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IN-DEPTH PERSPECTIVE

WRIA 16 INSTREAM FLOW STUDIES
JEFFERSON AND MASON COUNTIES, WASHINGTON

Prepared for: WRIA 16 Planning Unit

FUNDING SOURCE: WRIA 16 Instream Flow Grant
Department of Ecology Grant #G0300041

Project No. 040012-001-04 • December 23, 2005

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Aspect Consulting, LLC

In Association with Entrix, Inc.

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The WRIA16 Planning Unit contributed to this document by providing assistance in scope development, property access, siting fish passage transects and gaging stations, developing fish passage criteria, and review of the document.

This project would not have been possible without the assistance of the many landowners that allowed us access to the stream gage and fish passage study locations.

The following contract individuals made significant contributions to this project:

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Larry Wise and Coralie Dayde - Assisted with modeling and analysis

Executive Summary

The State of Washington created the Watershed Management Act (1998) with the intention of providing a means to identify and solve water-related problems in each of 62 geographic areas known as Water Resource Inventory Areas (WRIAs). WRIA 16 is located on the western side of Hood Canal on the Olympic Peninsula in western Washington (Figure 1.1) and is one of 62 Water Resource Inventory Areas (WRIAs) in the State of Washington. The WRIA 16 Planning Unit (PU) subcontracted to Aspect Consulting, LLC to perform stream gaging and fish passage studies on selected streams. Fish passage studies were performed by the Olympia Office of Entrix, Inc. under subcontract to Aspect Consulting. The purpose of these studies is to provide streamflow and fish passage data to support the Planning Unit's development of instream flow recommendations. The principal project elements consisted of:

- Establishment of temporary stream gages and monitoring for a 1 year period on the following seven streams:
  - Dosewallips River, Duckabush River, and Fulton Creek in Jefferson County; and,
  - Hamma Hamma River, John Creek, Jorsted Creek and Eagle Creek in Mason County.
- Extension of the gaging record based on interstation correlations.
- Use of the Instream Flow Incremental Methodology (IFIM) to identify streamflows of sufficient magnitude to provide passage of anadromous salmonids over limiting riffles on Fulton, John and Jorsted Creeks.

The larger catchments (Duckabush, Dosewallips, and Hamma Hamma Rivers) are snow-pack dominated with peak discharge events typically occurring in December in response to fall precipitation events and again in late May to early June following snow melt. The smaller creeks (Fulton, John, Jorsted, and Eagle Creeks) have precipitation dominated stream flows that typically peak in December and decline into the summer months.

Gaging stations were established as far downstream as possible but above tidal influence at the area of best hydraulic control where land owner permission could be obtained. Due to access constraints, Eagle Creek gaging station was located in a tidally influenced location. Rating curves were developed for each of the stations. Flow measurements were made using the area-velocity method (Rantz, et al., 1982). The maximum flow measurement used in each rating curve was limited by the stream's wadeability. Gaging stations were operated from June 25, 2004 through July 17, 2005, with the exception of Jorsted Creek which was operated from August 5, 2004 through August 18, 2005. Given the relatively short project duration, the stage discharge relations developed in the rating curves were considered excellent.

The flow record was extended beyond the approximate 1 year monitoring period based on interstation correlations of the stations of interest with long-term base stations. Squared correlation coefficients (r^2 values) ranged from a low of 0.7 for the Fulton Creek- South Fork Skokomish River to high of 0.99 for the Duckabush River gaging station with the upstream USGS Duckabush gaging station. Mean daily flows were synthesized for the duration of the base station gaging record (typically extending back to the 1930s) based on the correlations. Exceedance curves showing the flow value that will be exceeded 10, 50 and 90 percent of the time on a specified date were developed.

Table ES-1
Summary of 2004/2005 Annual Mean Daily Flows
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Stream	Averaging Period	Average Annual Mean Daily Flow (cfs)	Percent of Years Exceeding 2004/2005 Flows
Dosewallips River	7/01/04 - 6/30/05	385	73%
Duckabush River	7/01/04 - 6/30/05	398	78%
Fulton Creek	7/01/04 - 6/30/05	40	85%
Hamma Hamma River	7/01/04 - 6/30/05	480	76%
John Creek	7/01/04 - 6/30/05	16	87%
Jorsted Creek	8/15/04 - 8/14/05	14	90%
Eagle Creek	7/01/04 - 6/30/05	20	85%

Hamma Hamma River had the greatest average annual mean daily flow for the snow-pack dominated streams and Fulton Creek had the greatest mean daily flow of the precipitation dominated streams (Table ES-1). A relatively dry gaging year is reflected in the high exceedance values shown in this table (73 to 90 percent of the years had more flow than 2004/2005 period). The percent of years exceeding 2004/2005 flows is based on comparison with the synthesized record. Precipitation dominated streams (Fulton, John, Jorsted and Eagle Creeks) had higher Exceedance values (85 to 90 percent) than the larger, snow-pack dominated streams (Dosewallips, Duckabush and Eagle Creek, 73 to 78 percent), indicating that for the 2004/2005 conditions, the larger, snow-pack dominated basins were less effected by the drought.

Limitations to the data are discussed including extension of rating curves beyond highest measured flow, interstation correlations based on a single year of data, variations in hydrologic response between station of interest and base stations used in making correlations, and assumptions used in correcting the tidal effects on stage data for Eagle Creek. Continued monitoring is recommended to reduce these uncertainties.

