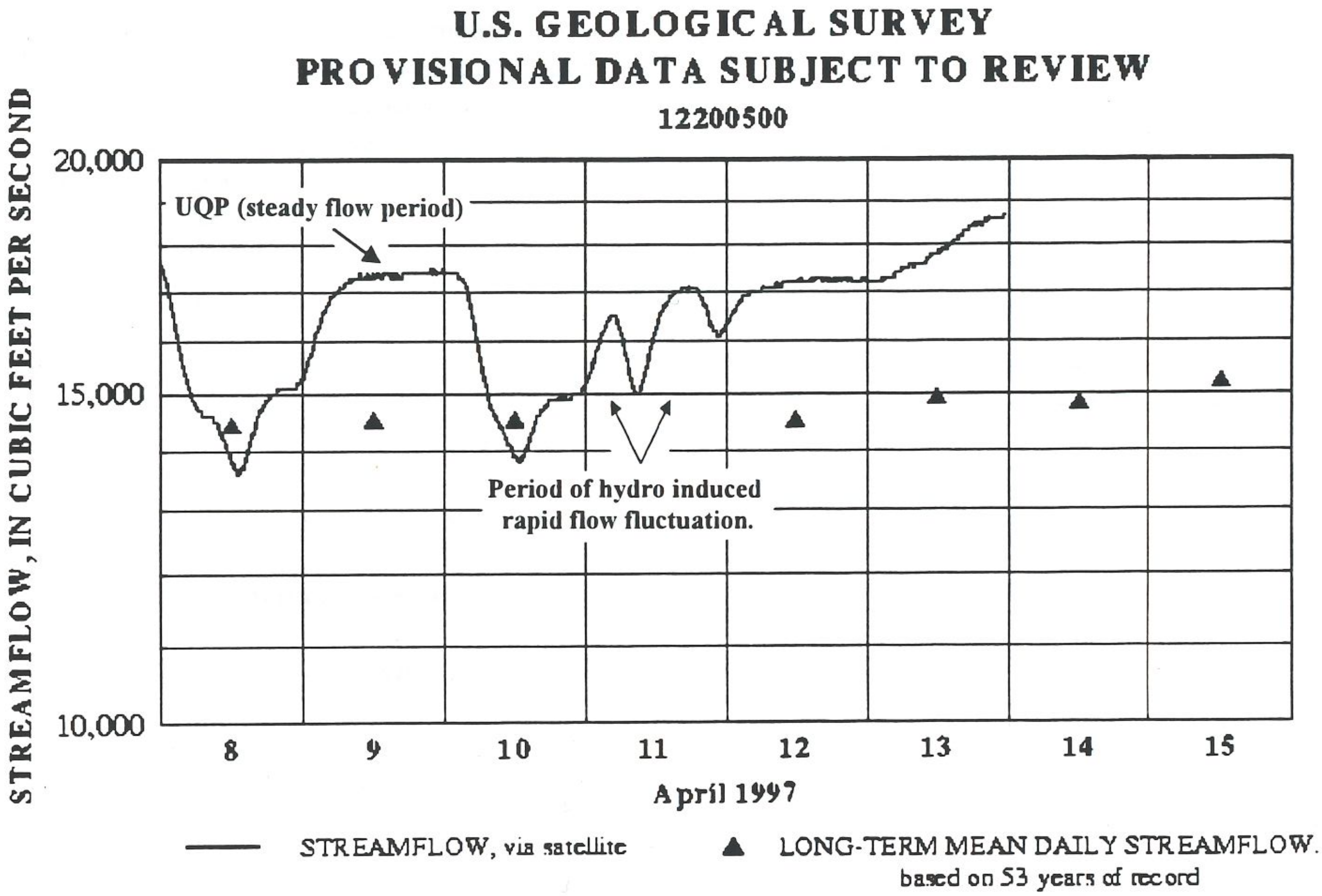


Figure 3.3-3

12200500 - SKAGIT RIVER NEAR MOUNT VERNON, WA

```
Latitude (degrees, minutes, and seconds)...... 482642
Longitude (degrees, minutes, and seconds)..... 1222003
State Code.................................... 53
County Code................................... 057
Hydrologic Unit Code.......................... 17110007
Drainage Area (square miles)..................  3093.00
Gage Datum (feet above NGVD)..................     0.00
----Period(s) of Record----
    1940.10.01-Current
```



Revised: 04-14-97 03:32

Retrieve postscript of hydrograph

- Return to the Real-time Data Retrieval Page
- Return to the Current Streamflow Conditions Page

Figure 3.3-4

Gage accuracy is +/- 0.01 feet. Measurements of low tide were limited to 0.9 feet MLLW by a man-made sill at the entrance to the cove. This was not a hindrance to the study since low tides were not used in the analyses. Figure 3.3-2 shows a tide trace at Mariners Cove over a 36 hour period. Actual tide data was used in the regression analyses whereas analyses requiring a long term record were based on predicted tides at the NOAA subordinate tide station at Crescent Harbor, approximately 4.5 miles west of Mariners Cove (Figure 3.3-5). Figure 3.3-6 is a tide duration curve for the Crescent Harbor station.

Southerly wind can cause the tide to "pile up" on the Skagit delta, resulting in a difference between the tide level at the margin of the estuary and the tide level measured at the Mariners Cove gage. This potential source of error was eliminated by removing periods of strong wind from the data base.

3.3.7.6 Meteorological Conditions

Wind speed and direction, barometric pressure, and ambient air temperature were continuously recorded at the mouth of Hall Slough (Figure 3.3.5). The barometric pressure instrument was accurate to +/- 1 hecta pascals (0.033 feet of water). Simultaneous measurements of barometric pressure at Hall Slough were subtracted from each pressure transducer water level recording at the study sites to obtain actual WSE. Wind data were used to identify and remove periods of tide "pile-up" from the data base.

3.3.7.7 Measurement Time Step and Clock Synchronization

WSE, tide, and meteorological measurements were collected at 10 minute intervals. Instrument clocks were synchronized to a laptop computer clock at each download of data. Stored data was downloaded from the instruments approximately every 2-3 weeks.

Data analysis methods are presented in Section 3.5.

3.4 Field Method Results

3.4.1 Field Data Collection

Few difficulties were encountered in the data collection phase. With the exception of one WSE recorder that failed and was replaced early in the study, all instrumentation operated as designed. Frequent cross checks against staff gages at each study site verified instrument accuracy and careful data filing and organization prevented data-file mix-ups. With one exception, all study sites and gage housings survived the fall and winter conditions with no damage. One gage housing was damaged in a 60,000 cfs plus flow and was replaced with no loss of data. The data collection phase provided a complete and accurate record to meet study objectives.

Figure 3.3-5

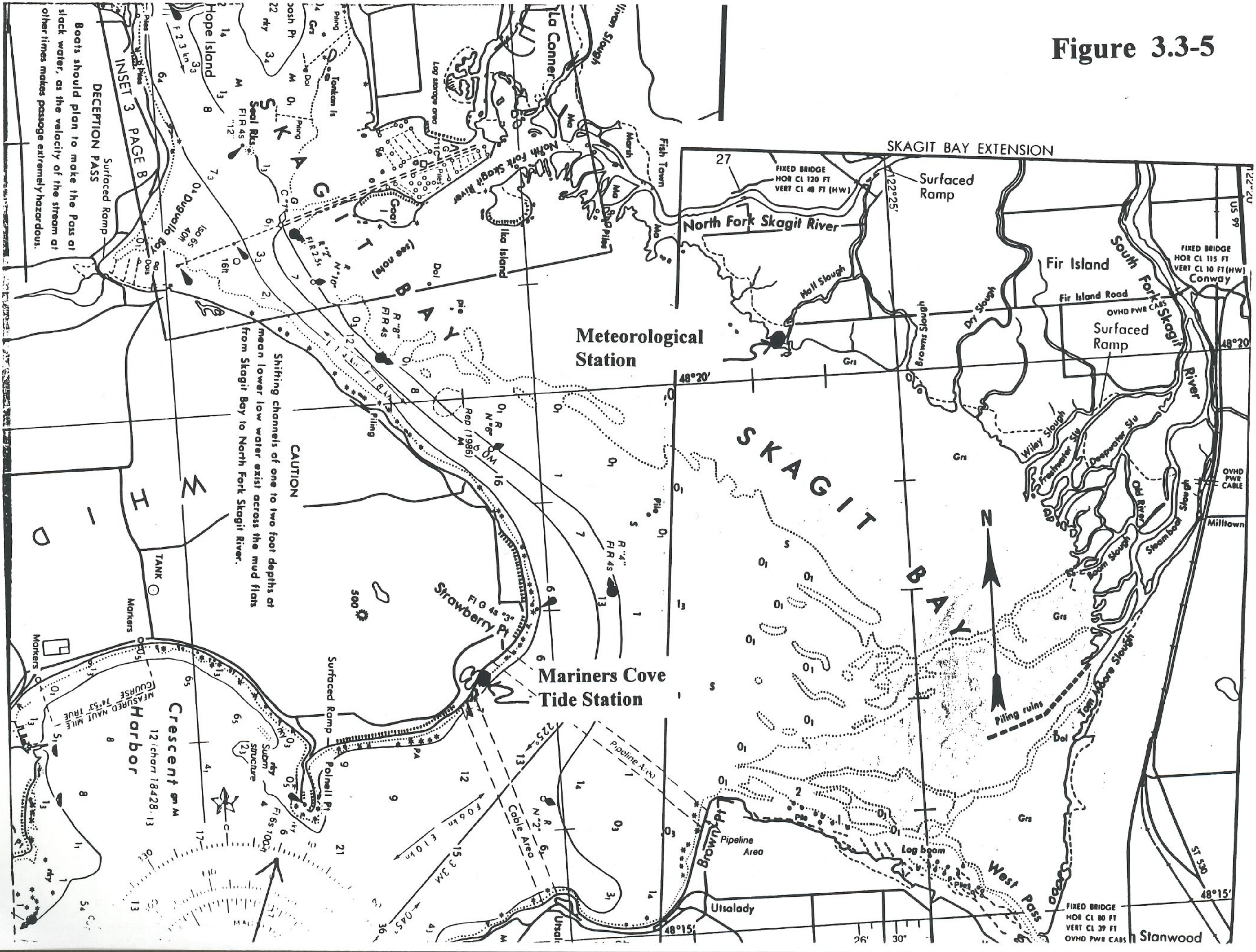
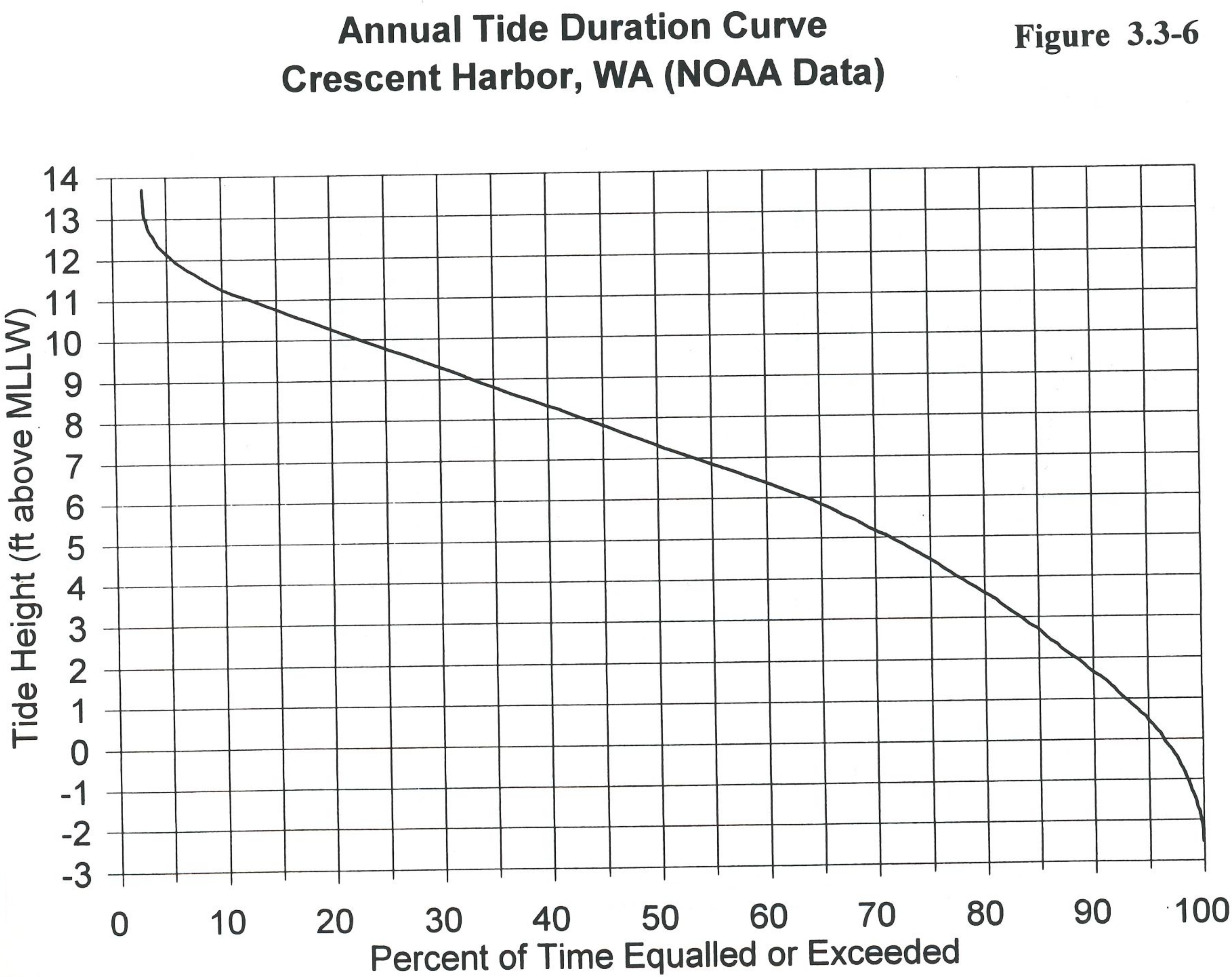

SKAGIT BAY EXTENSION
SKAGIT BAY
Meteorological Station
Mariners Cove Tide Station
North Fork Skagit River
South Fork Skagit River
Fir Island
Fir Island Road
Surfaced Ramp
FIXED BRIDGE HOR CL 120 FT VERT CL 40 FT (HW)
FIXED BRIDGE HOR CL 115 FT VERT CL 10 FT (HW)
FIXED BRIDGE HOR CL 80 FT VERT CL 39 FT OVHD PWR CABS
OVHD PWR CABLE
Conway
Milltown
Stanwood
US 99
ST 530
Hall Slough
Browns Slough
Dry Slough
Wiley Slough
Freshwater Slu
Deepwater Slu
Old River
Steamboat Slough
Boom Slough
Tom Moore Slough
Piling ruins
West Pass
Log boom
Pipeline Area
Brown Pt
Utsalady
Cable Area
Strawberry Pt
Polnell Pt
Crescent Harbor
MEASURED NAUT MILE COURSE 74°53' TRUE
TANK
Markers
Ika Island
Goat I
La Conner
Fish Town
Marsh
Log storage area
Tonkon Is
Seal Rks
Hope Island
Dugualla Bay
INSET 3 PAGE B
WHID
(see note)
Subm structure
48°20'
48°15'
122°25'
CAUTION
Shifting channels of one to two foot depths at mean lower low water exist across the mud flats from Skagit Bay to North Fork Skagit River.
DECEPTION PASS
Boats should plan to make the Pass at slack water, as the velocity of the stream at other times makes passage extremely hazardous.

Figure 3.3-6


Annual Tide Duration Curve
Crescent Harbor, WA (NOAA Data)
Tide Height (ft above MLLW)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60
70
80
90
100
Percent of Time Equalled or Exceeded

3.4.2 Data Record

Simultaneous data collection of discharge, tide, meteorological, and site WSE began in April 1997 and ended in November 1997. Site WSE, tide, discharge, and meteorological measurements were generally continuous during this period. Table 3.4-1 shows the rotation schedule of pressure transducers between the two groups of estuary WSE measurements sites.

Table 3.4-1. Rotation schedule of pressure transducers between the two groups of WSE measurements sites.

Group A Sister Site Name	Recording Periods for All Sites in Group A		Group B Sister Site Name	Recording Periods for All Sites in Group B
Upper Boom Slough	11 April - 2 May		Lower Freshwater	2 May - 15 May
Cattail Slough	15 May - 30 May		Crooked Slough Blind	30 May - 13 June
Freshwater Pond	17 June - 3 July		Cattail Blind	7 July - 17 July
Brandstedt Slough	17 July - 29 July		Upper Steamboat	29 July - 22 Aug
Lower North Fork	22 Aug - 14 Sept		Upper Freshwater	14 Sept - 26 Nov
Tom Moore Slough			Tom Moore Slough	
Deepwater Blind			North Fork Blind	
Upper North Fork			Upper South Fork	

3.5 Data Analysis

Data were analyzed in basically three steps: 1) data aggregation and reduction; 2) regression coordinate set selection; and 3) statistical analysis. These three steps are described below.

3.5.1 Data Aggregation and Reduction

Over 300,000 individual measurements of water surface elevation, tide level, discharge, and meteorological conditions were collected over the six month study period. Through a computer aided screening and merging process these data points were reduced to fewer than 70 coordinate sets for each of the 15 study sites. The following is an explanation of the how the raw data were aggregated and reduced.

3.5.1.1 Useable Discharge and WSE Period

Usable Discharge Period (UQP)

Because reliable hydrodynamic modeling of the estuary depends on accurately linking WSE measurements at estuary sites with total river discharge, only steady flow periods from the Mt. Vernon river gage record could be used in the analysis. A criteria based computer search of the Mt. Vernon river gage record was used to isolate steady flow periods. The criteria based search defined a useable discharge period as at least 8 hours when discharge at the USGS gage did not vary by more than 800 cfs. Eight hours was deemed the shortest period of time that would encompass at least one high or one low tide. Once such a period was isolated, the median discharge during that steady flow period was calculated and used as the discharge variable in a coordinate set. The median flows of an 800 cfs range would result in a +/- 400 cfs estimate of flow during the useable discharge period (approximately 2.6 % of the mean annual flow) . Coordinate set selection is described later in this section. To compensate for lag time in water flow between the USGS gage at Mt. Vernon and the estuary 3.2 hours was added to the beginning and ending times of the steady flow period recorded at the gage. This expected lag time was estimated from travel rate of flow between the USGS gage at Concrete and the Mt. Vernon gage. The file containing all useable discharge periods is referred to as the **UQP File.** An example period of flows at the Mt. Vernon gage, including a UQP period, is shown in Figure 3.3-4.

Study Site WSE

As previously described, the type of water level recorders used at the study sites to record channel WSE required that barometric pressure be measured separately and simultaneously. Barometric pressure readings were subtracted from total pressure readings of the water level recorder to obtain actual water pressure. Water pressure was then converted to WSE relative to MLLW. The file containing all WSE's adjusted for barometric pressure and referenced to MLLW is referred to as the **Site WSE File.**

3.5.1.2 Non-tidal Period Data Reduction

Non-tidal WSE (NTWSE) Search

This was an electronic search of the Site WSE File for periods when water surface elevation at the study site was not influenced by tide. Pilot study tests showed that a criteria of less or equal to a 0.04 foot change in WSE for a period of 1.5 hours or greater would isolate periods of non-tidal influence. The program generated a file of the non-tidal WSE data strings that met the NTWSE Search criteria. It includes the water surface elevation and duration of each non-tidal period. This file is referred to as the **NTWSE File.** An example period of site WSE's, including a NTWSE period, is shown in Figure 3.3-2

NTWSE Regression Coordinates Search

This was a manual search of the UQP and NTWSE Files to identify non-tidal period discharge and corresponding WSE coordinates that could be used in the non-tidal WSE/discharge regression.

Prior High Tide Site WSE

The prior high tide WSE is the highest WSE at the estuary site immediately prior to the non-tidal period. The prior WSE would have been propagated by the previous high tide in combination with the river discharge. Please refer to Figure 3.3-2. This volume of water inundating the tidal channels and tidal marshes at high tide begins to drain as the tide begins to ebb and could affect the magnitude and duration of the non-tidal WSE period.