Fish passage flows in John, Fulton, and Jorsted creeks were evaluated using the Thompson Methodology (1972) and Thompson's passage criteria. Passage flows were also evaluated using the Observation Based Criteria, which are based on a limited number of site specific observations, observations from other systems, and the physical and physiological characteristics of the target species. These species included Chinook salmon, fall- and summer-run chum salmon, pink salmon, coho salmon, steelhead trout, and coastal cutthroat trout. Each species, except Chinook salmon and summer chum salmon, are thought to use each stream. Chinook salmon are thought to use only John Creek and summer chum salmon are not thought to use Jorsted Creek.

The passage flow requirements based upon the two sets of criteria varied substantially, due to differences in the depth and width requirements for passage. These flows are summarized in Table ES-2.

Table ES-2
Recommended Passage Flows (cfs)
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

	Thompson Criteria			Observation Based Criteria		
Species	John Creek	Fulton Creek	Jorsted Creek	John Creek	Fulton Creek	Jorsted Creek
Chinook Salmon	105.0	NA*	NA*	7.5	NA*	NA*
Chum Salmon	42.5	40.0	26.3	7.5	10.0	5.5
Coho Salmon	42.5	40.0	26.3	7.5	10.0	5.5
Pink Salmon	42.5	40.0	26.3	7.5	10.0	5.5
Steelhead Trout	42.5	40.0	26.3	7.5	10.0	5.5
Cutthroat Trout	15.0	15.0	7.8	7.5	10.0	5.5

*Not applicable

The Observation Based Criteria provide a more realistic estimate of the flow levels required to provide passage in these streams than the Thompson criteria. These criteria reflect field observations of fish crossing critical riffles in the project streams, and the passage frequency analysis based on these criteria suggest that suitable passage flows occur regularly, except under dry conditions. This fits the known utilization of these streams by the target species.

The passage flows suggested by the Thompson criteria appear to be unrealistic based on several factors. These factors are site-specific observations of fish moving across transects where conditions did not meet the depth and width criteria specified by Thompson, and the passage frequency analysis, that suggested that most of the target species would rarely be able to move upstream. This does not fit with observed patterns of fish use of the three study streams.

The results and conclusions of this analysis are based on a limited set of observations in the study streams. We recommend that both hydrologic and regular spawning surveys be implemented to validate the results of this analysis, as described in the Conclusions section of the Instream Flow Study report.

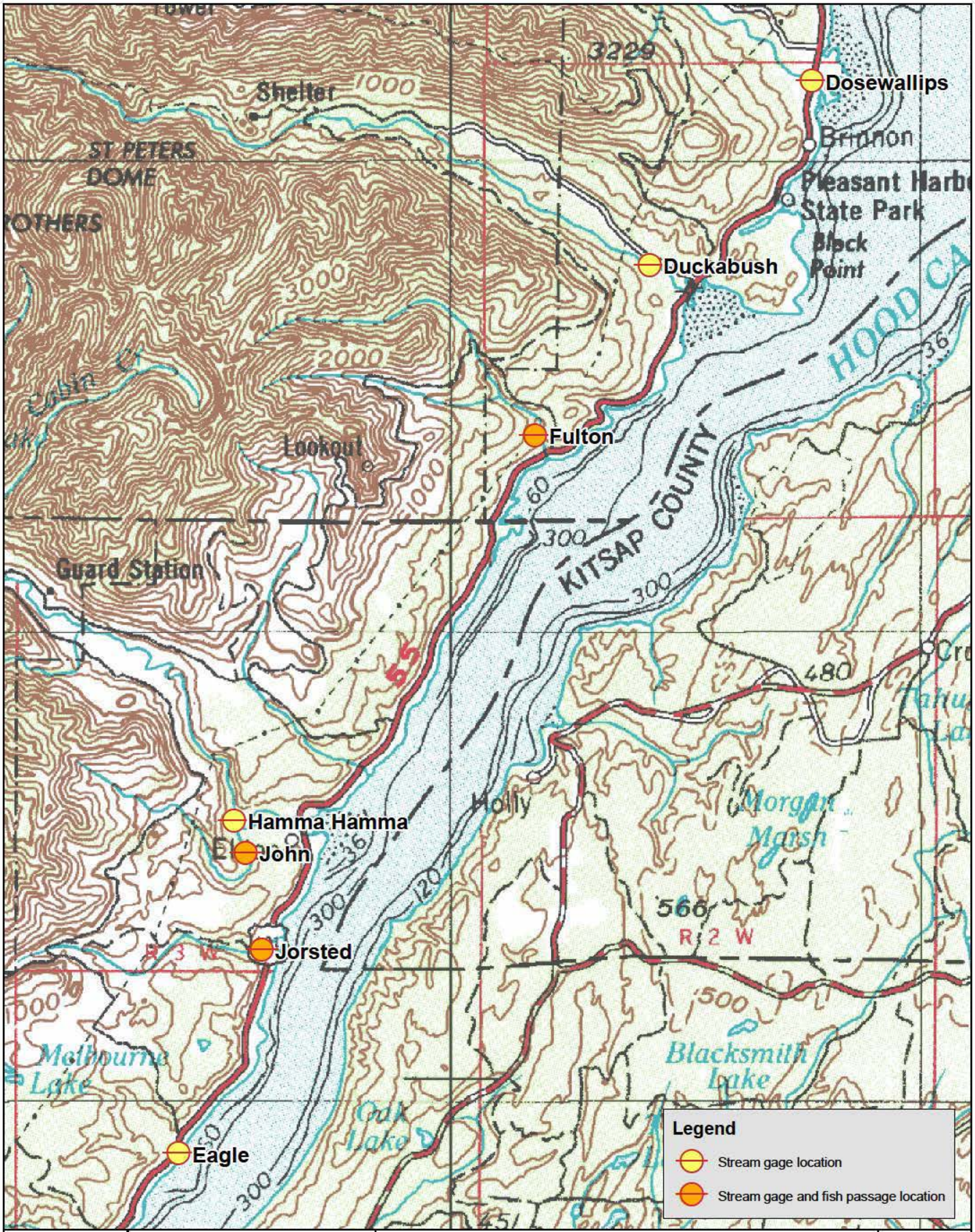
1 Introduction

The State of Washington created the Watershed Management Act (1998) with the intention of providing a means to identify and solve water-related problems in each of 62 geographic areas known as Water Resource Inventory Areas (WRIAs). WRIA 16 is located on the western side of Hood Canal on the Olympic Peninsula in western Washington (Figure 1.1). Elevations in WRIA 16 range from over 7,000 feet to sea level. Roughly 60 percent of land within WRIA 16 falls under federal ownership, either the Olympic National Park or the Olympic National Forest. Less than 8,000 people were full-time residents in WRIA 16 during the year 2000 (Golder, 2002). Most residences are concentrated near the southern end of Hood Canal.

The WRIA 16 Planning Unit (PU) subcontracted to Aspect Consulting, LLC to perform stream gaging and fish passage studies on selected streams. Fish passage studies were performed by the Olympia office of Entrix, Inc. under subcontract to Aspect Consulting. The purpose of these studies is to provide streamflow and fish passage data to support the Planning Unit's development of instream flow recommendations. Data collection was accomplished by:

- Establishing temporary stream gages and monitoring stream flows for a 1 year period on seven streams;
- Synthesizing stream flow exceedance curves based on the 1 year of monitoring data and correlation with a nearby long-term base station; and,
- Using the Instream Flow Incremental Methodology (IFIM) to identify streamflows of sufficient magnitude to provide passage of anadromous salmonids, over limiting riffles.

In addition to these principal study elements, water quality sampling was also performed on the Dosewallips River to support ongoing water quality characterization efforts in the WRIA. Figure 1.1 presents a map of the temporary stream gage locations and fish passage transects. Table 1.1 presents a summary of the studies performed on each stream.



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STREAM GAGE AND FISH
PASSAGE TRANSECT LOCATIONS
WRIA 16 Instream Flow Studies, Mason and Jefferson Co., WA

Figure
1.1

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Table 1.1
Studies Performed on WRIA 16 Streams in this Investigation
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

River/Creek	Stream Gaging	Fish Passage	Water Quality Sampling
Dosewallips River	•		•
Duckabush River	•		
Fulton Creek	•	•	
Hamma Hamma River	•		
John Creek	•	•	
Jorsted Creek	•	•	
Eagle Creek	•		

The streamflow data displays developed during this project are presented in the Appendices and organized by stream as follows:

Appendix A – Dosewallips River

Appendix B – Duckabush River

Appendix C – Fulton Creek

Appendix D – Hamma Hamma River

Appendix E – John Creek

Appendix F – Jorsted Creek

Appendix G – Eagle Creek

In addition, summary statistics for individual study area fish passage transects are presented in Appendix H.

2 Stream Gaging Methodology

2.1 Stream Gage Locations

Stream gage locations for the seven steams studied were established as far downstream as possible, at the best available hydraulic controls, above tidal influence, and where land owner permission could be obtained. Due to access constraints, however, the stream gage at Eagle Creek was located within an area of tidal influence (Figure 1.1). Stream gage locations are presented in detailed scale in the “1” figures series in Appendices A through G (i.e., Figures A-1, B-1, etc.).

Hydraulic control is determined by the stream morphology and can change during a season as a result of channel remodeling by erosion or deposition. Each stream channel was examined in the field to locate the best available hydraulic control. Desirable features for the hydraulic control include a constriction in channel width, a channel incised into the topography, stable banks (e.g., bridge abutment, trees, or bedrock), and a relatively stable bottom. The greatest likelihood for shifts in hydraulic control occur during the high flows of late fall and winter. Typically, the hydraulic control of possible gaging locations would be evaluated by observations at different stages prior to establishing a stream gage. Because of the time limitations for this project, locations of stream gages were selected during a stream reconnaissance in May, 2004; however, shifts in hydraulic control occurred in the vicinity of the stream gage locations for both the Duckabush River and Eagle Creek. Therefore, additional area-velocity measurements were made to define the new rating curves at these two stream gage locations following the control changes. The changes in hydraulic control and the rating curves for Duckabush River and Eagle Creek are further discussed in Section 3. Additional data analysis required to evaluate stream gage data in tidally influenced Eagle Creek is discussed in Section 3 and Appendix G-8.