3.5.1.3 Tidal Period Data Reduction

Useable Tide Period (UTP) Search

This was an electronic search of the anemometer records for periods when wind speed may have caused a differential tide level between Mariners Cove and the estuary. Criteria selected was 11.6 mph for 1.5 hours. Time periods during the study when winds exceeded these criteria were not used in the analyses. The tide record with periods of potential tide level differentials removed is referred to as the **UTP File.** An example period of useable tides is shown in Figure 3.3-2.

WSE-UQP/UTP Search

This was a manual step. Peak water surface elevations at the study sites that occurred during a useable discharge period were identified by cross referencing the UQP and WSE files. The UTP file was then searched to find the peak tide elevation at Mariner's Cove that propagated the peak water surface elevation at the estuary study site. Figure 3.3-2 shows a peak WSE and a corresponding peak tide level that would constitute a coordinate pair.

Tidal Period WSE Regression Coordinates File

This file contains the median discharge and peak tide elevations that propagated the corresponding WSE at the study sites. The two independent input variables (median discharge and tide level) and the dependent variable (site WSE) were used as the coordinate set in the tidal period multiple regression.

3.5.2 Regression Coordinate Set Selection

Tidal and non-tidal regression coordinate sets were selected to represent the normal range of discharge and tide levels that occur in the Skagit estuary. Discharge during the period of record ranged from 7,000 cfs to 75,000 cfs and tide ranged from -2.5 to 13.5 feet above MLLW 88.

Examples of non-tidal and tidal coordinate worksheets are shown in Figures 3.5-1 and 3.5-2. The examples show only a portion of the worksheet. The independent input variables of discharge, tide, prior WSE and the dependent variable of site WSE are highlighted. These worksheets provide various dates, time periods, and elevations related to the input variables.

3.5.3 Statistical Analysis

With non-tidal and tidal coordinate sets described above, multiple regression equations were used to predict water surface elevation relative to the geometry and habitat structure of selected study channels for any river discharge and/or tide level combination. These relationships are the foundation of the hydrodynamic habitat/discharge model.

Statistical analyses were performed using the 1998 edition of software program STATISTICA for Windows 98.

The multiple regression equation used to determine the relationship of non-tidal WSE to river discharge and prior tide WSE is:

$$\text{WSE} = b_o + b_1 K + b_2 Q + e$$

Where: WSE = water surface elevation at the study site
b_o = *constant*
b_1 and b_2 = regression coefficients
K = prior tide WSE
Q = river discharge at Mt. Vernon
e = residuals (if necessary)

NON-TIDAL WORKSHEET

Site Name FRESH WATER POND **Date** **6-14-98**
Acronymn FWP

Page **1 of 3**
Initials RD

Row #	Tide at Mariners Cove: Date	Time	Low Tide	Prior Hi Tide	River Discharge at Mt. Vernon Gage: Index Number	Date	Begin Time	# Hrs	Median Discharge	Site WSE: Date	Begin Time	# Hrs	WSE	Prior Tide WSE	Time
1	04/07	11:41	0.3	12.35	2291	04/07	6:45	21.8	17562	04/07	12:50	1.5	7.316	12.4991	4:00
2	04/08	12:23	-0.4	12.38											
3	04/09	1:07	-0.8	12.15	2348	04/09	7:15	24.5	17259	04/09	12:50	1.7	7.176	12.428	6:50
4	04/10	1:51	-0.8	11.59											
5	04/11	2:37	-0.5	10.70											
6	04/12	3:27	1.0	10.03	2441	04/12	4:15	26.8	17107	04/12	2:30	3.2	7.062	10.252	9:10
7	04/23	12:11	-0.1	11.52	2823	04/23	5:30	14.5	24756	04/23	1:00	2	7.727	11.826	6:00
8	04/24	12:45	-0.6	10.99	2880	04/23	7:45	27.0	25009	04/24	12:40	2	7.666	11.295	6:40
9	04/25	1:23	-0.9	10.78	3008	04/25	3:45	28.8	23585	04/25	1:00	1.5	7.529	11.048	7:10
10	04/26	2:04	-1.0	10.88											
11	04/27	3:50	-0.8	10.22											
12	04/28	3:41	-0.4	9.71											
13	04/29	4:39	0.2	9.13	3153	04/29	6:00	17.0	26922	04/29	2:20	3.8	7.76	9.829	10:10
14	05/20	10:35	0.0	11.45	4230	05/20	12:15	26.3	29517	05/20	10:50	2.3	5.607	11.813	4:30
15	05/21	11:08	-0.7	11.49											
16	05/22	11:42	-1.4	11.61	4348	05/22	6:00	9.3	25574	05/22	11:30	1.5	5.357	11.792	5:40
17	05/23	12:19	-1.8	11.60	4400	05/23	12:15	50	24363	05/23	10:10	2.3	4.994	11.852	6:00
18	05/24	12:59	-2.0	11.38	4400	05/23	12:15	50	24363	05/24	12:00	2	5.13	11.602	6:40
19	05/25	1:41	-1.9	11.03	4609	05/25	4:30	55.8	23918	05/25	12:30	2.2	4.626	11.312	7:20
20	05/26	2:27	-1.5	10.50	4609	05/25	4:30	55.8	23918						
21	05/27	3:18	-0.7	9.68	4825	05/27	11:15	10.3	24699	05/27	3:00	3	4.786	10.145	9:10
22	05/28	4:13	0.3	9.10	4864	05/27	9:00	23.5	25262	05/28	3:50	3.2	4.892	9.809	10:20

Figure 3.5-1

TIDAL CONDITION WORKSHEET

Site Name FRESHWATER POND **Date** ______
Acronymn FWP

Page 1 OF 7
Initials RD

Row #	Tide at Mariners Cove: Date	Time	High Tide	River Discharge at Mt. Vernon Gage: Index Number	Date	Begin Time	# Hrs	Median Discharge	Site WSE: Date	Time	WSE
68	05/20	4:00	11.5	4214	05/19	8:15	20.0	29580	05/20	4:00	8.794
69	05/22	5:10	11.6	4331	05/22	1:45	8.5	25943	05/22	5:10	8.427
70	05/27	10:50	12.6	4831	05/27	12:45	17.8	25009	05/27	10:50	9.296
71	05/28	11:30	12.9	4876	05/27	12:00	20.5	25375	05/28	11:10	9.757
72	05/28	10:00	9.1	4876	05/27	12:00	20.5	25375	05/28	10:10	6.034
73	06/27	11:40	12.5	5955	06/27	11:30	13.5	25801	06/27	11:30	13.013
74	06/28	12:30	8.7	5955	06/27	11:30	13.5	25801	06/28	12:50	9.637
75	06/29	2:00	9.2	6001	06/28	7:15	17.3	25971	06/29	1:50	10.000
76	07/03	3:50	11.1	6205	07/03	1:45	11.3	25489	07/03	4:00	11.495
77	07/14	12:10	11.1	6436	07/13	8:45	14.3	25886			
78	07/19	5:40	11.5	6792	07/19	12:15	22.3	25150			
79	07/20	5:00	12.0	6792	07/19	3:15	22.3	25150	07/20	5:10	12.394
80	07/23	8:40	12.8	7059	07/23	2:00	8.0	25971	07/23	8:50	13.210
81	07/24	9:20	12.9	7063	07/24	5:15	17.0	22896	07/24	9:40	13.273
82	07/25	9:40	9.5	7146	07/25	2:00	9.8	22023	07/25	9:40	10.180
83	07/26	10:50	9.1	7195	07/26	1:30	14.0	19076	07/26	10:50	9.750
84	07/30	1:20	10.9	7487	07/29	4:30	40.3	19284			

Figure 3.5-2

The multiple regression equation used to determine the relationship of tidal WSE to river discharge and tide level in Skagit Bay is:

$$WSE = b_o + b_1 M + b_2 Q + e$$

Where: WSE = water surface elevation at the study site
b_o = *constant*
b_1 and b_2 = regression coefficients
M = tide level in Skagit Bay
Q = river discharge at Mt. Vernon
e = residuals (if necessary)

3.5.4 Regression Results

3.5.4.1 Non-tidal

Non-tidal Site WSE showed a significant positive correlation at the .05 level to discharge and no correlation at the .05 level to prior tide WSE (Table 3.5-1).

3.5.4.2 Tidal

Tidal Site WSE showed a significant correlation at the .05 level to the combined effect of discharge and Skagit Bay tide (Table 3.5-2). The power (BETA) of each of these two independent variables (discharge and tide) on site WSE varied between sites. With the exception of Upper South Fork, WSE at all sites was positively correlated to tide level. With the exception of Crooked Slough Blind, Lower Freshwater Slough, and Upper Boom Slough WSE at all sites was positively correlated to river discharge.

Table 3.5-1. Non tidal statistics multiple regression results. Dependent Variable: Water Surface Elevation Independent Variable: River Discharge and Prior Tide Water Surface Elevation.

Site Name	N	R^2	Discharge Corr.	Discharge BETA	Discharge p-level	Prior Tide WSE Corr.	Prior Tide WSE BETA	Prior Tide WSE p-level
Crooked Slough Blind	19	0.890	0.943	**0.938**	0.00000	-0.300	-0.016	0.85547
Cattail Blind slough	32	0.985	0.993	**0.990**	0.00000	-0.140	-0.012	0.63312
Cattail Slough	30	0.943	0.971	**0.970**	0.00000	0.400	0.002	0.96981
Deepwater Blind Slough	24	0.932	0.961	**1.017**	0.00000	0.430	-0.106	0.12872
Freshwater Pond Slough	26	0.735	0.853	**0.830**	0.00000	0.310	0.087	0.44407
Lower Brandstedt Slough	32	0.941	0.970	**0.969**	0.00000	0.206	0.003	0.94899
Lower Freshwater Slough	19	0.986	0.991	**0.978**	0.00000	0.326	0.051	0.11806
Lower North Fork	25	0.977	0.987	**0.980**	0.00000	0.149	0.049	0.16523
North Fork Blind Slough	28	0.887	0.939	**0.950**	0.00000	-0.052	0.080	0.24775
Upper Boom Slough	32	0.936	0.967	**0.965**	0.00000	0.212	0.009	0.84910
Tom Moore Slough	25	0.996	0.998	**0.998**	0.00000	-0.117	0.010	0.42776
Upper Freshwater Slough	19	0.998	0.999	**0.999**	0.00000	0.200	-0.000	0.99846
Upper North Fork	25	0.994	0.997	**0.997**	0.00000	0.121	0.002	0.92742
Upper Steamboat Slough	25	0.986	0.993	**0.997**	0.00000	0.113	-0.027	0.30025
Upper South Fork	28	0.992	0.995	**0.989**	0.00000	-0.177	-0.047	0.01841

Bold font indicates beta is significant at the 0.05 level.

Table 3.5-2. Tidal statistics multiple regression results. Dependent Variable: Water surface elevation. Independent Variable: Tide level and River Discharge

Site Name			Discharge			Tide		
	N	R^2	Corr.	BETA	p-level	Corr.	BETA	p-level
Crooked Slough Blind	52	0.905	-0.166	-0.028	0.53239	0.951	**0.947**	0.00000
Cattail Blind slough	47	0.883	-0.039	**0.166**	0.00301	0.925	**0.961**	0.00000
Cattail Slough	64	0.946	0.191	**0.243**	0.00000	0.942	**0.955**	0.00000
Deepwater Blind Slough	63	0.895	0.704	**0.709**	0.00000	0.626	**0.631**	0.00000
Freshwater Pond Slough	55	0.980	0.986	**0.093**	0.00023	0.278	**0.968**	0.00000
Lower Brandstedt Slough	64	0.949	0.175	**0.186**	0.00000	0.956	**0.958**	0.00000
Lower Freshwater Slough	47	0.963	-0.014	**0.153**	0.00001	0.970	**0.995**	0.00000
Lower North Fork	62	0.911	0.584	**0.612**	0.00000	0.733	**0.755**	0.00000
North Fork Blind Slough	53	0.849	0.801	**0.921**	0.00000	0.236	**0.471**	0.00000
Upper Boom Slough	28	0.968	-0.123	**0.090**	0.00000	0.980	**0.999**	0.02112
Tom Moore Slough	93	0.929	0.097	**0.310**	0.00000	0.915	**0.983**	0.00000
Upper Freshwater Slough	32	0.889	0.739	**0.809**	0.00000	0.493	**0.589**	0.00000
Upper North Fork	51	0.968	0.969	**0.930**	0.00000	0.380	**0.176**	0.00000
Upper Steamboat Slough	57	0.587	0.618	**0.709**	0.00000	0.322	**0.462**	0.00000
Upper South Fork	66	0.965	0.979	**0.998**	0.00000	- 0.146	**0.082**	0.00113
Bold font indicates beta is significant at the 0.05 level.								

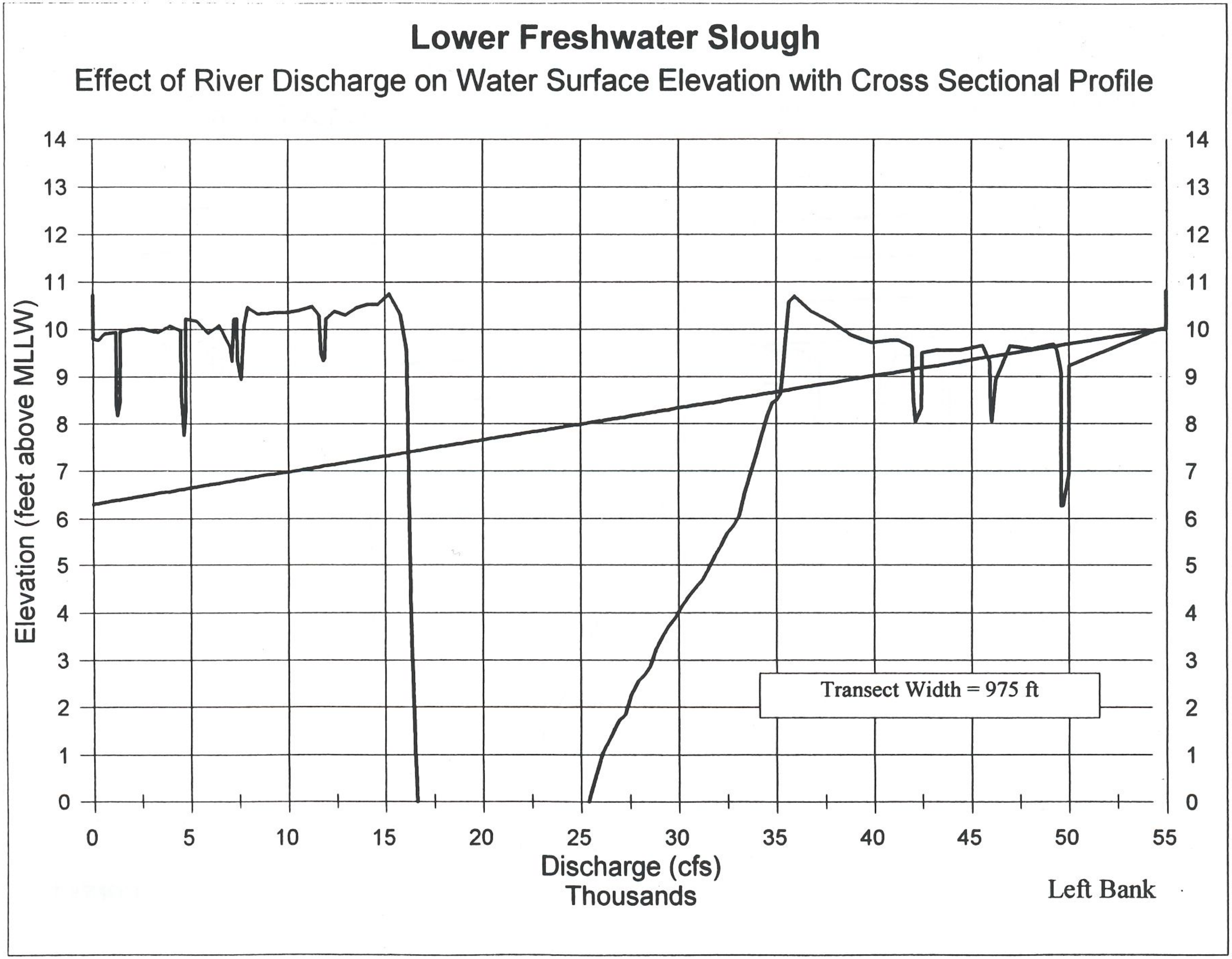
3.5.5 WSE Regression and Channel Cross Section Plots

3.5.5.1 Non-tidal

Regression lines of non-tidal WSE versus discharge were then plotted over the channel cross sectional profile at each site. A example non-tidal plot of one site is shown in Figure 3.5-3. Plots of the remaining sites are presented in Appendix E.

3.5.5.2 Tidal

Regression lines of tidal WSE versus discharge and tide were then plotted over the channel cross sectional profile at each site. An example tidal plot of one site is shown in Figure 3.5-4. Plots of the remaining sites are presented in Appendix E.



Lower Freshwater Slough
Effect of River Discharge on Water Surface Elevation with Cross Sectional Profile
Elevation (feet above MLLW)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
5
10
15
20
25
30
35
40
45
50
55
Discharge (cfs)
Thousands
Transect Width = 975 ft
Left Bank

Figure 3.5-3

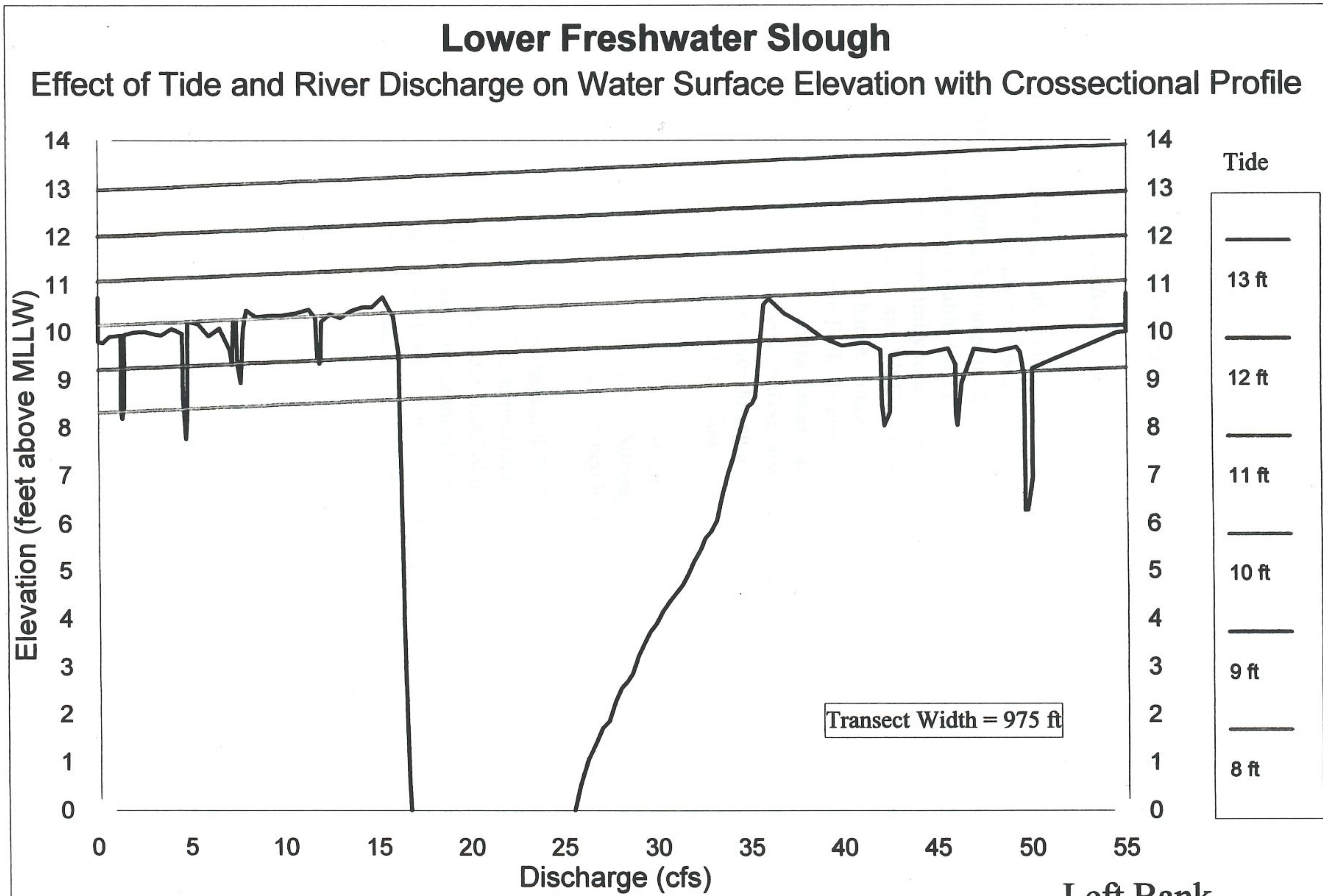

Lower Freshwater Slough
Effect of Tide and River Discharge on Water Surface Elevation with Crossectional Profile
Elevation (feet above MLLW)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
5
10
15
20
25
30
35
40
45
50
55
Discharge (cfs)
Thousands
Transect Width = 975 ft
Tide
13 ft
12 ft
11 ft
10 ft
9 ft
8 ft
Left Bank

Figure 3.5-4

3.6 Analysis and Interpretation of Results

Results were analyzed and interpreted in collaboration with the Skagit River Instream Flow Committee. The focus of the Committees' analysis was the effect of incremental changes in river discharge on the magnitude, duration, and frequency of inundation of the estuary.

3.6.1 WSE Sensitivity Analysis

One of the first steps was an analysis of the sensitivity of the different zones of the estuary to changes in discharge. All study sites were ranked relative to the sensitivity of WSE to discharge (change in WSE per 1,000 cfs change in discharge). Site sensitivity was ranked under both the non-tidal and tidal condition (Table 3.6-1). This ranking revealed that estuary site sensitivity is closely related to the site's proximity to marine water. Based on this ranking the sites could be correlated to three zones. Study site WSE's in the lower zone (nearest the marine water) were least sensitive to changes in discharge. Study site WSE's in the upper zone (nearest the branching of the North and South Forks) were most sensitive to changes in discharge. Study site WSE's in the middle zone (between the lower and upper zones) was intermediate in sensitivity to changes in discharge. The sensitivity analysis also revealed that WSE is more sensitive to discharge during a non-tidal period than during a tidal period. Some reasons for the variability in sensitivity of estuary zones are presented below.

The influence of discharge on WSE increases in an upstream direction while the influence of tide on WSE decreases in an upstream direction. Although the relative effects of these variables on WSE are a continuum they can be broadly defined by the three zones.

Lower Zone: Channel elevations (bankfull WSE) and channel bank profiles are lowest in this zone. Average bankfull WSE is approximately 10.5 - 11.0 feet above MLLW. Channels in this zone are primarily lower order small blind or small subsidiary channels. These three factors (low channel elevation, low channel bank profile and flow confinement, and low channel order) make this zone least sensitive to changes in discharge. Low channel elevations relative to MLLW make this zone most sensitive to tidal effects.

Middle Zone: Channel elevations and channel bank profiles are intermediate in this zone. Average bankfull WSE is approximately 13 - 14 feet above MLLW. Channels in this zone are primarily higher order small blind, subsidiary or main channels. These three factors (intermediate elevation, intermediate channel bank profile and flow confinement, and higher channel order) make this zone more sensitive to changes in discharge than the Lower Zone. Slightly higher channel elevations relative to MLLW make this zone slightly less sensitive to tidal effects.

Table 3.6-1. Sensitivity of WSE in the Skagit estuary to river discharge. Stratified by tidal condition and by estuary zone.

Zone (proximity to saltwater)	Tidal (tidal influence) Site	Tidal WSE Change/ 1000 cfs Q	Non Tidal (no tidal influence) Site	Non Tidal WSE Change/ 1000 cfs Q
Lower Zone	Crooked Slough Blind	-0.00 ft	Lower Freshwater	0.07 ft
	Upper Boom Slough	0.00	Freshwater Pond	0.07
	Cattail Slough	0.01	Crooked Slough Blind	0.08
	Freshwater Pond	0.01	Cattail Blind	0.08
	Lower Freshwater	0.02	Upper Boom Slough	0.08
	Lower Brandstedt	0.02	Cattail Slough	0.10
	Cattail Blind	0.02	Lower Brandstedt	0.10
		avg = 0.01		avg = 0.08
	(Average sensitivity ratio of non tide to tide is 8:1)			
Middle Zone	Lower North Fork	0.06	Deepwater Blind	0.12
	Deepwater Blind	0.08	North Fork Blind	0.13
	Upper Steamboat	0.08	Lower North Fork	0.15
	Upper Freshwater	0.08	Upper Freshwater	0.20
	North Fork Blind	0.11	Upper Steamboat	0.21
		avg = 0.08		avg =0 .16
	(Average sensitivity ratio of non tide to tide is 2:1)			
Upper Zone	Upper South Fork	0.19	Upper South Fork	0.24
	Upper North Fork	0.21	Upper North Fork	0.26
		avg = 0.20		avg =0 .25
	(Average sensitivity ratio of non tide to tide is 1.25:1)			

Upper Zone: Channel elevations and channel bank profiles are highest in this zone. Average bankfull WSE is approximately 18 to 22 feet above MLLW. Channels in this zone are main channels. These three factors (higher channel elevations, higher channel bank profile and flow confinement, and higher channel order) make this zone most sensitive to changes in discharge. Highest channel elevations relative to MLLW make this zone least sensitive to tidal effects.

3.6.2 Non-tidal Period Habitat Analysis

Based on studies and observations by SSC and others (Congleton 1978) salmonids prefer a certain depth of water in estuary channels for refuge during a non-tidal condition. Based on these studies and observations, the Committee established a minimum thalweg depth criteria of 1 foot in study channels to protect salmonid refuge habitat during a non-tidal period. Using the non-tidal regressions and channel profiles, a matrices was developed of all study sites that showed the river discharge at which thalweg depth during a non-tidal period would fall below one foot (Table 3.6-2). This matrices was later used by the Committee in evaluating the effects of incremental changes in river discharge on salmonid refuge habitat.

3.6.3 Tidal Period Habitat Analysis

The primary goal of the Committee in analyzing the tidal period was to determine the effect of alternative instream flows on the magnitude, duration, and frequency of inundation of over-bank habitats.

The tidal period habitat analysis was limited to two study channels in the middle zone. The two study channels analyzed were Deepwater Blind Slough and North Fork Blind Slough. The analysis excluded the upper and lower zones for the following reasons.

> **Lower Zone:** As is shown in Table 3.6-1, WSE sensitivity to discharge in the lower zone is low during the tidal period. Tide is the dominant factor controlling WSE in this zone. This is true for magnitude, frequency, and duration of inundation. For example, the analysis indicated that a 10,000 cfs change in discharge causes a 0.1 foot change in WSE and less than a 1.5 % shift in the frequency of inundation.
>
> **Upper Zone:** As is shown in Table 3.6-1 discharge is the dominant factor controlling WSE in the upper zone. Morphologically, mainstem channels of the upper South Fork and North Fork are more similar to the mainstem Skagit river than they are to the estuary proper. For these reasons the Committee chose to evaluate this zone based on the habitat/discharge relationship of the mainstem IFIM.

Of the five study sites in middle zone, only Deepwater Blind Slough and North Fork Blind Slough have channel configurations that provide over-bank habitat that is diurnally flooded by a combination of river discharge and tide. The other three sites are main channels with high banks that are not overtopped on a diurnal frequency and therefore would not provide over-bank salmonid rearing habitat.

3.6.4 Tidal Period Habitat Analysis Criteria

Based on research done by Congleton (1978) the Committee elected to use a depth criteria of one foot over-bank inundation as the minimum criteria to evaluate the effects of discharge on salmonid rearing habitat. Tidal period habitat analyses would be limited to flows above 10,000 cfs and to February through August, the primary period of estuary rearing for salmonids.

Table 3.6-2 Matrices showing the flow at which thalweg depth equals or exceeds 1 foot in selected Skagit River estuary channels.

	5,000	7,500	10,000	12,500	15,000	17,500	20,000	22,500	25,000	27,500	30,000	32,500	35,000	37,500	40,000
Crooked Slough Blind - 1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Crooked Slough Blind - 2				x	x	x	x	x	x	x	x	x	x	x	x
Upper Boom Slough	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cattail Slough	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cattail Blind	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Freshwater Pond - 1								x	x	x	x	x	x	x	x
Freshwater Pond - 2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lower Freshwater	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lower Brandstedt - 1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lower Brandstedt - 2		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lower North Fork	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Deepwater Blind - 1		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Deepwater Blind - 2		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Upper Steamboat	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Tom Moore Slough	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Upper Freshwater	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
North Fork Blind				x	x	x	x	x	x	x	x	x	x	x	x
Upper South Fork	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Upper North Fork	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Total	13	16	16	18	18	18	18	19	19	19	19	19	19	19	19
% of total	68%	84%	84%	95%	95%	95%	95%	100%	100%	100%	100%	100%	100%	100%	100%

The 10,000 cfs floor was based on the Committee's decision that habitat/discharge analyses and flow recommendations below 10,000 cfs would be derived from the riverine IFIM results.

3.6.5 Analysis of Duration of Inundation

The WSE level required to inundate over-bank habitat to a depth of one foot was plotted on the regression/cross sectional profiles for the three transects at the two study sites (Figures 3.6-1, 3.6-2, and 3.6-3). Based on these plots, matrices of river discharge versus time duration that the one foot criteria is equaled or exceeded were developed for each transect for each month from February through August. An example matrix for one transect for one month is presented in Figure 3.6-4. Note that the example is only the upper left corner of the matrix and is only a portion of the entire matrix.

The matrix is read as follows.

Step 1: Refer to the "Initial Flow" column on the left side of Figure 3.6-4 and pick a flow. For this example pick 22,000 cfs.

Step 2: At 22,000 cfs at least an 8.9 foot tide is required to cause the WSE to equal or exceed the criteria of 1 foot above bankfull (Figure 3.6-3). During March an 8.9 foot tide is equaled or exceeded 34.7% of the time (tide exceedence curve Figure 3.3-3). The percent exceedence of the corresponding tide is shown in the adjacent column on the left titled "Corresponding Tide Exceedence".

Step 3: To determine the loss in percent time that the 1 foot criteria is equaled or exceeded follow the 22,000 cfs shaded row to the right to the flow column of interest. For example, reducing the river discharge by 500 cfs (from 22,000 to 21,500 cfs) in March results in 2.9% loss in the duration that the one foot above bankfull criteria are equaled or exceeded.

3.6.6 *Analysis of Frequency of Inundation*

The regression/cross sectional profiles in Figures 3.6-1, 3.6-2, and 3.6-3 were also used in this frequency analysis. Based on these plots, matrices of flow versus the frequency that the one foot criteria is equaled or exceeded were then developed for each transect for each month from February through August. An example matrix for one transect for one month is presented in Figure 3.6-5.

The matrix is read as follows.

Step 1: Refer to the "Initial Flow" column on the left side of Figure 3.6-5 and pick a flow. For this example pick 22,000 cfs.

Step 2: At 22,000 cfs at least an 8.9 foot tide is required to cause the WSE to equal or exceed the criteria of 1 foot above bankfull (refer to Figure 3.6-3). According to the Crescent Harbor tide duration curve (Figure 3.3-6) an 8.9 foot tide is equaled or exceeded 60 times during March

Step 3: Determine the effect of a change in discharge on the frequency that the 1 foot criteria is equaled or exceeded. In this example follow the 22,000 cfs shaded row to the right to the flow column of interest. For example, reducing the river discharge by 2,000 cfs (from 22,000 to 20,000 cfs) in March results in a 6.7% loss (60 events versus 56 events) in frequency that WSE will equal or exceed 1 foot inundation criteria. The explanation is that at 20,000 cfs a 9.5 foot tide is required to equal or exceed 1 foot criteria. A 9.5 foot tide is equaled or exceeded 56 times in March. Thus the frequency is reduced from 60 times per month at 22,000 cfs to 56 times per month at 20,000 cfs, a 6.7% reduction.

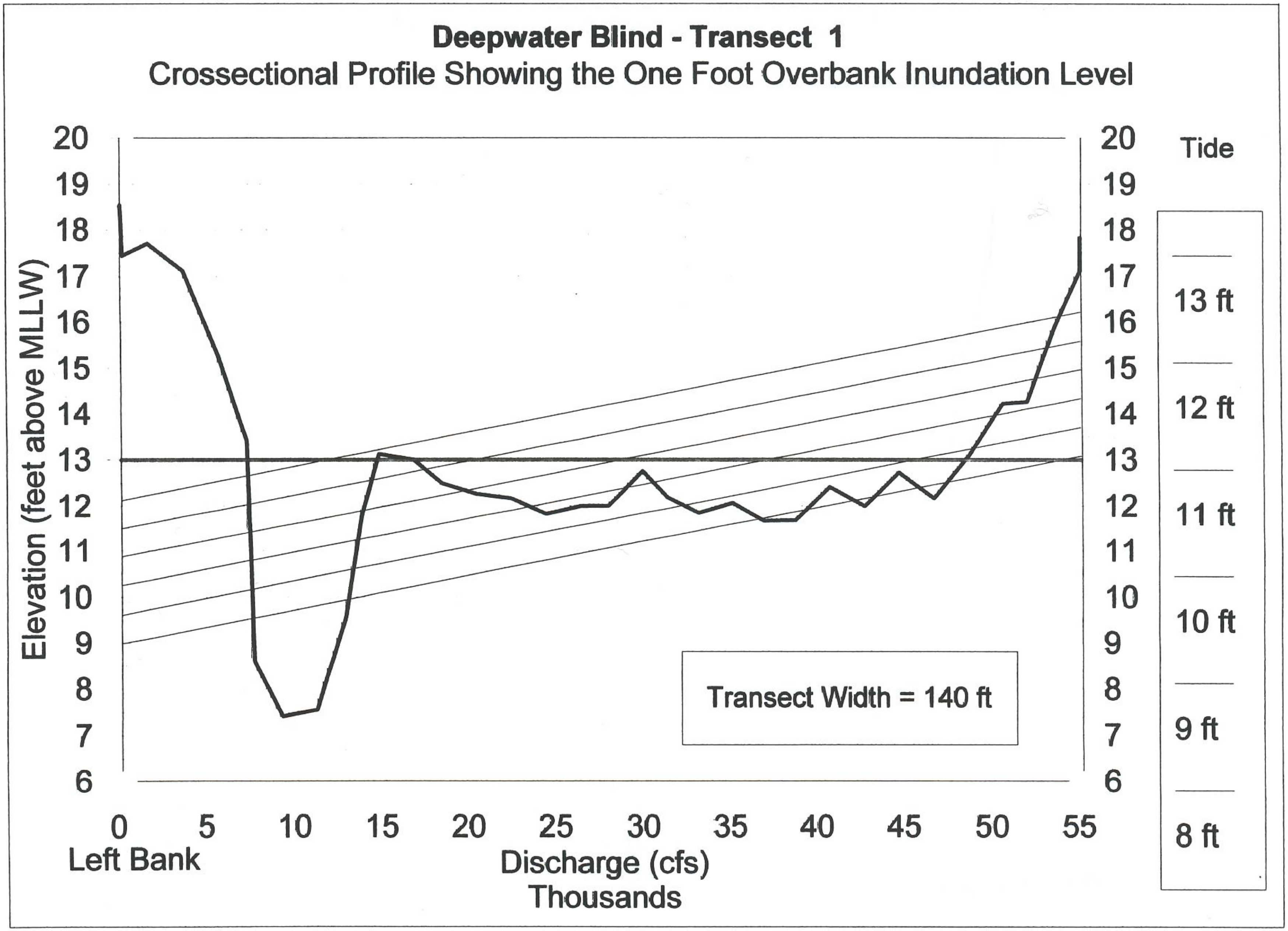
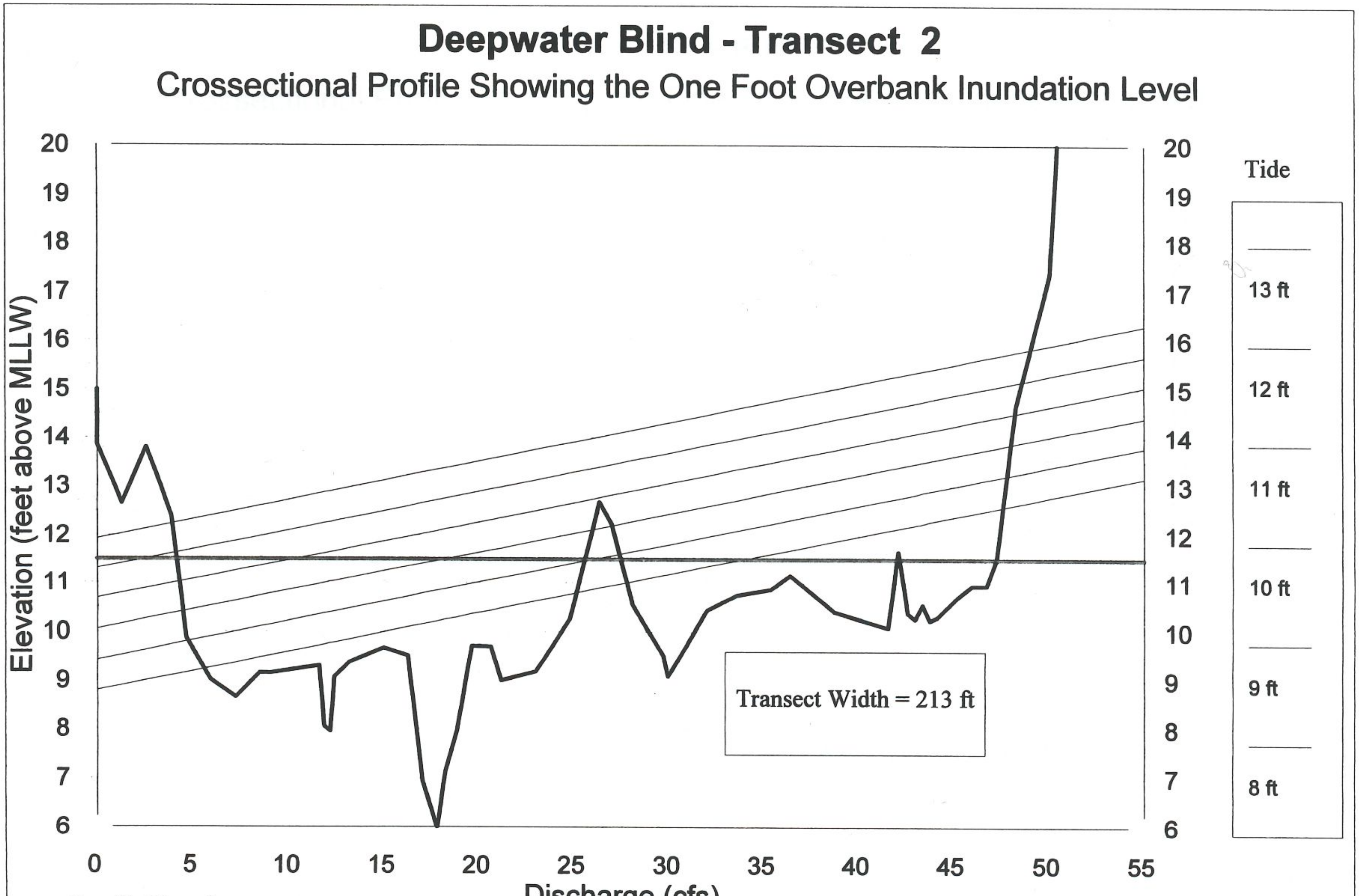