2.2 Stage and Temperature Measurements

Stream stage at each site was monitored with a staff gage and electronic transducer. The transducer also recorded water temperature. Electronic measurements were made with Instrumentation Northwest, Inc. (INW) PT2X pressure transducer/dataloggers (full scale range of 11.6 feet water) for a period slightly greater than 1 year (see Table 2.1 for period of operation). Dataloggers were programmed to collect measurements at 15-minute intervals. Datalogger downloads and maintenance visits were performed on a near-monthly basis (a total of 11 visits) during the project, with visits more closely spaced during the winter season when storm events were more likely to result in increased station maintenance.

Stilling wells with transducers and staff gages were located at or upstream of the hydraulic controls in pools or portions of the channel not expected to go dry. Installation techniques varied and included anchoring to rip-rap, pilings, stream boulders, and steel fence posts. An existing staff gage was used for monitoring the Hamma Hamma River.

Staff gages were referenced to the elevation of a fixed feature (e.g., a bridge abutment) by survey or by direct measurement. Each site was located with a field grade GPS and photographed.

Table 2.1
Gaging Station Locations and Period of Operation
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Station	Period of Operation[1]		Location[2]	
	From	To	Latitude	Longitude
Dosewallips River	6/25/04	7/18/05	-122.8990413	47.69006065
Duckabush River	6/25/04	7/18/05	-122.9449859	47.65489112
Fulton Creek	6/25/04	7/18/05	-122.9772534	47.62233908
Hamma Hamma River	6/25/04	7/18/05	-123.0625251	47.54857279
John Creek	6/25/04	7/18/05	-123.058936	47.542885
Jorsted Creek	8/05/04	8/18/05	-123.0547035	47.52384944
Eagle Creek	6/25/04	7/18/05	-123.0780626	47.48487186

[1]Period of operation applies to monitoring under this contract. Monitoring stations operation and maintenance were transferred to Hood Canal Dissolved Oxygen Program (HCDOP) on August 18, 2005.

[2]Location determined using field grade GPS.

For quality control, the offset (or difference) between the manual staff gage reading and the transducer output was monitored monthly for stability at each installation. In a good installation, the offset value will stay within +/-0.02 feet. During the course of the study, the offsets remained constant for stations on the Dosewallips, Duckabush, and Hamma Hamma Rivers and Jorsted Creek. The staff gages on Fulton and John Creeks were hit repeatedly by floating debris during the winter months, which resulted in the staffs working upward out of the stream bed about 0.1 feet. However, the offsets were stable before and after the high water events, which confirmed that the transducer installations were stable and the collected data was reliable. The transducer at Eagle Creek was found to have a small, but out-of-specification sensitivity to temperature. The pressure-temperature relationship was characterized and the stage data corrected. The transducer has been repaired and reinstalled. Monthly maintenance activities included debris removal, replacement of transducer desiccant as required, and repair of any damage to the installation.

At the Jorsted Creek gage, the pressure transducer's vent tube was not properly vented to atmospheric pressure at the time of initial installation in June, 2004. The problem was recognized and corrected during the first download. Initial data was discarded and operation of the station continued for an additional month beyond the gaging period of the other stations.

At the WRIA 16 Planning Unit's request, operation and maintenance of the stations was transferred to the Hood Canal Dissolved Oxygen Program on August 18, 2005. Aspect Consulting provided training on gage operation and maintenance procedures to HCDOP personnel.

2.3 Discharge Measurements

A minimum of 6 discharge measurements were taken at each of the stream gage locations using USGS area-velocity techniques (Rantz, et al., 1982). Flow velocity was measured with a Swoffer Model 3000 current meter, calibrated propeller assemblies, and top set wading rod. Details of the gaging methodology are presented in the Quality Assurance Project Plan WRIA 16 Instream Flow (Aspect Consulting, 2004). The meter was calibrated in a 28-foot test tank before and after the study, during the summers of 2004 and 2005.

Discharge measurements were taken as near the gaging stations as possible and rating curves established for each site (Section 3.1). The position of acceptable transect locations depended on both channel morphology and stream conditions. In most cases, flows were measured within 100 feet of the gage location. However, flow measurements on the Duckabush and Hamma Hamma Rivers were made at different locations which were up to 500 yards apart. The effect of different measurement locations does not appear to be significant.[1]

The discharge and stage measurements were used to establish rating curves for each site (Section 3.1). Efforts were made to collect discharge measurements at each of the sites over as large of a range of discharges as possible. However, the ability to measure high flows at each of the sites was limited by the wadeability of the stream and the relatively short project duration. The discharge at stages above those bracketed by the area-velocity measurements were estimated by extrapolation of the rating curves as discussed in Section 3.1.

The scope of work for this project included 6 discharge measurements on each stream to define rating curves. Additional flow measurements were authorized by the Planning Unit to better define specific rating curves (Fulton Creek) and to provide additional data

[1] At the Duckabush River, low flow measurements were made at the gaging station. Measurements during higher flows were made at the nearest wadeable location, about 400 yards upstream. The Hamma Hamma staff is located along a section of the river with deep pools and flow measurements were usually made just above the primary hydraulic control about 300 yards downstream of the gaging station. One low flow measurement was made about 200 yards upstream of the station due to shallow depths and slow velocities at the downstream location.