Deepwater Blind - Transect 1
Crossectional Profile Showing the One Foot Overbank Inundation Level
Elevation (feet above MLLW)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
0
5
10
15
20
25
30
35
40
45
50
55
Left Bank
Discharge (cfs)
Thousands
Transect Width = 140 ft
Tide
13 ft
12 ft
11 ft
10 ft
9 ft
8 ft

Figure 3.6-1


Deepwater Blind - Transect 2
Crossectional Profile Showing the One Foot Overbank Inundation Level
Elevation (feet above MLLW)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
0
5
10
15
20
25
30
35
40
45
50
55
Discharge (cfs)
Thousands
Left Bank
Transect Width = 213 ft
Tide
13 ft
12 ft
11 ft
10 ft
9 ft
8 ft
Figure 3.6-2

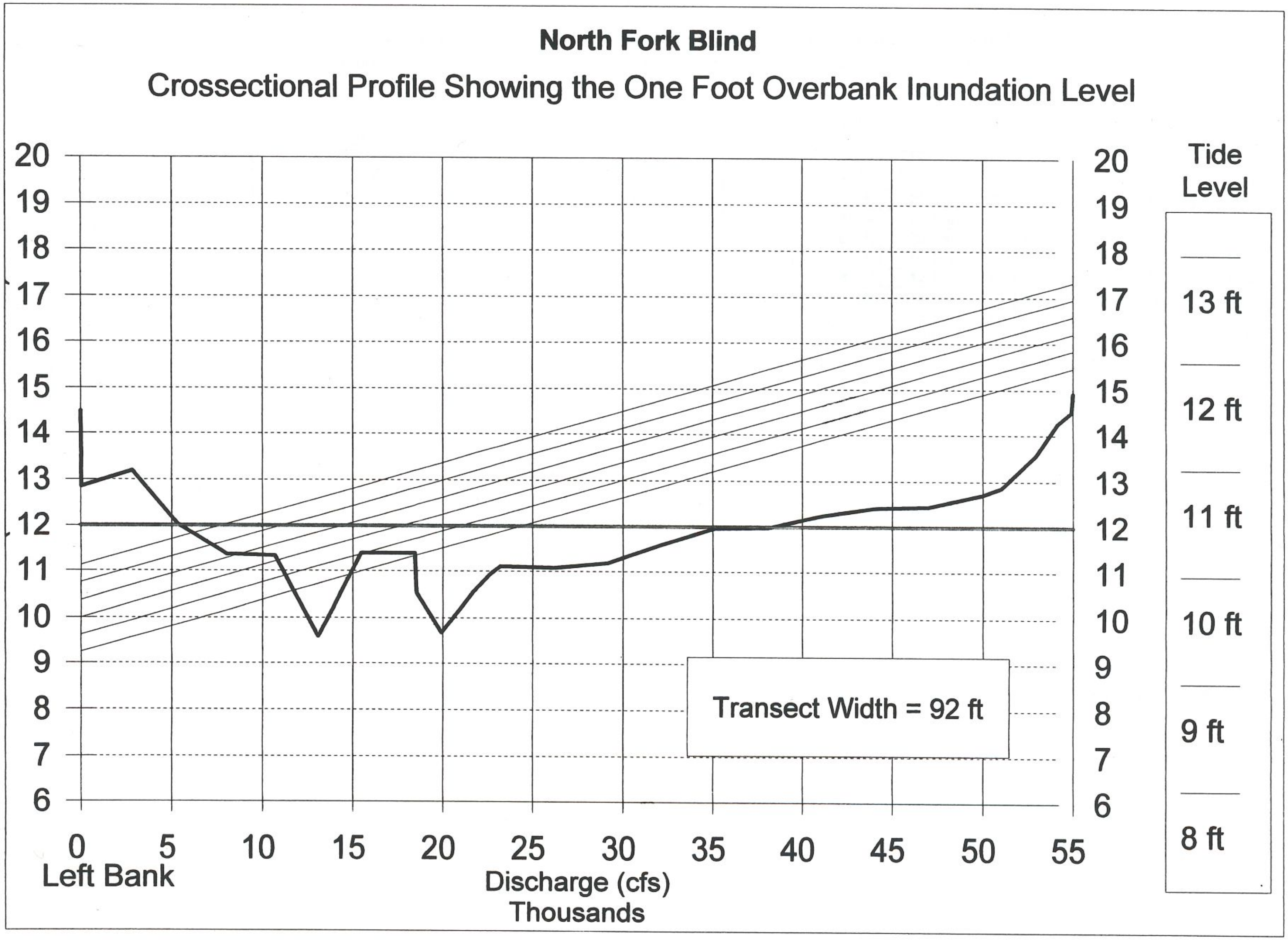

North Fork Blind
Crossectional Profile Showing the One Foot Overbank Inundation Level
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
0
5
10
15
20
25
30
35
40
45
50
55
Left Bank
Discharge (cfs)
Thousands
Transect Width = 92 ft
Tide Level
13 ft
12 ft
11 ft
10 ft
9 ft
8 ft

Figure 3.6-3

NORTH FORK BLIND - MARCH

Effect of Flow Reduction on the Percent Time that WSE Exceeds One Foot Above Bankfull

(values represent the amount of reduction in percent time that WSE exceeds one foot above bankfull)

Corresponding Tidal Exceedance	Initial Flow (cfs)	43.9% 25,000	42.0% 24,500	40.7% 24,000	39.0% 23,500	37.9% 23,000	35.8% 22,500	34.7% 22,000	33.7% 21,500	31.9% 21,000	30.0% 20,500	27.5% 20,000	25.2% 19,500	23.9% 19,000	22.5% 18,500	21.1% 18,000
43.9%	25,000	0.0%	4.3%	7.3%	11.2%	13.7%	18.5%	21.0%	23.2%	27.4%	31.7%	37.4%	42.6%	45.6%	48.7%	51.9%
42.0%	24,500		0.0%	3.1%	7.1%	9.8%	14.8%	17.4%	19.8%	24.2%	28.6%	34.5%	40.0%	43.1%	46.4%	49.8%
40.7%	24,000			0.0%	4.2%	6.9%	12.0%	14.7%	17.2%	21.7%	26.3%	32.4%	38.1%	41.3%	44.7%	48.2%
39.0%	23,500				0.0%	2.8%	8.2%	11.0%	13.6%	18.3%	23.1%	29.5%	35.4%	38.7%	42.3%	45.9%
37.9%	23,000					0.0%	5.5%	8.4%	11.1%	16.0%	20.8%	27.4%	33.5%	36.9%	40.6%	44.3%
35.8%	22,500						0.0%	3.1%	5.9%	11.0%	16.2%	23.2%	29.6%	33.2%	37.2%	41.1%
34.7%	**22,000**							**0.0%**	**2.9%**	**8.2%**	**13.5%**	**20.7%**	**27.4%**	**31.1%**	**35.2%**	**39.2%**
33.7%	21,500								0.0%	5.5%	11.0%	18.4%	25.2%	29.1%	33.2%	37.4%
31.9%	21,000									0.0%	5.8%	13.7%	20.9%	25.0%	29.4%	33.8%
30.0%	20,500										0.0%	8.3%	16.0%	20.3%	25.0%	29.7%
27.5%	20,000											0.0%	8.4%	13.1%	18.2%	23.3%
25.2%	19,500												0.0%	5.2%	10.7%	16.3%
23.9%	19,000													0.0%	5.9%	11.7%
22.5%	18,500														0.0%	6.2%
21.1%	18,000															0.0%

Figure 3.6-4

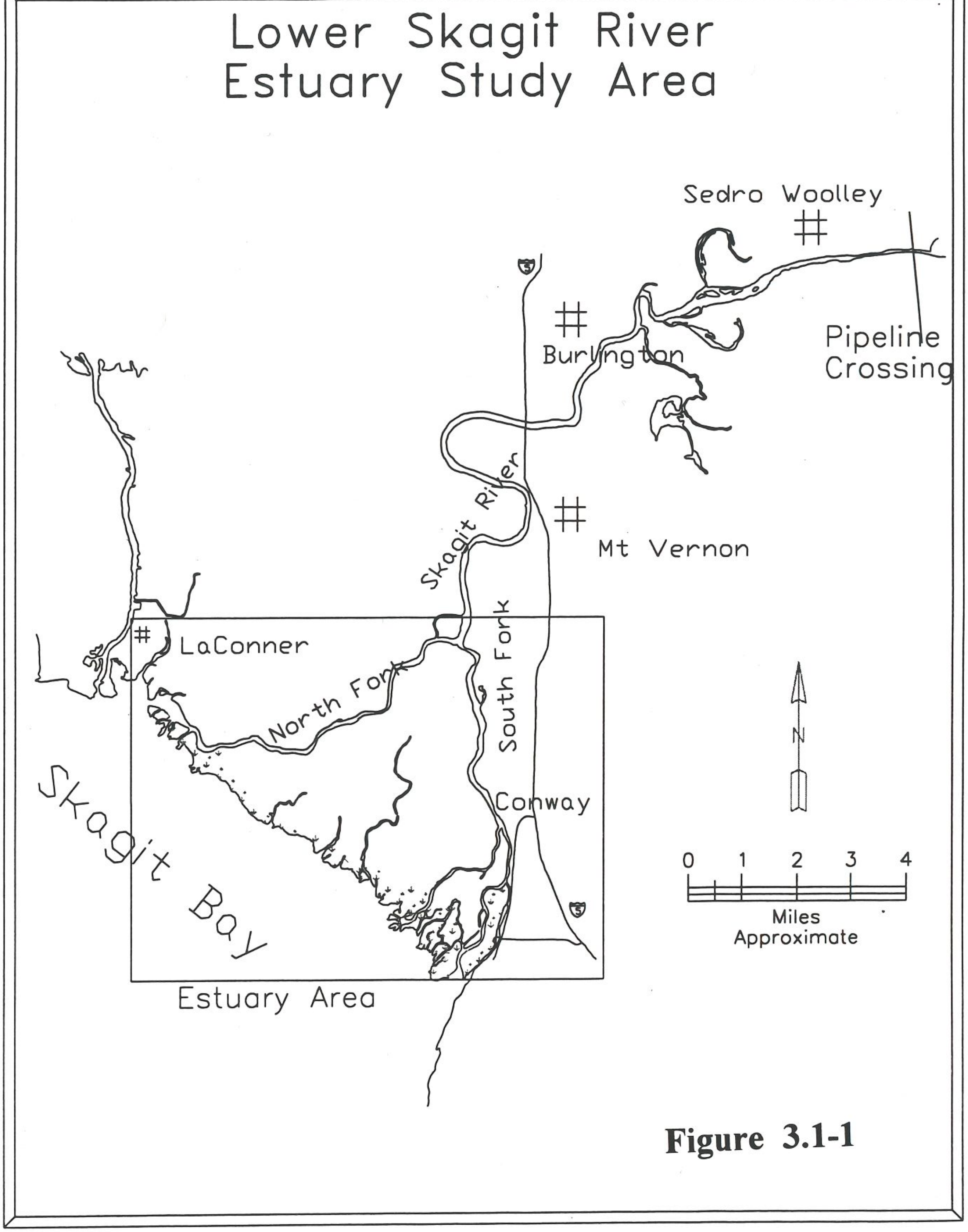
NORTH FORK BLIND - MARCH

Effect of Flow Reduction on the Frequency (in percent) that WSE Equals Exceeds One Foot Above Bankfull

(values represent the amount of reduction in percent time that WSE exceeds one foot above bankfull)

			Analysis Flow (cfs)											
Tide Height	Exceedance Frequency	Initial Flow (cfs)	60 25,000	60 24,000	60 23,000	60 22,000	60 21,000	56 20,000	55 19,000	51 18,000	43 17,000	36 16,000	27 15,000	18 14,000
8.0	60	25,000	0.0%	0.0%	0.0%	0.0%	0.0%	6.7%	8.3%	15.0%	28.3%	40.0%	55.0%	70.0%
8.3	60	24,000		0.0%	0.0%	0.0%	0.0%	6.7%	8.3%	15.0%	28.3%	40.0%	55.0%	70.0%
8.6	60	23,000			0.0%	0.0%	0.0%	6.7%	8.3%	15.0%	28.3%	40.0%	55.0%	70.0%
8.9	**60**	**22,000**				**0.0%**	**0.0%**	**6.7%**	**8.3%**	**15.0%**	**28.3%**	**40.0%**	**55.0%**	**70.0%**
9.0	60	21,000					0.0%	6.7%	8.3%	15.0%	28.3%	40.0%	55.0%	70.0%
9.5	56	20,000						0.0%	1.8%	8.9%	23.2%	35.7%	51.8%	67.9%
9.8	55	19,000							0.0%	7.3%	21.8%	34.5%	50.9%	67.3%
10.0	51	18,000								0.0%	15.7%	29.4%	47.1%	64.7%
10.5	43	17,000									0.0%	16.3%	37.2%	58.1%
10.7	36	16,000										0.0%	25.0%	50.0%
11.0	27	15,000											0.0%	33.3%
11.3	18	14,000												0.0%

Figure 3.6-5



Lower Skagit River
Estuary Study Area
Sedro Woolley
Burlington
Pipeline
Crossing
Skagit River
Mt Vernon
LaConner
North Fork
South Fork
Conway
Skagit Bay
Estuary Area
N
0 1 2 3 4
Miles
Approximate

Figure 3.1-1

3.6.7 Aggregation of Inundation Results

3.6.7.1 Duration of Inundation

The Committee elected to average the duration data for the three transects and seven months. The Committee believed that averaging was reasonable for the following reasons:

Averaging Effects Over the Range of Flows: Averaging the effect (percent reduction in duration of inundation) for the entire range of flows from 10,000 to 25,000 cfs was deemed reasonable for two reasons. The first is that discrete differences (between any two compared flows) can be somewhat peculiar to the nuances of the tide duration. For example, the affect of a 500 cfs difference between 15,000 and 14,500 cfs can be abnormally greater than the difference between 14,500 and 14,000 cfs. Averaging smooths out these apparent anomalies. The second reason is that flow recommendations will be set for the entire range of flows. Focusing on a single increment of change and letting that drive the evaluation for the full range of flows was deemed too narrow an analysis by the Committee.

Averaging Effects Over Analysis Period: Because the Committee would prefer that a recommended flow be somewhat constant and not change from month to month, a decision was made to average the effects of flow alterations over the seven month analysis period.

Averaging Effects Over the Three Transects: The Committee established that any one transect was no more important or critical than another. Therefore the Committee decided to average the effects of flow alterations over the three transects.

Effects of alternative instream flows on duration of inundation were first evaluated in increments of 500 cfs, 1,000 cfs, and 1,500 cfs. Table 3.6-3 shows the effect of flow change on duration of inundation for individual sites in 500 cfs increments. Finer increments than 500 cfs were necessary for instream flow setting and were obtained through interpolation. This step is described in the discussion section 5.0.

Table 3.6-3. Effect of flow change on percent reduction in time that 1 foot criteria is equaled or exceeded. Effects averaged over the range of flows from 10,000 to 25,000 cfs.

Site	500 cfs	1000 cfs	1500 cfs
Deepwater Blind T-1	7.0%	12.1%	16.9%
Deepwater Blind T-2	3.5%	6.9%	10.4%
North Fork Blind	8.6%	16.3%	23.0%
Combined (Avg)	6.4%	11.8%	16.8%

3.6.7.2 Frequency of Inundation

After thorough review and consideration of the inundation frequency data, the Committee elected to focus its analysis on duration of inundation as the key indicator for estuary habitat protection. The two key reasons were: a) focusing on duration would preserve the amount of time that over-bank habitat is made available and would inherently preserve the natural frequency based on the tide cycle; and 2) peculiarities in combining discharge, WSE and tide frequencies made the Committee less comfortable with the reliability of the frequency analysis over the duration analysis.

4.0 HYDROLOGY

4.1 Seasonal Flow Patterns

Streamflows in the Skagit River originate from direct runoff from rainfall, meltwater stored in snowpack or glaciers, and groundwater. The proportion that each of these sources contributes to the total stream flow varies depending on the time of year and short term weather patterns. Low streamflows in late summer and early fall are due to a long period of low precipitation and decreased glacial and snow melt at higher elevations. Streamflow increases into mid fall and early winter due to the onset of moisture laden Pacific storms. Streamflow decreases during winter and early spring as most precipitation falls as snow and freezing temperatures prevent snowmelt. Streamflow increases in mid to late spring as most precipitation falls as rain and warmer temperatures cause snowmelt at higher elevations. The large volume of water stored in snowpack and glaciers maintains a relatively high base flow through July.

Daily and seasonal streamflow patterns in the Skagit River are moderately modified by water storage and releases from two hydroelectric projects in the head waters of the basin. Daily fluctuations in streamflow due to hydroelectric project operations occur frequently but the magnitude of the flow changes in the lower Skagit River are limited by two factors. First, nearly two thirds of the watershed upstream of the study area is unregulated by reservoirs. Second, the hydroelectric projects have physical and regulatory limits within which they can alter streamflow. Seasonal streamflow is primarily modified by reservoir storage of a portion of the snow melt during the spring and release of this additional water in the late summer and fall.

A US Geologic Survey (USGS) gaging station (No. 12200500), Skagit River at Mt. Vernon, is located at RM 15.8. The drainage area for this station is 3,093 square miles. Mean monthly mean flows range from 9,559 cfs in September to 25,493 cfs in June. The long term mean annual flow is 16,708 cfs. Mean monthly flows are presented in Figure 4.1-1.

4.2 Flow Duration Analysis

Although mean monthly flows show the average long term seasonal trends much important hydrologic information is not apparent. Flow duration curves, computed from records of daily discharge, show a much broader and indepth spectrum of flow characteristics of the Skagit River.

Flow duration analysis shows the persistency of normal flows as well as the timing, magnitude and frequency of more extreme flow events. Many fish species as well as other aquatic resources are adapted to and depend on the timing and duration of seasonal hydrologic events for critical parts of their life cycle. For example, persistent high spring flows from snowmelt runoff help to carry salmonid fry and smolts quickly to sea, thereby reducing mortality by predators.

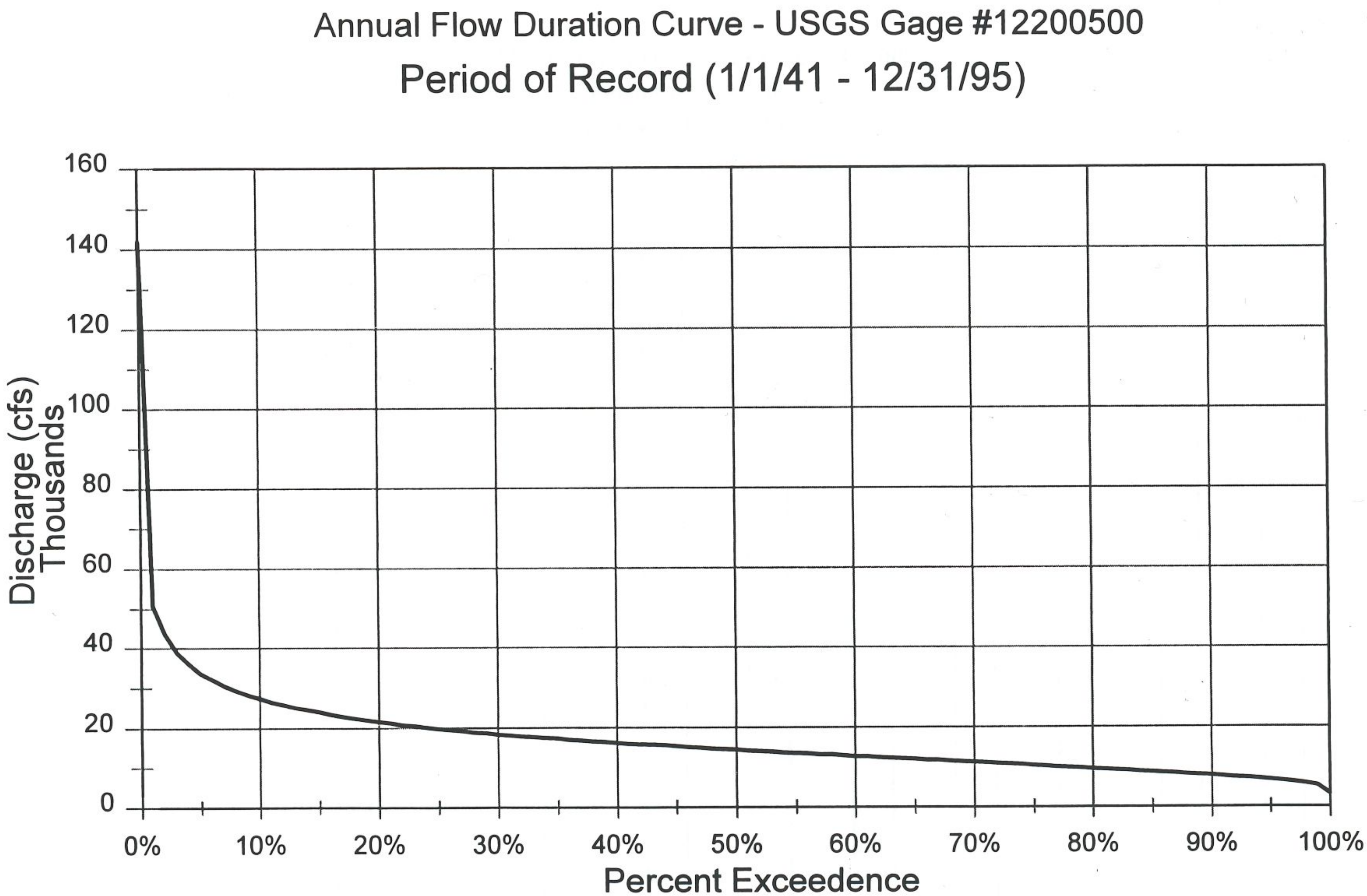


Figure 4.2-2 Lower Skagit Flow Duration Curves - Annual

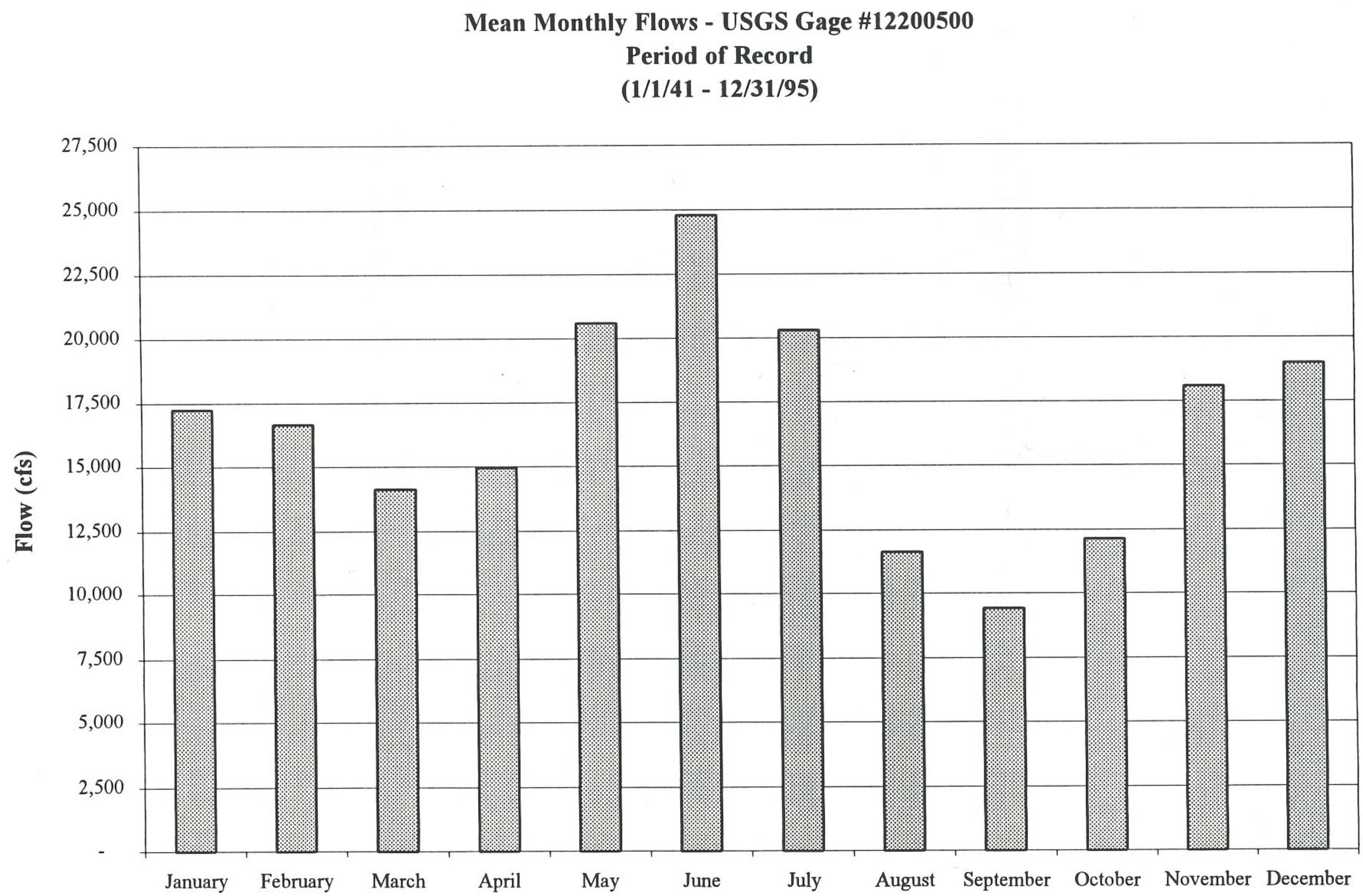

Mean Monthly Flows - USGS Gage #12200500
Period of Record
(1/1/41 - 12/31/95)
Flow (cfs)
27,500
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500
-
January
February
March
April
May
June
July
August
September
October
November
December

Figure 4.1-1

Annual and monthly flow duration curves were computed for the period of record from January 1941 through December 1995. The computations were based on daily flows as reported by the USGS for the gaging station at the Skagit River near Mt. Vernon. Figure 4.2-1 shows the annual flow duration curve while Figure 4.2-2 shows monthly flow duration curves for the period of record. The annual and monthly data is presented in Table 4.2-1.

Comparisons of the normal runoff pattern for are easily seen from the monthly flow duration figures. In June during the spring snowmelt stream flow is always above 10,000 cfs while in September streamflow is above 10,000 cfs on only 30% of the days.

Table 4.2-1 Annual and Mean Monthly Flow Duration Curves

Percent Exceedence	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0%	142000	81300	138000	50500	82300	74200	71400	73900	38100	37500	88000	142000	123000
1%	50800	49600	48800	32700	30700	48600	54600	47800	27200	24300	45600	77200	61000
2%	43600	42200	42000	28200	26900	42700	51900	44500	24800	20600	36500	57300	53400
3%	38900	38900	37500	25700	25200	39000	49400	41400	23000	19000	32400	50900	47600
4%	36100	36100	34500	24400	24400	37200	46300	39700	20700	17500	29000	48200	43800
5%	33700	33800	33000	23600	23700	35700	44400	37800	19800	16500	26400	44500	41000
6%	32100	31900	30900	22400	23000	34400	42300	36400	19100	15900	25300	40600	38900
7%	30600	30300	29600	21800	22600	33200	40100	35300	18800	15400	23500	36500	37100
8%	29300	28800	28400	21300	22100	32400	39200	34200	18200	15000	22500	33900	34300
9%	28300	27800	27100	21000	21600	31400	37800	33400	17500	14500	21800	32300	32100
10%	27400	27000	26000	20500	21200	30700	37100	32300	17300	14100	21100	30800	30500
11%	26500	26200	25100	20100	20800	30100	36400	31800	16800	13500	20400	29100	29200
12%	25900	25600	24200	19600	20400	29600	35800	31100	16600	13200	19500	28100	28400
13%	25200	25000	23600	19300	20100	28900	34900	30300	16100	12900	19100	27100	27500
14%	24600	24400	22800	19100	19900	28500	34200	29700	15800	12700	18300	26100	26800
15%	24100	23800	22100	18800	19600	28000	33800	29100	15600	12500	17800	25600	26400
16%	23500	23200	21700	18500	19300	27700	33000	28500	15400	12300	17400	24800	25900
17%	23000	22600	21400	18100	19100	27400	32500	28000	15100	12100	17200	24100	25200
18%	22500	22100	21100	17900	18800	26800	32000	27400	14900	11900	16800	23300	24700
19%	22100	21800	20700	17600	18700	26400	31600	26900	14700	11600	16500	23000	24200
20%	21700	21300	20400	17400	18400	26100	31200	26500	14500	11300	16100	22600	23700
21%	21300	21100	20100	17200	18200	25800	30600	26200	14300	11100	15800	22000	23200
22%	20900	20700	19800	16900	18000	25500	30200	25900	14000	11000	15400	21400	22800
23%	20600	20500	19600	16700	17900	25200	29900	25600	13900	10900	15000	21000	22400
24%	20200	20100	19300	16600	17700	24800	29400	25200	13700	10700	14800	20600	22100
25%	19900	19800	19000	16400	17500	24500	29000	24900	13500	10600	14400	20200	21800
26%	19600	19600	18900	16300	17400	24100	28700	24500	13400	10500	14200	19900	21500
27%	19300	19300	18700	16200	17300	23900	28400	24100	13200	10300	14000	19700	21200
28%	19000	19100	18500	16100	17100	23600	28100	23800	13100	10100	13700	19400	20800
29%	18800	18900	18300	15900	16900	23400	27900	23500	12900	10000	13500	19100	20600

Table 4.2-1 Annual and Mean Monthly Flow Duration Curves

Percent Exceedence	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
30%	18500	18600	18100	15800	16800	23100	27500	23100	12700	9860	13300	18800	20200
31%	18200	18400	18000	15600	16700	22900	27200	22900	12600	9760	13100	18600	20000
32%	18000	18200	17800	15400	16500	22600	26800	22500	12400	9680	12800	18200	19700
33%	17800	18100	17600	15300	16300	22400	26500	22100	12300	9600	12600	17900	19400
34%	17600	17900	17500	15200	16200	22200	26300	21900	12200	9550	12400	17500	19000
35%	17400	17800	17400	15100	16100	22100	26000	21600	12000	9470	12300	17200	18700
36%	17100	17600	17100	14900	16000	21900	25800	21300	11900	9380	12100	17000	18500
37%	16900	17500	17000	14800	15800	21700	25600	20900	11800	9280	11900	16800	18300
38%	16700	17200	16800	14700	15700	21400	25300	20600	11800	9180	11800	16600	18100
39%	16500	17100	16600	14600	15600	21100	25000	20400	11600	9140	11500	16400	18000
40%	16300	16900	16300	14400	15400	20900	24800	20100	11500	9040	11400	16100	17800
41%	16100	16800	16100	14300	15300	20700	24700	19900	11400	8980	11300	16000	17600
42%	15900	16600	15900	14200	15100	20500	24500	19600	11300	8910	11100	15800	17500
43%	15800	16500	15800	14100	15000	20300	24200	19400	11200	8830	11000	15600	17300
44%	15600	16400	15600	14000	14900	20100	24000	19200	11100	8760	10900	15500	17000
45%	15400	16200	15400	13900	14700	19800	23700	19000	11000	8730	10700	15300	16900
46%	15200	16100	15200	13700	14600	19700	23500	18800	10900	8610	10600	15200	16800
47%	15000	16000	15100	13600	14500	19600	23300	18600	10900	8540	10400	15000	16600
48%	14800	15900	15000	13500	14400	19300	23200	18400	10800	8450	10200	14800	16400
49%	14600	15700	14800	13300	14200	19200	22900	18300	10700	8400	10100	14600	16300
50%	14500	15600	14600	13200	14100	19000	22600	18100	10600	8350	9910	14500	16100
51%	14300	15500	14500	13100	14000	18800	22400	17900	10500	8300	9680	14400	15900
52%	14100	15400	14400	13000	13900	18700	22300	17800	10400	8210	9580	14200	15700
53%	14000	15200	14200	12900	13800	18500	22100	17600	10300	8180	9430	14000	15500
54%	13800	15100	14100	12800	13700	18300	22000	17400	10300	8140	9310	13800	15300
55%	13600	14900	14000	12700	13600	18000	21900	17300	10200	8090	9180	13800	15200
56%	13500	14700	13800	12600	13500	17900	21800	17200	10100	8050	9080	13600	15000
57%	13300	14500	13700	12500	13400	17700	21600	17000	10000	8000	8960	13500	14800
58%	13200	14300	13600	12400	13200	17600	21500	16800	9930	7970	8820	13400	14600
59%	13000	14100	13500	12300	13100	17500	21200	16600	9830	7920	8680	13200	14500
60%	12800	14000	13300	12200	13000	17400	20900	16500	9780	7830	8580	13100	14400
61%	12700	13800	13200	12100	12900	17100	20800	16300	9720	7780	8490	13000	14200
62%	12500	13700	13100	12000	12800	16900	20600	16200	9650	7720	8340	12800	14100
63%	12400	13600	13000	12000	12700	16700	20400	16000	9560	7670	8210	12700	14000
64%	12200	13400	12900	11800	12600	16600	20200	15800	9470	7610	8130	12500	13800
65%	12100	13300	12800	11700	12500	16400	20100	15600	9380	7560	8040	12400	13700
66%	11900	13100	12600	11600	12400	16300	19900	15500	9320	7510	7970	12300	13600
67%	11800	13000	12500	11500	12200	16100	19700	15300	9240	7460	7850	12200	13400
68%	11600	12800	12400	11400	12100	16000	19500	15100	9170	7400	7700	12100	13200
69%	11500	12700	12200	11300	12000	15900	19400	15000	9140	7360	7600	12000	13100
70%	11300	12500	12100	11200	11900	15700	19100	14800	9080	7300	7500	11900	13000
71%	11200	12500	11900	11000	11800	15500	18900	14700	8960	7260	7380	11800	12900
72%	11000	12300	11800	10900	11700	15400	18700	14500	8900	7230	7270	11700	12700

Table 4.2-1 Annual and Mean Monthly Flow Duration Curves

Percent Exceedence	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
73%	10800	12200	11800	10800	11600	15200	18600	14300	8800	7180	7170	11500	12500
74%	10700	12100	11600	10600	11500	15000	18300	14100	8760	7130	7100	11200	12400
75%	10500	11900	11500	10400	11400	14900	18100	14000	8630	7080	7010	11000	12300
76%	10300	11800	11200	10300	11300	14800	17900	13800	8550	7020	6970	10900	12200
77%	10100	11600	11100	10200	11200	14600	17800	13600	8490	6940	6880	10700	12000
78%	9960	11500	10900	10100	11000	14500	17600	13400	8380	6900	6780	10500	11900
79%	9790	11300	10800	9990	10900	14300	17500	13300	8340	6810	6680	10400	11700
80%	9630	11200	10700	9910	10800	14100	17300	13100	8250	6780	6590	10100	11600
81%	9470	10900	10500	9810	10600	14000	17100	12900	8180	6710	6520	9910	11500
82%	9310	10700	10400	9730	10500	13800	16900	12700	8110	6630	6460	9720	11300
83%	9160	10500	10300	9650	10400	13600	16700	12500	8000	6570	6300	9570	11200
84%	8970	10400	10000	9510	10300	13400	16400	12300	7900	6500	6190	9380	11000
85%	8800	10200	9840	9430	10200	13100	16200	12100	7770	6400	6100	9190	10900
86%	8600	9820	9690	9290	10200	13000	15900	11900	7680	6310	5990	9040	10600
87%	8390	9600	9570	9160	10000	12800	15800	11700	7600	6230	5900	8760	10400
88%	8220	9380	9380	8980	9930	12600	15300	11500	7520	6180	5780	8520	10200
89%	8070	9120	9240	8890	9780	12400	15000	11400	7430	6080	5730	8350	10000
90%	7870	8960	9050	8760	9690	12300	14800	11200	7340	6000	5610	8160	9730
91%	7670	8850	8870	8510	9530	12000	14500	11000	7200	5880	5470	7800	9510
92%	7460	8760	8760	8320	9350	11800	14400	10700	7040	5800	5330	7580	9340
93%	7240	8500	8380	8000	9220	11700	14000	10400	6920	5680	5240	7330	9020
94%	7010	8350	8180	7850	8960	11500	13800	10000	6820	5530	5110	7140	8630
95%	6800	8110	7900	7640	8760	11200	13500	9730	6700	5410	4860	6850	8340
96%	6530	7820	7660	7390	8470	10800	13200	9460	6540	5320	4800	6620	7960
97%	6180	7570	7360	7010	8250	10500	12600	9250	6300	5140	4470	6180	7600
98%	5760	7170	6830	6820	8020	10200	11900	8830	6020	4990	4260	5860	7140
99%	5250	6820	6320	6250	7790	9550	11600	8040	5660	4600	3860	5470	6220
100%	3050	5500	5160	4970	6630	7730	10200	6540	4700	3860	3050	3700	4920