Since the flow measurement locations varied substantially at Duckabush and Hamma Hamma Rivers, two lines of evidence were checked to ensure that measurements were comparable. First, no in-flows were noted between the staff and transect locations. Second, the rating curve data for both rivers (Figure B-2 and D-2) are internally consistent; that is, the data falls onto smooth power-law curves with no indication that gains or losses along the channel between measurement locations are skewing the rating curves.

for streams where the hydraulic control had shifted during high water events (Eagle and Duckabush Rivers). Gaging locations at both Duckabush River and Eagle Creek experienced shifts in hydraulic control during the study year and additional measurements were made to define rating curves applicable to the remodeled channels. The changes in hydraulic controls were not unexpected for the low gradient, gravel bottom, and soft bank channels of this study, but were minimized by the relatively low precipitation. During high water years, more frequent and extensive alterations of channel morphology would be expected. An additional discharge measurement was also taken at Fulton Creek in order to more fully define the rating curve within the range of measured flows. As part of the Fish Passage Study, additional discharge measurements were also made at Fulton, John and Jorsted Creeks.

2.4 Water Quality

As part of the Stream Gaging Study, surface water quality of the Dosewallips River near the stream gage location was monitored on a monthly basis for approximately a 1 year period (12 samples). Data was collected to contribute to on-going water quality monitoring efforts in WRIA 16 and to support investigations being done by the Hood Canal Dissolved Oxygen Project (HCDOP). Field measurements were made of: temperature, specific conductance and dissolved oxygen. Instrumentation used for these measurements is listed in Table 2.2. The specific conductance and dissolved oxygen meters were field calibrated prior to each measurement. Two water samples were collected during each sample event and submitted for analytical testing to Aquatic Research, Inc. in Seattle, Washington and Twiss Analytical Inc. in Poulsbo, Washington for the analytes listed in Table 2.2.

Sampling and analysis followed guidelines presented in the Hood Canal Water Quality Monitoring Quality Assurance Project Plan (Envirovision, 2003). Table 2.3 presents the results of the surface water quality monitoring for the Dosewallips River near the stream gage location.

Table 2.2
Water Quality Parameters, Analytes and Test Methods
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Analyte	Analytical Method
Temperature	Field – YSI 556
Specific Conductance	Field – YSI 556
Dissolved Oxygen	Field – YSI 556
Nitrate-Nitrite	EPA 353.2
Total Nitrogen	SM 4500NC
Fecal Coliform	SM 9222D

Table 2.3
Water Quality Results Summary, Dosewallips River at Hwy 101 Bridge
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Date	Time	Temperature (°F)	Specific Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Sample ID	Nitrates/ Nitrites (mg/L)	Total Nitrogen (mg/L)	Fecal Coliform (#/100ml)
8/3/04	15:30	59	99	10.5	Dose080304	0.010	< 0.100	est 8
9/7/04	15:25	58.4	114	11.1	Dose090704	0.010	< 0.100	est 8
10/11/04	15:00	52.4	104	11.6	Dose101104	0.020	< 0.100	est 1
11/10/04	13:00	45.8	95	13.0	Dose111004	0.061	0.169	est 2
12/20/04	9:30	41.3	86	15.6	Dose122004	0.059	< 0.100	est 4
1/12/05	10:30	37.2	106	14.5	Dose011205	0.067	< 0.100	2
2/16/05	10:00	36.9	108	14.2	Dose021605	0.040	< 0.100	2
3/29/05	10:00	43.0	92	13.4	Dose032905	0.057	< 0.100	< 1
4/28/05	15:25	47.4	76	12.8	Dose042805	0.038	< 0.100	< 1
5/11/05	14:00	48.5	80	12.6	Dose051105	0.022	< 0.100	2
6/21/05	16:00	53.5	95	11.9	Dose062105	0.010	<0.100	4
7/19/05	15:30	61.5	103	10.2	Dose071905	0.010	<0.100	3

3 Stream Gaging Data Analysis

This section describes the methodology for:

- Development of rating curves from the stage data;
- Calculation of measured flow using the rate curve;
- Correlation of flow at the study sites with long-term base stations;
- Synthesis of study site flows to the longer period of record for the base stations; and
- Development of exceedance plots.

Hydrographs were developed for the year of gaging and synthesized for an extended period (typically back to the 1930s) based on interstation correlation with a nearby station with an extended record. Exceedance plots showing the 10, 50 and 90 percent probability that a given streamflow will be exceeded were also developed.

Rating curves, hydrographs, correlation graphs, and exceedance plots are presented in Appendices A through G as follows:

- Rating Curves – "2" and "3" series figures (i.e., Figures A-2, A-3, B-2, B-3, etc.).
- Hydrographs for the gaging period – "4" series figures.
- Interstation Correlation Plots – "5" series figures.
- Synthesized Hydrographs – "6" series figures.
- Exceedance Probability Curves based on synthesized data – "7" series figures.

3.1 Rating Curves

Rating curves predict streamflow (discharge) from stream stage based on an empirical mathematic formula. Stage and discharge measurements collected over the 1 year monitoring period were used to these create rating curves for each of the stream gage locations. Techniques of discharge measurement are discussed in Section 2.3. The stage-discharge data for each stream were fit with a power-law equation (Maidment, 1993) of the form:

$Q = C(h+a)^N$

Where: Q = discharge,

h = stage,

a = stage at which discharge is zero, and

N = constant related to cross-sectional shape or the stream channel.

The "2" series figures in Appendices A through G show the rating curves over the range of flow measurements for each of the streams gaged in this study. The "3' series figures extrapolate the rating curves up to the maximum observed stage. Verification of the ratings curves at high flows (that were not wadeable) may be accomplished by other measurement techniques or analytical methods. Application of these techniques and methods were beyond the scope of this project.