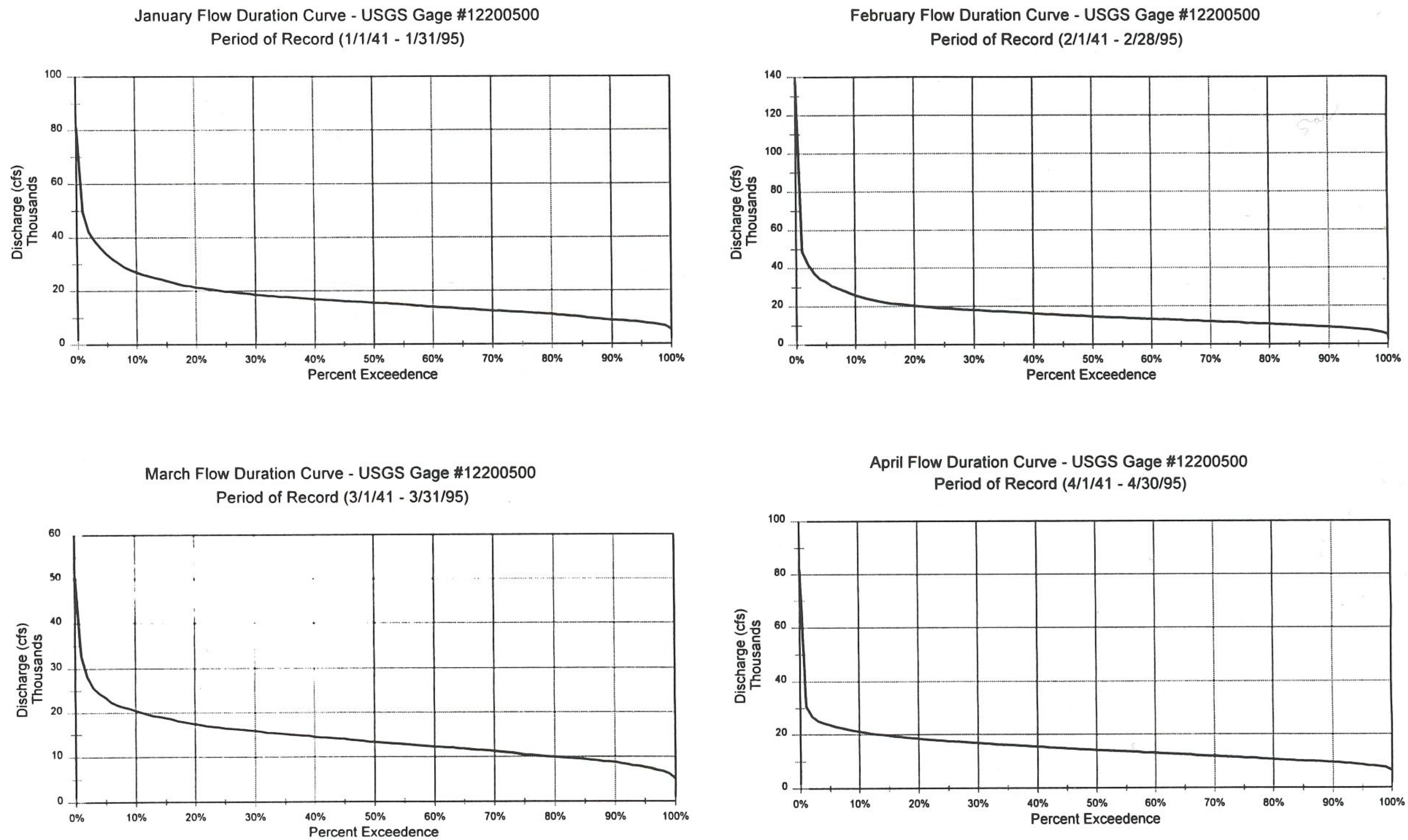
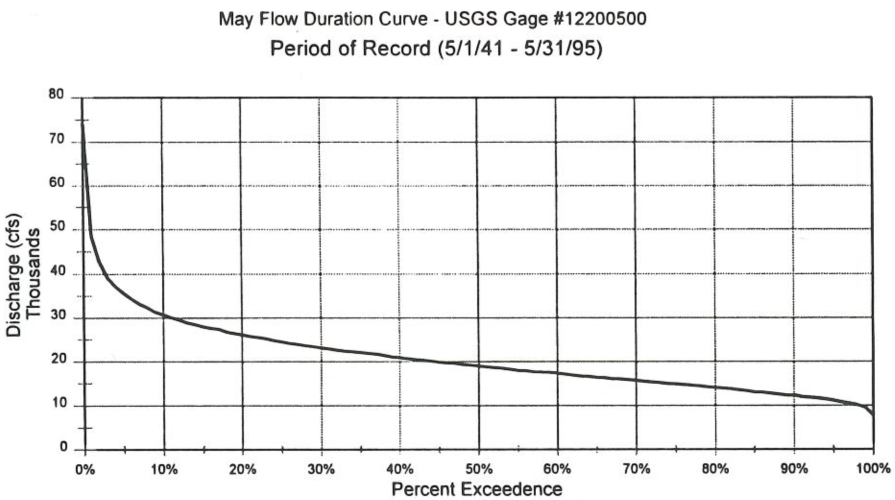
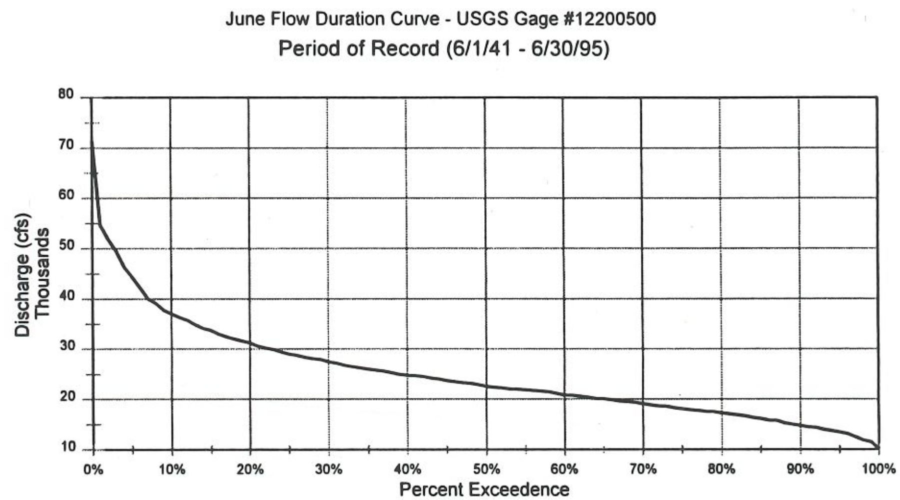
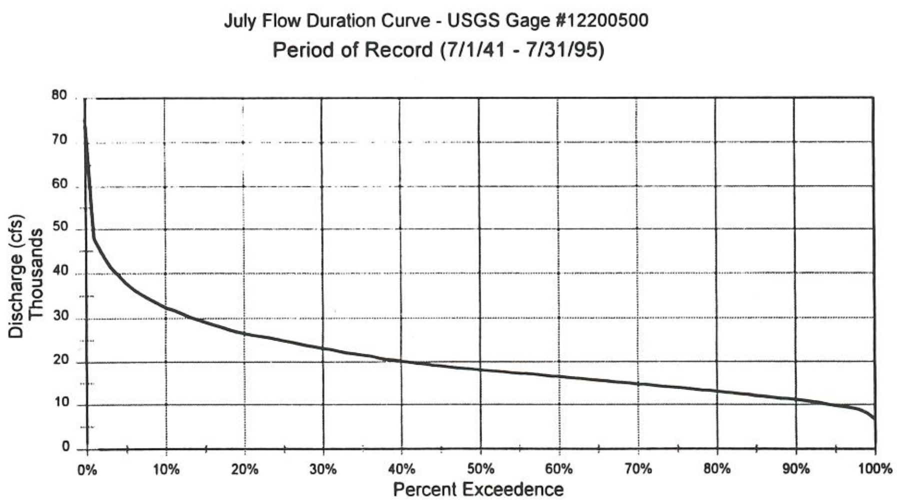


Figure 4.2-1 Lower Skagit Monthly Flow Duration Curves - January Through April







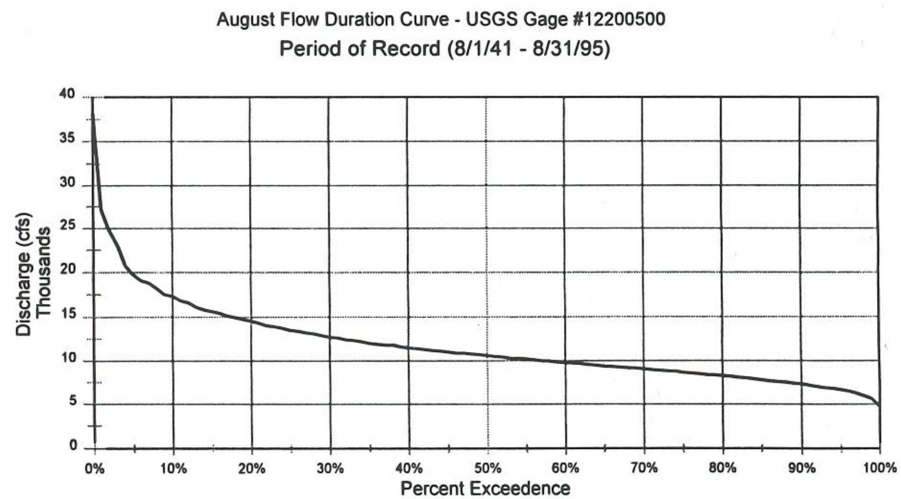
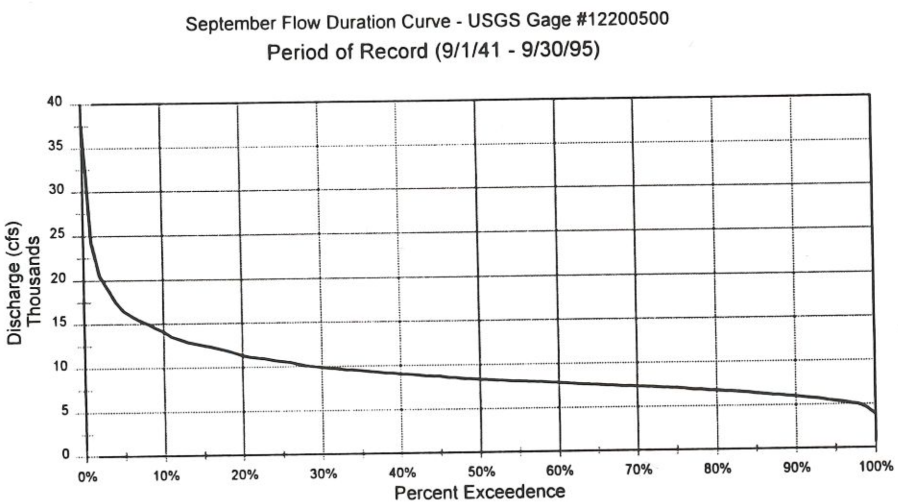
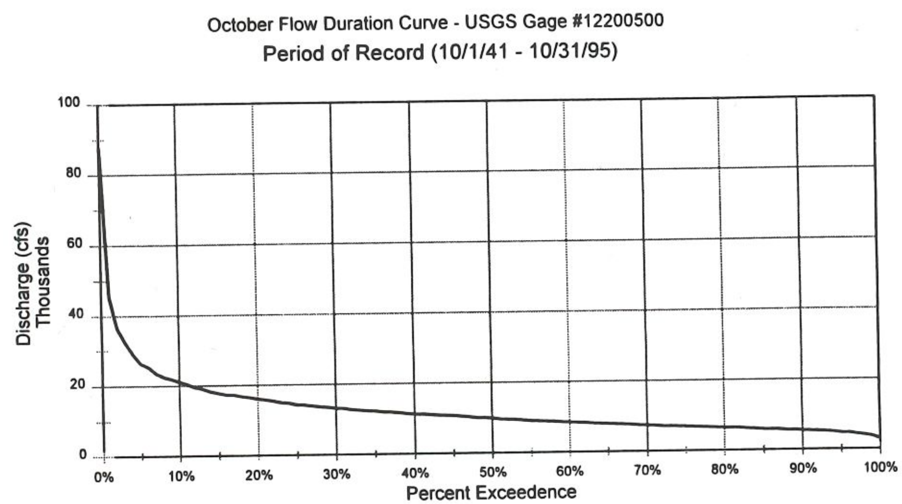
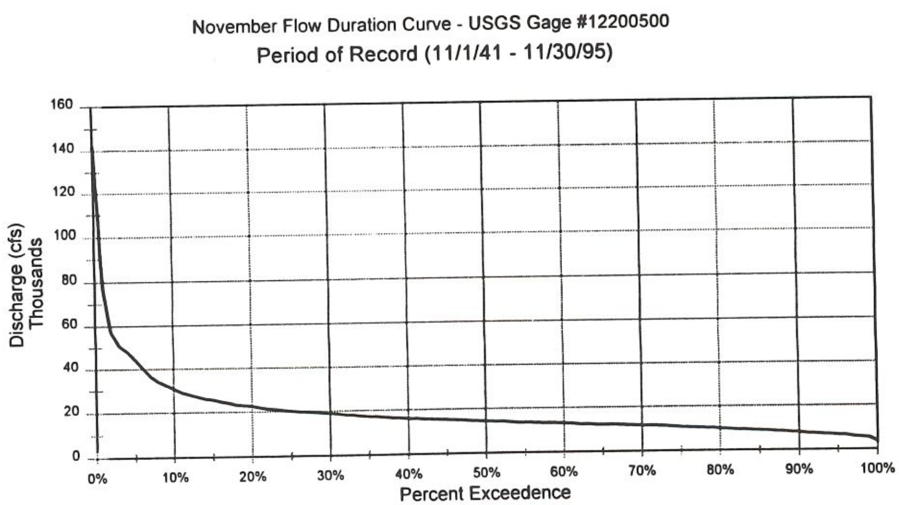


Figure 4.2-1 Lower Skagit Monthly Flow Duration Curves - May Through August







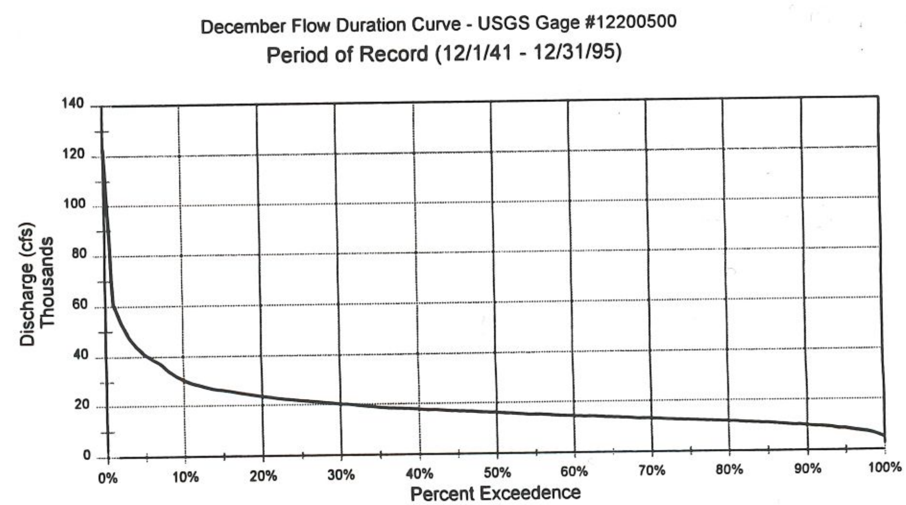


Figure 4.2-1 Lower Skagit Monthly Flow Duration Curves - September Through December

5.0 DISCUSSION AND FLOW RECOMMENDATIONS

This section is organized into three subsections that address separate topics in the overall instream flow issue: the first section uses the results of the Lower Skagit IFIM as the basis for recommended instream flows for the Lower Skagit River; the second and third sections use the results of the estuary studies and the hydrology analysis as the basis for recommending a maximum allowable water allocation from the Lower Skagit River.

5.1 Main River IFIM

The Main River IFIM study produced Weighted Useable Area results (WUA), an index of habitat value, for both the spawning and rearing life stages of several salmonid species. Although WUA values have been presented for several species, the Committee selected to incorporate recommendations primarily on results of the relevant life stages of three target species. The target species and life stages are chinook and steelhead in the rearing life stage and chinook, chum, and steelhead in the spawning lifestage. Using the results from these species should protect other species and aquatic resources of the lower Skagit River.

5.1.1 Rearing Life Stage.

Of the salmonids addressed in this study, four species spend substantial time rearing in the mainstem Skagit River as juveniles or adults. These four species are chinook salmon, steelhead trout, cutthroat trout, and bull trout. Both chinook salmon and steelhead trout are species of concern in the Skagit River basin. Skagit River chinook salmon have recently been listed as threatened under the Endangered Species Act (March 16, 1999). Skagit River steelhead are an extremely important fish to both tribal and sport fishers. Populations of both species have declined in the last 20 years.

5.1.1.1 Life History Considerations

Juveniles of both chinook salmon and steelhead trout rear in the mainstem Skagit throughout the year (see Figure 2.1-2, *Periodicity*). Cutthroat trout and bull trout both use tributaries as well as the mainstem Skagit for rearing during juvenile and adult life stages. Cutthroat trout and bull trout frequency is naturally less abundant in the mainstem Skagit than most other salmonid species.

Chum and pink salmon fry begin downstream migration soon after emerging from the gravel. Both species use the mainstem Skagit primarily as an outmigration corridor. Although both species feed during this outmigration, any rearing is considered to be transitory and brief at any location.

During the juvenile rearing life stage, coho salmon show a strong affinity for instream cover and low water velocity. This factor generally produces more coho salmon rearing area in smaller tributaries and off channel sloughs than in the mainstem Skagit (Pete Castle, WDFW, personal communication).

5.1.1.2 Rearing WUA Results

Figure 5.1-1 shows the Weighted Usable Area (WUA) and discharge relationship for the rearing life stage of all species of salmon and trout in the Lower Skagit River. Selecting the flow with the maximum habitat for one species can significantly reduce the amount of habitat available for another species. For example, the maximum habitat for rearing chinook (24,909 sq. ft./1,000 linear ft. of stream) occurs at a flow of 7,500 cfs (Table 5.1.1). The corresponding habitat area for steelhead rearing at 7,500 cfs is 19,571 sq. ft. which is 76% of the maximum steelhead rearing habitat of 27,211 sq. ft. that occurs at a flow of 26,000 cfs. Consequently, instream flows must be carefully shaped to consider all target species in a system.

Under flow conditions that occur more than 80% of the time in the Lower Skagit River (over 9600 cfs), changes in river discharge do not dramatically effect cutthroat trout or coho salmon rearing habitat (Figure 5.1-2).

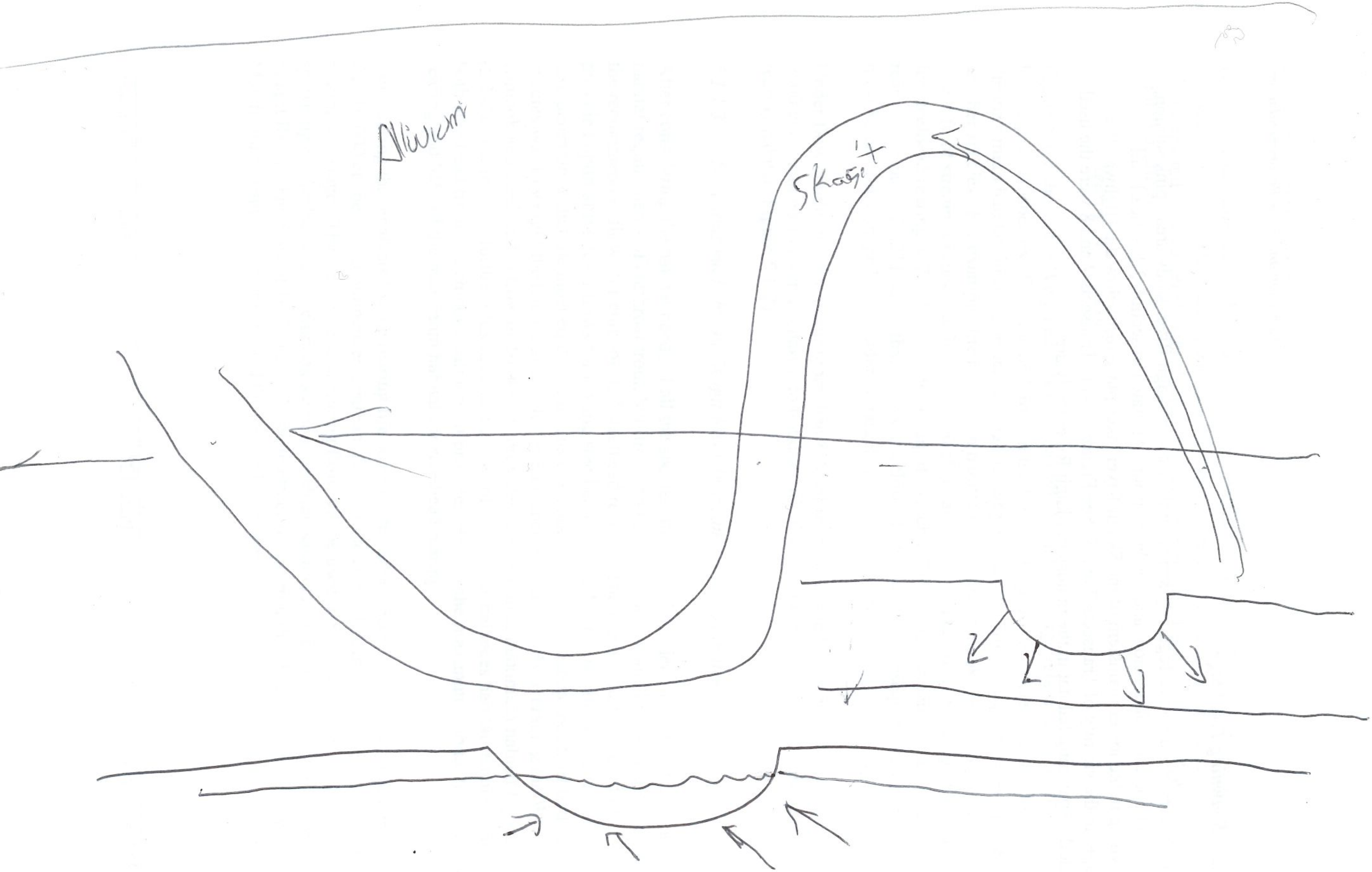
5.1.1.3 Decisions made by the Skagit River Instream Flow Committee

After considering the habitat needs of all the species, the committee determined that the rearing habitat requirements of cutthroat trout, bull trout, and coho salmon would be adequately met with the recommended flows for chinook and steelhead rearing. Therefore, efforts focused on provided optimal instream flows for rearing steelhead trout and chinook salmon. The Committee also determined that the most equitable means to balance the rearing habitat needs of both target species was to weight the habitat available for each species equally. By averaging the WUA for chinook and steelhead, a flow of 10,000 cfs provides the combined maximum habitat Figure (5.1-2). Table 5.1-1 further illustrates that a flow of 10,000 cfs balances habitat requirements for both steelhead trout and chinook salmon; it provides 92% of the maximum habitat for chinook rearing and 86% of the maximum habitat for steelhead rearing.

Considering this analysis for the rearing life stage of the target species, the Committee agreed that 10,000 cfs be the recommended instream flow for the chinook salmon and steelhead trout rearing life stage. The recommended rearing flow will be used during the time periods when spawning by steelhead trout, chinook salmon, or chum salmon is not occurring in the Lower Skagit River. The flow of 10,000 cfs will be in effect for the months of January, February, March, July, August, September, and the period December 16 - 31.

5.1.2 Spawning Life Stage

Four species of salmonids regularly spawn in the Lower Skagit River study area: pink salmon, chum salmon, chinook salmon, and steelhead trout. As stated in section 2.1.3, nearly all spawning in the lower mainstem of the Skagit River takes place just below the Highway 9 bridge, in the vicinity of Transects 7 and 8 (See Figure 2.1-1). Transects 7 and 8 were the used to model spawning habitat in the mainstem Skagit River study area..


Aluvium
Skočit

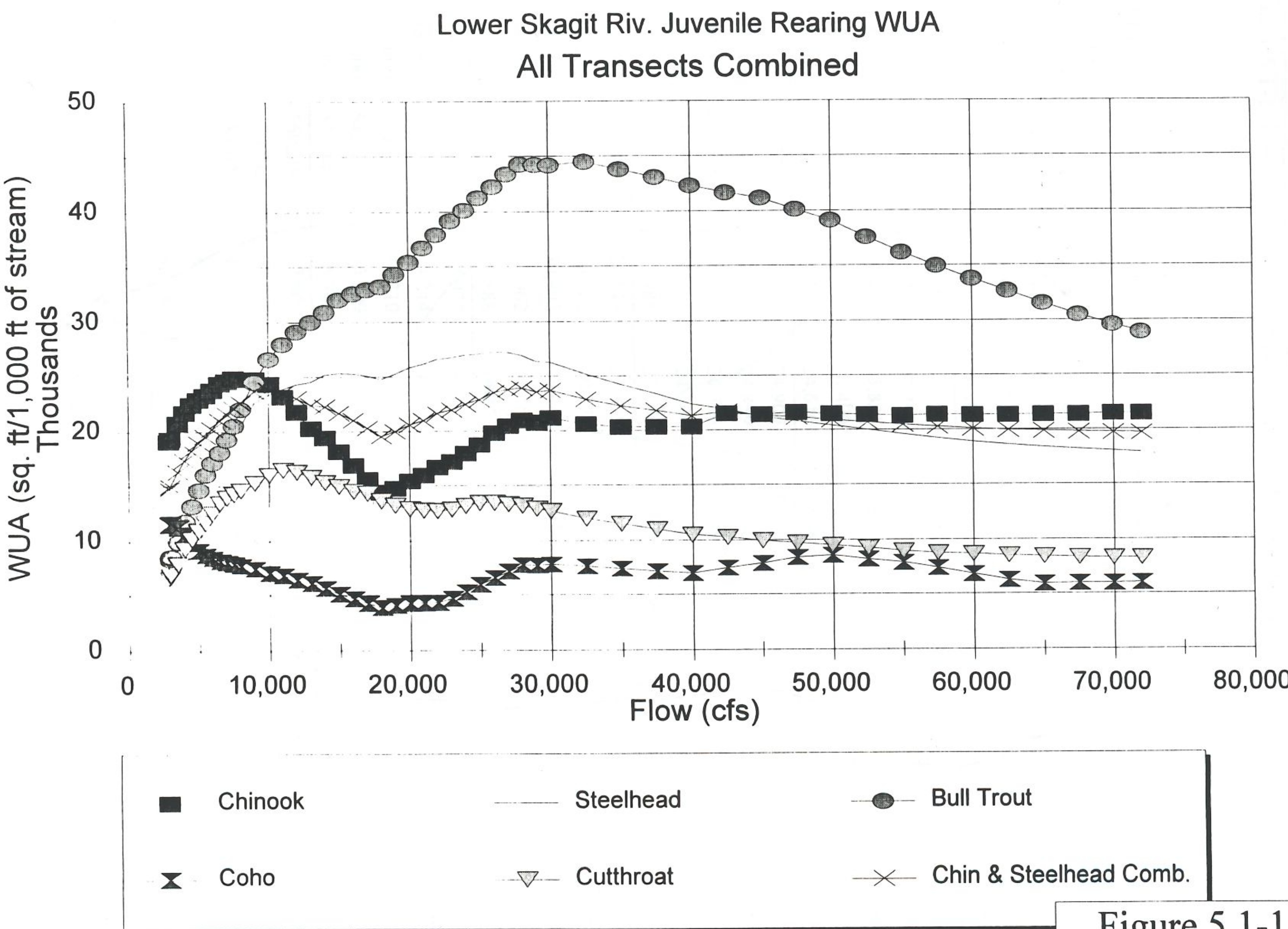

Lower Skagit Riv. Juvenile Rearing WUA
All Transects Combined
WUA (sq. ft/1,000 ft of stream)
Thousands
50
40
30
20
10
0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Flow (cfs)
Chinook
Steelhead
Bull Trout
Coho
Cutthroat
Chin & Steelhead Comb.

Figure 5.1-1

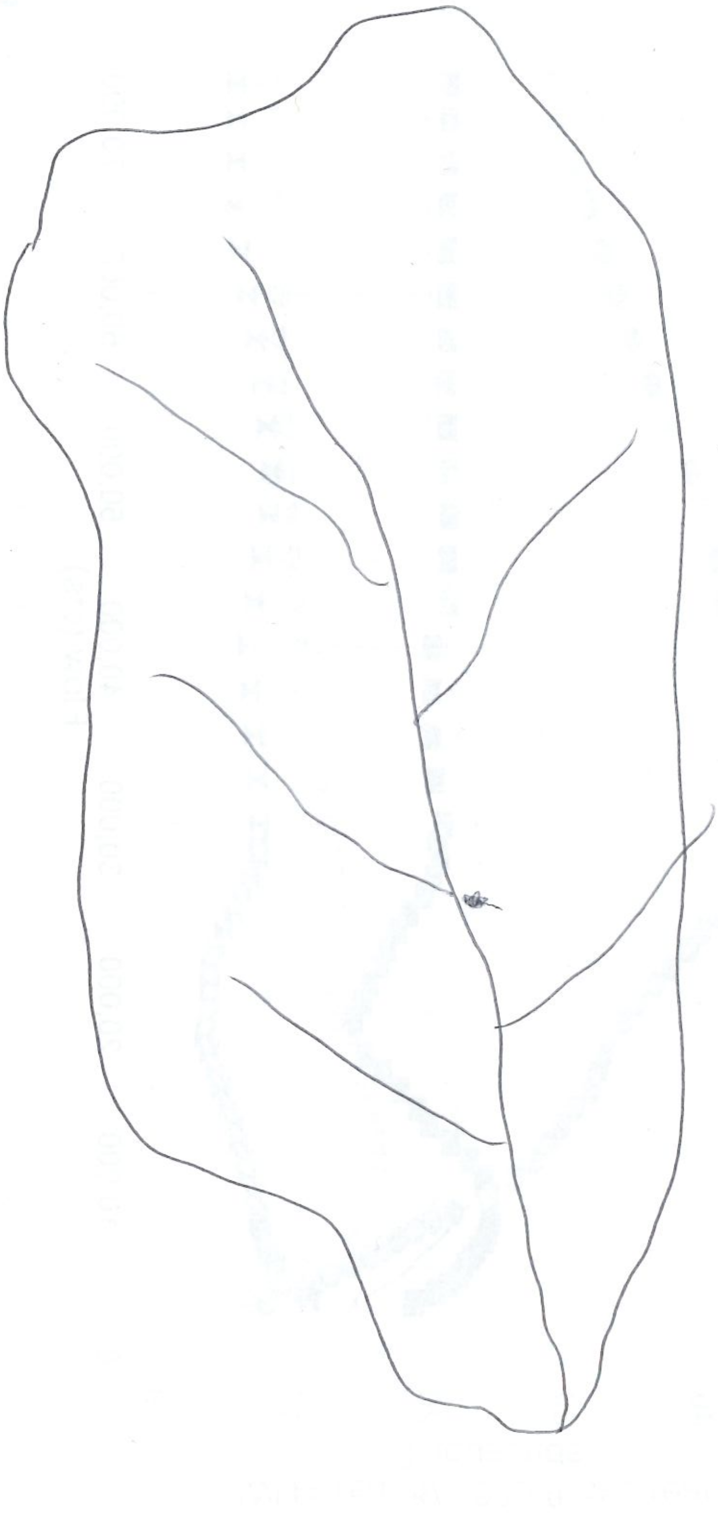


Table 5.1-1 Lower Skagit River Rearing WUA - All Transects Combined

Flow	Total Area	Bull Trout Rearing	Chinook Rearing	Coho Rearing	Cutthroat Rearing	Steelhead Rearing	Combined Chinook & Steelhead Rearing
2,900	368,196	8,412	19,117	11,586	6,601	10,488	14,803
3,000	369,184	8,644	19,347	11,651	6,880	10,689	15,018
3,500	378,070	10,008	20,803	11,332	7,933	11,892	16,347
4,000	381,271	11,855	21,777	10,689	9,339	13,029	17,403
4,500	385,578	13,232	22,504	9,916	10,274	14,149	18,326
5,000	389,611	14,682	22,946	9,163	10,978	15,130	19,038
5,500	393,121	16,070	23,295	8,771	11,731	15,927	19,611
6,000	397,411	17,193	23,821	8,482	12,576	16,767	20,294
6,500	400,903	18,109	24,400	8,228	13,468	17,779	21,089
7,000	404,869	19,301	24,616	8,078	14,005	18,754	21,685
7,500	409,728	20,604	24,909	7,938	14,300	19,571	22,240
8,000	420,592	22,109	24,839	7,766	14,626	20,559	22,699
9,000	434,575	24,563	24,796	7,489	15,330	22,632	23,714
10,000	443,727	26,653	24,380	7,056	16,027	23,387	23,883
11,000	451,795	27,985	23,200	6,842	16,499	23,915	23,558
12,000	460,570	29,149	21,819	6,442	16,289	24,334	23,077
13,000	471,225	30,022	20,335	6,114	15,874	24,543	22,439
14,000	480,057	30,902	19,440	5,644	15,371	25,193	22,316
15,000	490,766	32,062	18,156	5,126	14,975	25,326	21,741
16,000	498,314	32,588	16,911	4,689	14,525	25,279	21,095
17,000	506,438	32,972	15,629	4,233	14,367	25,076	20,353
18,000	514,988	33,214	14,436	3,869	13,660	24,772	19,604
19,000	530,544	34,310	14,812	4,070	13,263	25,248	20,030
20,000	542,238	35,399	15,443	4,241	12,959	25,799	20,621
21,000	551,343	36,749	15,981	4,282	12,793	26,126	21,054
22,000	560,304	37,907	16,726	4,345	12,776	26,597	21,662
23,000	570,043	39,172	17,236	4,701	12,914	26,732	21,984
24,000	581,621	40,169	18,005	5,298	13,230	26,978	22,491
25,000	593,669	41,265	18,789	5,977	13,471	27,054	22,921
26,000	603,048	42,285	19,845	6,616	13,507	27,211	23,528
27,000	611,373	43,425	20,473	7,198	13,343	27,169	23,821
28,000	624,595	44,308	21,014	7,793	13,215	26,896	23,955
29,000	626,082	44,243	20,818	7,766	12,954	26,361	23,590

Table 5.1-1 Lower Skagit River Rearing WUA - All Transects Combined

Flow	Total Area	Bull Trout Rearing	Chinook Rearing	Coho Rearing	Cutthroat Rearing	Steelhead Rearing	Combined Chinook & Steelhead Rearing
30,000	627,569	44,192	21,215	7,860	12,736	26,266	23,740
32,500	631,792	44,500	20,613	7,674	12,030	25,187	22,900
35,000	635,803	43,845	20,341	7,457	11,517	24,213	22,277
37,500	640,075	43,129	20,362	7,179	11,049	23,344	21,853
40,000	657,373	42,338	20,357	6,981	10,543	22,406	21,381
42,500	661,296	41,679	21,541	7,488	10,298	21,949	21,745
45,000	667,787	41,201	21,458	7,879	9,999	21,251	21,355
47,500	670,032	40,129	21,616	8,458	9,778	20,874	21,245
50,000	671,792	39,135	21,493	8,636	9,533	20,449	20,971
52,500	673,222	37,583	21,406	8,270	9,288	20,032	20,719
55,000	675,772	36,208	21,332	7,943	8,993	19,619	20,475
57,500	676,933	34,948	21,393	7,441	8,813	19,264	20,329
60,000	678,118	33,786	21,373	6,846	8,693	18,895	20,134
62,500	679,602	32,689	21,373	6,309	8,564	18,617	19,995
65,000	680,677	31,549	21,389	5,917	8,473	18,416	19,903
67,500	683,061	30,520	21,405	5,960	8,390	18,206	19,805
70,000	684,030	29,597	21,501	6,005	8,337	18,038	19,770
72,000	684,601	28,912	21,507	6,020	8,327	17,895	19,701

5.1.2.1 Spawning Periodicity

In the Lower Skagit River, steelhead trout spawn in the spring from April through June. Fig. xx, shows the spawning periodicity for each of the species. Pink, Chum, and Chinook salmon begin spawning in the Lower Skagit River in October. Pink and chinook salmon spawn through mid November while chum spawning can continue through mid December (Figure xx). Chinook and chum salmon spawn every year while pink salmon only spawn in odd numbered years.

5.1.2.2 Spawning WUA Results

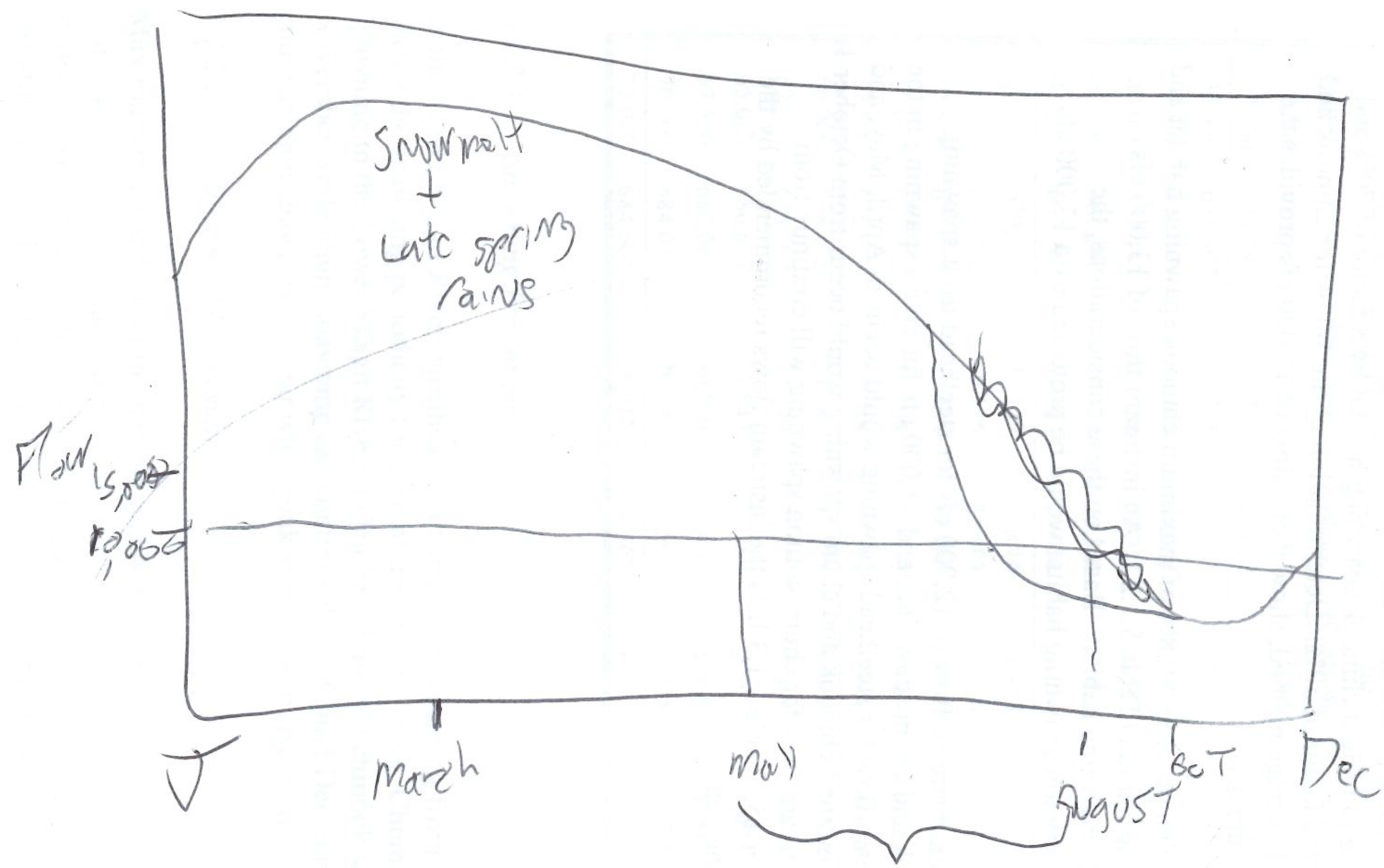
Maximum steelhead spawning habitat occurs at a flow of 12,000 cfs while the maximum chinook spawning habitat occurs at a flow of 14,000 cfs and the maximum chum and pink spawning habitat occurs at 11,000 cfs (Figure 5.1-2, Table 5.1.2). At the maximum chinook spawning flow of 14,000 cfs, chum spawning habitat is 87% of it's maximum.

5.1.2.3 Decisions made by the Skagit River Instream Flow Committee

As with the rearing life stage, the committee chose to combine life stages of two species in the final analysis. Due to the high concern placed on chinook by its listing under the Endangered Species Act, the Committee chose to weight chinook spawning habitat by a factor of 70% and weight chum spawning habitat by a factor of 30%. Determination of the WUA for chinook and chum spawning by this weighted average method, show that a flow of 13,000 cfs provides the maximum spawning habitat (Figure 5.1-2).

An instream flow of 13,000 cfs also provides 99.8% of maximum chinook spawning habitat and 93% of maximum chum spawning habitat (Table 5.1.2). An instream flow of 13,000 cfs provides 87% of maximum pink spawning habitat. Based on these considerations, the Committee concluded that pink salmon spawning habitat would be protected by a 13,000 cfs instream flow.

The Committee recommended an instream flow of 12,000 cfs for steelhead trout spawning, 13,000 cfs for combined chinook and chum spawning, and 11,000 cfs for chum spawning in the Lower Skagit River. The instream flow for steelhead spawning would occur in April, May, and June. The instream flow for combined chinook and chum spawning would occur from October 1 through November 15. The instream flow for chum salmon spawning will continue from November 16 through December 15. Table 5.1.3 lists the instream flows recommended by the Committee for each month of the year.