The figures include the parameter values used to provide the best fit to the data and the dates of application for each rating curve, if more than one rating curve applies to a station. The maximum peak transducer stage measured during the gaging period and the offset between the staff gage and transducer are also shown on these figures.

Table 3.1 summarizes the number and range of flow measurements used in rating curve development.

Table 3.1
Summary of Rating Curve Development
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Stream	Total Number of Flow Measurements	Minimum Flow Measured (cfs)	Maximum Flow Measured (cfs)	Rating curve shift observed during gaging period
Dosewallips River	6	117	533	No
Duckabush River	8	75	680	Yes
Fulton Creek	9	2	116	No
Hamma River	6	90	540	No
John Creek	8	2	73	No
Jorsted Creek	9	2	60	No
Eagle Creek	8	6	73	Yes

During the study, two shifts in hydraulic control were indicated by the flow measurements on the Duckabush River and, with analysis of the stage data, were determined to have occurred during high water events on December 10, 2004 and again on January 17, 2005.

A shift in hydraulic control at the Eagle Creek stream gage location occurred on January 17, 2005, as indicated by a change in the rating curve and analysis of the stage data.

No shifts in hydraulic control were noted at the Dosewallips River gaging station during the 2004-2005 period of gaging performed during this investigation. However, shifts in hydraulic control have occurred at this location. Stage and discharge measurements made during a 2003-2004 study of the hydrogeology of the Brinnon area at the location of the Dosewallips gaging station (Aspect Consulting, 2005) indicated that shifts in hydraulic control occurred during flooding in fall 2003 and again in the winter and/or spring. A relatively high flow measurement (the last in the Brinnon study) made on February 27, 2004 (Figure A-2) fell below the rating curve and indicates that the hydraulic control at the Highway 101 bridge shifted after that date prior to the gaging performed in this study. Additionally, we noted that the channel upstream of the bridge became significantly shallower and faster during the winter of 2004-2005. The observed shifts are significant when considering future long-term gaging on the lower Dosewallips River.

3.2 Hydrographs for 2004-2005

Stage measurements were converted to flow measurements using the rating curves described in Section 3.1. Flow data, at 15-minute intervals, for 2004-2005 are presented as hydrographs in the "4" series figures in Appendices A through G (i.e., Figures A-4, B-4, etc.). The resulting 15-minute flows were averaged to produce mean daily flow values for the gaging period. These hydrographs also include water temperature data collected at the gaging station and precipitation data from the USGS NF of Skokomish – Staircase Rapids station. Mean flow for 2004-2005 and mean synthesized flow for the base station period of record are presented on each of the hydrographs. Table 3.2, located at the end of this report, presents mean daily flow for each of the streams for the gaging period.

The rivers and streams which are part of this study have discharge patterns that are either snow-pack or precipitation dominated. The larger catchments (Duckabush, Dosewallips, and Hamma Hamma in Figures A-4, B-4 and D-4, respectively) are snow-pack dominated with peak discharge events typically occurring in December, in response to fall precipitation events, and again in late May to early June following snow melt. The smaller creeks (Fulton, John, Jorsted, and Eagle Creeks) are precipitation dominated stream flows that typically peak in December and decline into the summer months.

The gaging station at Eagle Creek was tidally influenced and stage data required additional processing to account for tidal effects. This processing is discussed at the end of Appendix G.

3.3 Interstream Correlations

Primary goals of the study are the future estimation of flows in the study stream from measurements at long-term monitoring stations on other streams and the development of exceedance curves based on synthesized historical hydrographs. Meeting these goals required interstation correlations between streamflow at the study streams with other, nearby long-term gaging stations.

Streams of interest were divided into snow pack and precipitation dominated streams and correlated to nearby streams with similar hydrologic characteristics. Criteria for a stream to be used as a long-term base station included:

- Geographic proximity
- Similar hydrologic response (i.e., snow-pack or precipitation dominated)

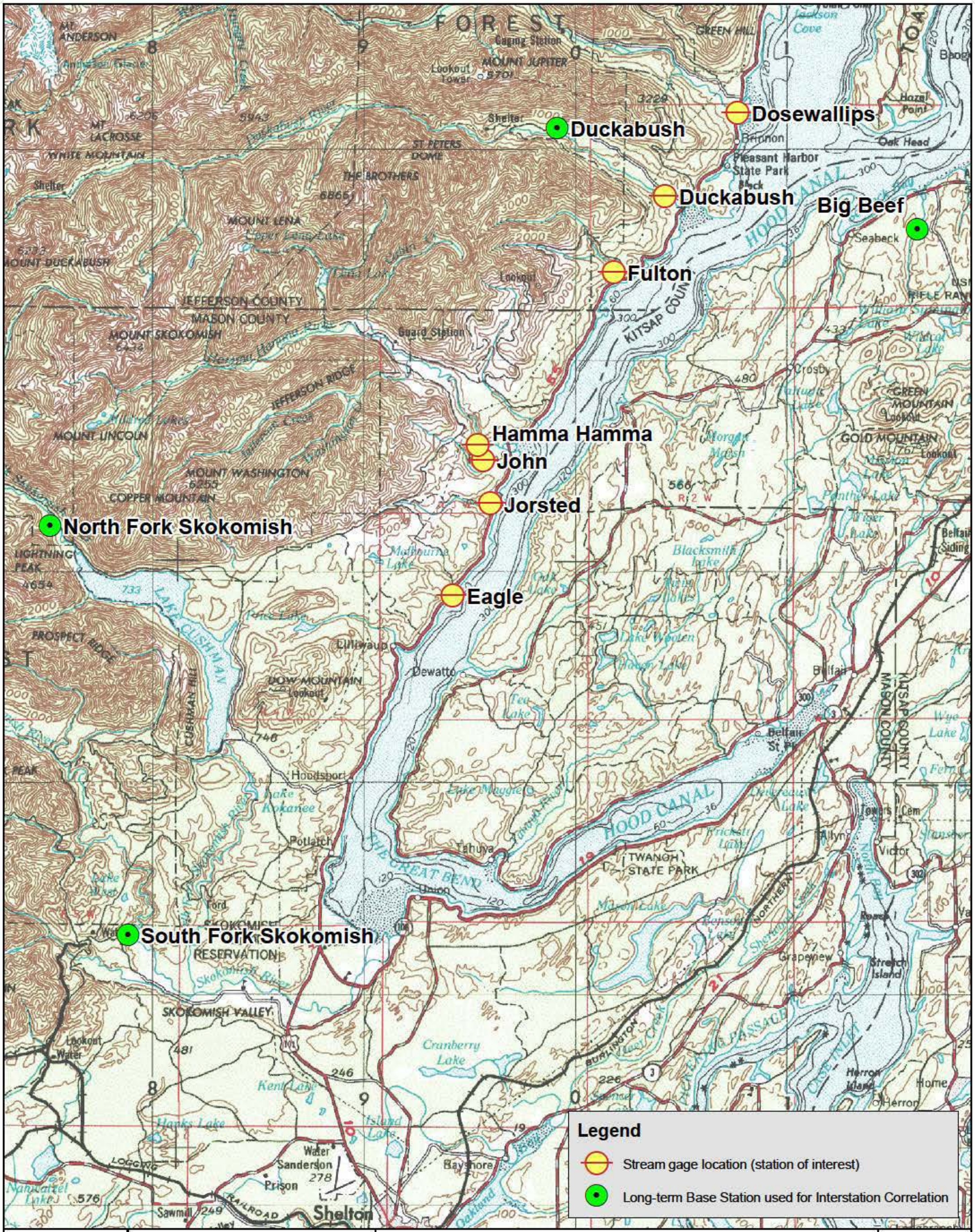
- Period of overlap with the station of interest
- Long historical record

Investigation of possible control streams indicated that the North Fork of Skokomish River in Mason County and the Duckabush River in Jefferson County (upstream of the stream gage location for this study) were suitable for correlation trials with snow pack dominated rivers. The South Fork of the Skokomish River, located in Mason County, and Big Beef Creek, located on the Kitsap Peninsula, were suitable for correlation trials with precipitation dominated streams. Each of these base stations have current, continuous monitoring and long historic records which could be used to create the necessary correlation plots. The locations of these streams are presented in Figure 3.1 relative to the streams of interest. Gaging period for each of these streams is presented in Table 3.3.

Interstream correlation trials were performed and the results summarized in Tables 3.4 and 3.5. The final correlation plots are presented in the "5" series figures in Appendices A through G (i.e., Figures A-5, B-5, etc.). The correlations were evaluated by the ordinary least squares regression method (OLS) (Hirsch, 1982), which uses the following equation:

Table 3.3
Base Station Streams Period of Record
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Stream	USGS Gaging Station	Period of Operation
North Fork Skokomish River	(12056500)	8/1/24 - Present
South Fork Skokomish River	(12060500)	8/1/31 - 9/30/84; 10/1/95 - Present
Duckabush River	(1205400)	7/1/38 - Present
Big Beef Creek	(12069550)	8/1/69 - 10/31/81; 6/23/83 - 11/3/94 (Intermittent); 5/1/95 - Present



Aspect consulting

LONG-TERM BASE STATION LOCATIONS

WRIA 16 Instream Flow Studies, Mason and Jefferson Co., WA

Figure 3.1

$\hat{y}_i = a + b\,\hat{x}_i$ where:

$\hat{y}_i$ = the estimated (or regressed) flow at the site of interest,

$\hat{x}_i$ = the flow at the long term base station, and

a and b = parameters used to minimize the sum of squared errors.

The quality of the correlation is characterized by the correlation coefficient r, typically expressed as the squared correlation r^2, which is a measure of the goodness-of-fit of the linear regression. The value of r^2 is between 0 and 1, where 1 indicates a perfect fit, and is calculated by the formula:

$$r^2 = 1 - \frac{SSE}{SS_{yy}}$$ with:

y_i = measured flow,

$\hat{y}_i$ = regressed flow, and

$\bar{y}$ = mean of all y_i. Then

SSE = sum of squared errors = $\Sigma (y_i - \hat{y}_i)^2$ and

SS_{yy} = sum of squares about the mean = $\Sigma (y_i - \bar{y})^2$.

SSE compares the data to the regressed line. SS_{yy} compares the data to a horizontal line, the mean, which represents the situation of no correlation. The squared correlation then represents the proportion of the total data spread accounted for by the regression.