Snowmelt
+
Late spring
rains
Flow
15,000
10,000
J
March
May
August
OCT
Dec

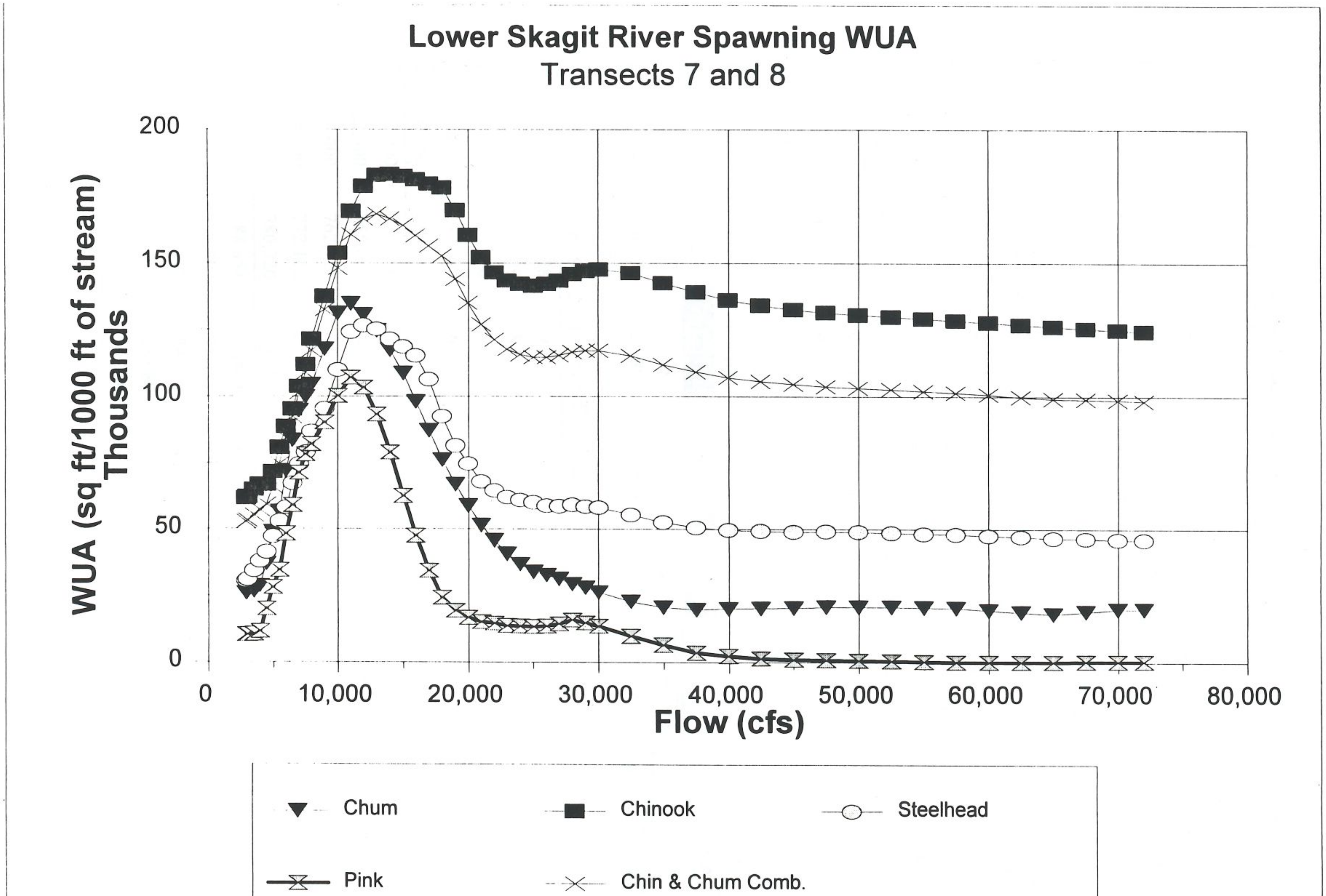

Lower Skagit River Spawning WUA
Transects 7 and 8
WUA (sq ft/1000 ft of stream)
Thousands
200
150
100
50
0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Flow (cfs)
Chum
Chinook
Steelhead
Pink
Chin & Chum Comb.

Figure 5.1-2

Table 5.1-2 Lower Skagit River Spawning WUA - Transects 7 & 8 Combined

Flow	Surface Area	Chum Spawning	Chinook Spawning	Pink Spawning	Steelhead Spawning	Combined Chinook & Chum Spawning
2,900	341,828	25,912	61,769	10,232	30,671	52,805
3,000	344,590	26,222	62,315	10,248	31,255	53,292
3,500	384,074	26,624	64,906	10,351	34,682	55,335
4,000	409,999	28,809	66,791	11,561	38,172	57,296
4,500	440,591	37,178	66,818	20,076	41,638	59,408
5,000	483,970	48,876	71,651	28,213	47,206	65,958
5,500	517,515	56,519	80,785	34,810	52,992	74,719
6,000	561,953	72,062	88,531	48,394	58,236	84,414
6,500	580,432	83,472	95,222	59,066	67,251	92,285
7,000	592,422	94,741	103,761	71,391	74,493	101,506
7,500	605,098	99,857	112,005	78,217	78,998	108,968
8,000	637,116	104,451	121,626	82,068	86,871	117,333
9,000	691,657	117,731	137,651	90,232	95,419	132,671
10,000	696,139	131,087	153,846	100,096	109,992	148,156
11,000	700,286	134,693	169,514	107,048	124,141	160,809
12,000	705,571	130,682	178,697	103,304	126,715	166,693
13,000	710,477	124,802	182,854	93,162	125,296	168,341
14,000	713,405	117,385	183,129	78,968	121,631	166,693
15,000	716,694	108,799	182,449	62,638	118,774	164,036
16,000	721,178	98,123	181,210	47,557	115,244	160,439
17,000	725,729	87,102	179,638	34,654	106,374	156,504
18,000	728,974	76,158	178,244	24,253	92,473	152,722
19,000	732,587	66,904	169,747	19,330	81,529	144,036
20,000	738,813	58,864	160,551	16,727	74,649	135,129
21,000	743,898	51,608	152,124	14,995	67,867	126,995
22,000	755,097	45,875	146,449	14,479	64,538	121,305
23,000	762,919	40,813	143,523	13,610	62,127	117,845
24,000	772,162	37,024	142,156	13,414	61,047	115,873
25,000	780,320	34,104	141,577	13,281	60,132	114,709
26,000	788,851	32,814	142,148	13,454	58,895	114,815
27,000	795,302	31,431	143,515	14,368	58,630	115,494
28,000	806,892	29,555	145,896	15,786	59,134	116,811
29,000	816,714	28,089	147,029	14,658	58,557	117,294
30,000	823,973	26,259	147,661	13,515	58,199	117,311

Table 5.1-2 Lower Skagit River Spawning WUA - Transects 7 & 8 Combined

Flow	Surface Area	Chum Spawning	Chinook Spawning	Pink Spawning	Steelhead Spawning	Combined Chinook & Chum Spawning
32,500	841,183	22,751	146,232	9,657	55,485	115,362
35,000	858,070	20,523	142,509	6,421	52,688	112,012
37,500	869,917	19,658	139,210	3,669	50,701	109,322
40,000	881,655	20,122	136,183	2,341	49,762	107,168
42,500	894,125	20,193	134,150	1,569	49,463	105,661
45,000	913,911	20,386	132,628	1,163	49,088	104,568
47,500	926,513	20,703	131,518	972	49,282	103,814
50,000	934,742	20,691	130,688	784	48,986	103,188
52,500	940,800	20,721	129,871	613	48,692	102,584
55,000	947,189	20,591	129,152	444	48,401	102,012
57,500	953,332	20,467	128,436	355	48,095	101,444
60,000	961,950	19,488	127,703	344	47,725	100,649
62,500	976,944	18,802	126,910	350	47,240	99,883
65,000	985,485	18,136	126,155	354	46,811	99,150
67,500	1,001,692	19,004	125,510	364	46,539	98,883
70,000	1,006,065	19,820	124,886	373	46,286	98,620
72,000	1,007,485	19,867	124,390	360	46,023	98,259

Table 5.1-3 Recommended Flows for the Lower Skagit River Based on IFIM and Estuary Studies - Measured at USGS Sta.#12200500 Skagit River near Mt. Vernon, WA

Month	Recommended Flow (CFS)	Issue
January	10,000	Steelhead & Chinook Rearing
February	10,000	Steelhead & Chinook Rearing
March	10,000	Steelhead & Chinook Rearing
April	12,000	Steelhead Spawning
May	12,000	Steelhead Spawning
June	12,000	Steelhead Spawning
July	10,000	Steelhead & Chinook Rearing
August	10,000	Steelhead & Chinook Rearing
September	10,000	Steelhead & Chinook Rearing
October	13,000	Chum Spawning Chinook Spawning
November 1-15	13,000	Chum Spawning Chinook Spawning
November 16-30	11,000	Chum Spawning
December 1-15	11,000	Chum Spawning
December 16-31	10,000	Steelhead & Chinook Rearing

5.2 Estuary Studies

Although the recommended instream flows from Section 5.1 will adequately protect the habitat for the target species in the Lower Mainstem Skagit River, other important factors described in the estuary studies (Section 3) are not adequately addressed by the instream flows in Table 5.1.3.

5.2.1 Life History Considerations

Many estuarine species including salmonids are adapted to exploit the constantly changing habitat conditions that are provided by the estuary. Congleton, (1978), and Mason, (1974), have noted the behavioral adaptations of juvenile salmonids in the estuary to migrate diurnally from refuge channels and feed in the temporarily inundated over-bank habitat. The estuary habitat is primarily utilized by rearing salmonids from February through August.

5.2.2 Estuary Habitat Results

The results in Section 3.6.5 of the estuary studies clearly indicate the relationship between both tide and stream flow as critical factors for determining the duration of inundation in estuarine habitats. Table 3.6.3 presents the average percent reduction in time that the critical 1 foot depth criteria is equaled or exceeded with a 500cfs incremental reduction in flow between the flows of 10,000 and 25,000 cfs.

Table 5.2-1 shows the effect of incremental flow changes on duration of inundation for all sites combined in increments of 100 cfs. Increments of 100 cfs as well as the 10% threshold were obtained by linear interpolation between 500, 1,000, and 1,500 cfs increments.

5.2.3 Decisions made by the Skagit River Instream Flow Committee

Given the results from Table 5.2-1 it was evident that any reduction in flow would cause some reduction in the duration of inundation for the estuary habitat. The Committee discussed the issue of impacts and decided that significant impacts to the duration of over-bank inundation should be avoided. Based on the professional judgement of the group, the Committee further determined that a 10% maximum threshold was a reasonable level to set for significant impacts.

Based on this analysis, the Committee determined that the 10% reduction threshold was reached at 836 cfs. The Committee recommended that for the months of February through August the maximum allocation of water from the Lower Skagit River be limited to 836 cfs.

Table 5.2-1. Effect of flow change on percent time that 1 foot criteria is equaled or exceeded. All sites combined and effects averaged over the range of flows from 10,000 to 25,000 cfs.

Flow Change of Interest (cfs)	Percent Reduction
500	6.4%
600	7.5%
700	8.6%
800	9.6%
836	10.0%
900	10.7%
1,000	11.8%
1,100	12.8%
1,200	13.8%
1,300	14.8%
1,400	15.8%
1,500	16.8%

5.3 Hydrologic Analysis

The Lower Skagit River IFIM and estuary studies and recommendations in this section have addressed the species microhabitat and behavioral requirements in their respective areas. Recommendations for both areas also have added benefit for other aquatic species within the Lower Skagit study area.

5.3.1 Functional Hydrologic and Biologic Considerations

Other ecologically relevant attributes of the river system, such as flushing flows for outmigrating fish, habitat diversity, biotic diversity, species distribution, ground water movement and nutrient cycling are recognized to be dependent upon the natural hydrologic variations within a river system (Richter et al., 1997). Natural hydrologic fluctuations that occur seasonally and annually are critical factors that shape nearly all functional aspects of the river system (Hill et al., 1991).

To retain the valuable functions of the hydrologic fluctuations, it is necessary to retain significant natural hydrologic variability within the flow regime (Allan, 1995; Hill et al., 1991).. Although a portion of the flow in the Lower Skagit study area is regulated by water releases from hydroelectric projects, flow from nearly 70% of the watershed is not subject to human control. In addition, size of the impoundments and regulatory restrictions on the projects limit the seasonal impacts to hydrologic variability (Appendix F).

5.3.2 Decisions made by the Skagit River Instream Flow Committee

The Committee discussed the issue of hydrologic impacts on the ecological function of the Skagit River and decided that significant impacts to the historical hydrologic regime should be avoided. Based on the professional judgement of the group, the Committee further determined that a 10% maximum threshold was a reasonable level to set for significant impacts.

In order to ensure that the historic hydrologic regime is not significantly altered, the Committee determined that a limit would be placed on the maximum water allocation from the Skagit River from September through January, when the recommended maximum allocation for estuarine habitat protection is not in effect.

After review of the historical hydrologic data from the gaging station at Skagit River near Mt. Vernon (USGS Sta.#12200500), the Committee decided that the monthly 50% exceedence flow was a reasonable criteria to use as a basis to compute the 10% impact threshold. The historical 50% exceedence flow is defined as the flow that is equaled or exceeded on 50% of the days during a particular month.

The Committee recommended the maximum water allocation from the Skagit River be limited to 10% of the flow that is equaled or exceeded 50% of the time for each month. The value for 10% of each monthly 50% exceedence flow is shown in Table 5.3-1. The flow duration table that lists all exceedence flows is shown in Table 4.x-x and the relevant 50% exceedence flows are shaded.

Table 5.3-1 Recommended Maximum Allocation for the Skagit River Based on Estuary and Hydrologic Studies - Measured at USGS Sta. #12200500 Skagit River near Mt. Vernon, WA

Month	Total Maximum Allocation (CFS)
January	1,560 = (10% of Monthly 50% Exceedence Flow)
February	Estuary Results = 836 cfs
March	Estuary Results = 836 cfs
April	Estuary Results = 836 cfs
May	Estuary Results = 836 cfs
June	Estuary Results = 836 cfs
July	Estuary Results = 836 cfs
August	Estuary Results = 836 cfs
September	830 = (10% of Monthly 50% Exceedence Flow)
October	991 = (10% of Monthly 50% Exceedence Flow)
November 1-15	1450 = (10% of Monthly 50% Exceedence Flow)
November 16-30	1450 = (10% of Monthly 50% Exceedence Flow)
December 1-15	1610 = (10% of Monthly 50% Exceedence Flow)
December 16-31	1610 = (10% of Monthly 50% Exceedence Flow)

5.4 Final Recommendations

The final instream flow recommendations of the Committee for the Lower Skagit River are listed in Table 5.4-1. The flows and allocation limits recommended represent an integrated set of conditions that will ensure adequate instream flows for fish habitat protection in both the Lower mainstem Skagit and estuary areas. The allocation limits recommended will allow the hydrologic regime to provide the multitude of beneficial functions which are critical to a healthy and diverse river ecosystem. Finally, governing bodies or involved representatives of all the signatories to the MOA have endorsed the final recommendations contained in Table 5.4-1.

Table 5.4-1 Recommended Flows and Maximum Allocation for the Lower Skagit River Based on IFIM, Estuary and Hydrologic Studies - Measured at USGS Sta. #12200500 Skagit River near Mt. Vernon, WA

Month	Recommended Flow (CFS)	Issue	Total Maximum Allocation (CFS)
January	10,000	Steelhead & Chinook Rearing	1,560 = (10% of Monthly 50% Exceedence Flow)
February	10,000	Steelhead & Chinook Rearing	Estuary Results = 836 cfs
March	10,000	Steelhead & Chinook Rearing	Estuary Results = 836 cfs
April	12,000	Steelhead Spawning	Estuary Results = 836 cfs
May	12,000	Steelhead Spawning	Estuary Results = 836 cfs
June	12,000	Steelhead Spawning	Estuary Results = 836 cfs
July	10,000	Steelhead & Chinook Rearing	Estuary Results = 836 cfs
August	10,000	Steelhead & Chinook Rearing	Estuary Results = 836 cfs
September	10,000	Steelhead & Chinook Rearing	830 = (10% of Monthly 50% Exceedence Flow)
October	13,000	Chum Spawning Chinook Spawning	991 = (10% of Monthly 50% Exceedence Flow)
November 1-15	13,000	Chum Spawning Chinook Spawning	1450 = (10% of Monthly 50% Exceedence Flow)
November 16-30	11,000	Chum Spawning	1450 = (10% of Monthly 50% Exceedence Flow)
December 1-15	11,000	Chum Spawning	1610 = (10% of Monthly 50% Exceedence Flow)
December 16-31	10,000	Steelhead & Chinook Rearing	1610 = (10% of Monthly 50% Exceedence Flow)

REFERENCES

Congleton, James, L., 1978. Feeding patterns of juvenile chum salmon in the Skagit River salt marsh; Proceedings of Second technical Workshop on Fish Food Habits Studies, October 1978.

Congleton, J. L., S.K. Davis, and S.R. Foley., 1982. "Distribution , Abundance, and Outmigration Timing of Chum and Chinook Salmon Fry in the Skagit Salt Marsh." In Proceedings of Salmon and Trout Migratory Behavior Symposium, 1981 June 3-5, edited by E.L. Brannon and E.O. Salo, 153-163. School of Fisheries: University of Washington, Seattle WA.

Hayman, R.A., E.M. Beamer, and R.E. McClure. 1996. FY95 Skagit River Chinook Restoration Research. Skagit System Cooperative. Chinook Restoration Research Project Report No. 1. Final Project Performance Report in Compliance in Part with NWIFC contract No. 33114 for FY95. August 1996. 113 pages plus appendices.

Healy, M.C., 1982. "Juvenile Pacific Salmon in Estuaries: The Life Support System". In Estuarine Comparisons, edited by V.S. Kennedy, 315-341. New York Academic Press, 1982.

Mason, J.C., 1974. Behavioral ecology of chum salmon fry (*Oncorhynchus keta*) in a small estuary. Journal of Fishery Research Board of Canada 31:83:92.

Morhardt, J.E, 1986. Instream Flow Methodologies. Research Project #2194-2. EA Engineering, Science and Technology, Inc., Lafayette, CA.

Phinney, L.A., and P. Bucknell. 1975. A Catalog of Washington Streams and Salmon Utilization. Volume 1. Puget Sound Region.

Thompson, R. E. 1981. Oceanography of the British Columbia coast. Canadian Special Publication of Fisheries and Aquatic Sciences. 56:291 p.

Thom, R. M., 1987. The biological importance of Pacific Northwest estuaries. College of Ocean and Fisheries Sciences, University of Washington, Seattle, WA.

Washington Department of Fisheries. 1994. Instream Flow Guidelines. November 2, 1994.

Richter, B. D., and Baumgartner, J. V., and Wigington, R. and Braun, D. V. 1997. "How Much Water Does a River Need". A special applied issues section from The Nature Conservancy. Range of Variability Approach.

Hampton, M., 1988. Development of habitat preference criteria for anadromous salmonids of the Trinity River. USF&WS, Sacramento, CA. May 1988.

Hampton, M., 1997. Microhabitat suitability criteria for anadromous salmonids of the Trinity River. U.S. Fish & Wildlife Service, Arcata CA. December 1997.

Kurko, K.W., 1977. Investigations on the amount of potential spawning area available to chinook, pink, and chum salmon in the upper Skagit River, Washington. Ms Thesis, University of Washington, Seattle, WA.

Allen, J. D. (1995) *Stream Ecology: Structure and Function of Running Waters*. Chapman & Hall, New York.

Hill, M. T., Platts, W. S. & Beschta, R. L. (1991) Ecological and geomorphological concepts for instream and out-channel flow requirements. *Rivers*, **2**, 198-210

Bovee, K.D. 1982. A Guide to Stream Habitat Analysis Using the Instream Flow Incremental Methodology. Instream Flow Information Paper #12. U.S. Fish & Wildlife Service, Fort Collins, Colorado.

Milhous, R.T., D.L. Wegner and T. Waddle. 1984. Users' Guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information paper #11. U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Milhous, R.T., M.A. Updike, and D.M. Schneider. 1989. Computer Reference Manual for the Physical Habitat Simulation System-Version II. Instream Flow Information Paper #26. U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Morlock, S.E. 1996. Evaluation of Acoustic Doppler Current Profiler Measurement of River Discharge. U.S. Geological Survey, Water Resources Investigations Report 95-4218, Indianapolis Indiana.

Trihey, E.W., and David Wegner. 1981. Field Data Collection Procedures for Use with the Habitat Simulation System of the Instream Flow Group. U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Thompson, K. 1972. Determining Streamflows for Fish Life. Proceedings of the Instream Flow requirements Workshop, Portland OR, March 15-16, 1972.

WDFW 1989 Instream Flow Guidelines. Washington Department of Wildlife, Habitat Management Division, Olympia, WA.