Initial trials were performed by correlating all mean daily flow values from the stream of interest and the base station during the period of overlap, without respect to seasonality or flow intensity. For some streams, a better correlation was obtained by dividing the data into low flow and high flow regimes. In this two-line method, the potential exists for the r^2 values for the two individual line segments to be worse than the r^2 value computed by the single line correlation method and still provide a better overall correlation between the synthesized and measured data.

OLS regression of log-transformed data was also attempted, but the process tended to "desensitize" the data and had poorer correlation coefficients than regression of non-log transformed data. Specific correlation trials, results, and quantitative analysis of bias and scatter are discussed below.

A summary of the goodness-of-fit values for single and two-line correlations are presented in Table 3.4. To test the final correlation, the synthesized data created by the two-line method were correlated to the measured data**.** In cases where a better overall correlation was obtained using the two-line correlation, that correlation was applied in data synthesis. The final goodness-of-fit values for correlation of synthesized 2004-2005 data with gaged 2004-2005 data are summarized in Table 3.5.

Table 3.4
Goodness-of-Fit (r^2) Comparison of Measured Flows in Observation and Reference Streams
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

	Base Station Stream (USGS Station No.)							
	Big Beef Creek[2]	South Fork Skokomish River			North Fork Skokomish River	Duckabush River		
	(#12069550)	(#12060500)			(#12056500)	(#1205400)		
Goodness-of-Fit[1] r^2 Value / Station of Interest	All Data	All Data	Flow <500 cfs	Flow >300 cfs	All Data	All Data	Flow <500 cfs	Flow >300 cfs
Dosewallips River					0.81	.088	0.82	0.85
Duckabush River					0.95		0.99	
Fulton Creek	0.46	0.70	0.27	0.67			0.64	
Hamma Hamma River					0.93		0.96	
John Creek	0.64	0.80	0.57	0.79			0.63	
Jorsted Creek	0.86	0.76					0.60	
Eagle Creek	0.84	0.86						

[1] Shaded cells indicate station and method selected for data synthesis.
[2] Note period of intermittent data (see Table 3.3 and Figure F-7).

Table 3.5
Goodness-of-Fit (r^2) Comparison of
2004-2005 Synthesized Data with Gaged Data
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Station of Interest	Base Station	Goodness-of-Fit (r^2) between Synthesized and Gaged Data
Dosewallips River	Duckabush	0.92
Duckabush River	Duckabush	0.99
Fulton Creek	South Fork Skokomish	0.70
Hamma Hamma River	Duckabush	0.96
John Creek	South Fork Skokomish	0.81
Jorsted Creek	Big Beef Creek	0.86
Eagle Creek	South Fork Skokomish	0.86

3.3.1 Dosewallips River

Trial correlations were made for the Dosewallips River with the Duckabush River and the North Fork Skokomish River. Each of these rivers are snow-pack dominated. The best correlation was obtained with the Duckabush River with an r^2 value of 0.88 for all data (Table 3.5). However, inspection indicated that synthesized low flows would be biased upward. Therefore, the correlation plot was subdivided into a low (0-500 cubic feet per second [cfs]) and high (300 and greater cfs) flow regime to obtain a better fit to the measured data.

The individual correlation coefficients in the two-line method were somewhat less (r^2 = 0.82 and 0.85 for low and high flows, respectively) than for the single line correlation (r^2 = 0.88), but the overall correlation of synthesized data to measured data for 2004/2005 monitoring period produced a better correlation (0.92 for the two-line method compared to 0.88 for the single line method, Tables 3.4 and 3.5). The final correlation plot is presented in Figure A-5.

3.3.2 Duckabush River

The Duckabush River gaging station had an excellent correlation (r^2 = 0.99) with the USGS gaging station located approximately 4 miles upstream on the Duckabush River

(Figure B-5). The good correlation of data extrapolated beyond the rating curve (flows above 680 cfs) with the USGS station data confirms the validity of extrapolation of the rating curve. In general, the downstream station on the Duckabush River gaged during this investigation has greater flow than at the USGS gaging station. The absolute difference in flow between these stations increases with increasing flow. For example, flow at the USGS station of 200 cfs corresponds to a flow of 212 cfs at the downstream station gaged during this investigation (Figure B-5). A flow of 800 cfs at the USGS station corresponds to a flow of approximately 893 cfs at the study station.

A trial correlation was also made against the North Fork of the Skokomish River which gave a very good correlation coefficient ($r^2 = 0.95$), but nonetheless, and not surprisingly, poorer than that with the Duckabush River.

3.3.3 Fulton Creek

Trial correlations were made between Fulton Creek and precipitation dominated streams Big Beef Creek and South Fork Skokomish River. In addition a trial correlation was made with the Duckabush River due its proximity to Fulton Creek. The best single-line correlation was obtained with South Fork Skokomish River ($r^2 = 0.70$). This correlation underestimated low flows and resulted in negative values, suggesting Fulton Creek could potentially run dry. The land owner at the Fulton Creek gage indicated that he has never observed Fulton Creek go dry since 1984 (MacNealy, 2005). As such, the correlation plot was subdivided into low (0-500 cfs) and high (above 300 cfs) flow regimes to obtain a better fit to the observed data (Figure C-5).

While the individual correlation coefficients were less ($r^2 = 0.27$ and 0.67 for low and high flows, respectively) than for the single line correlation ($r^2 = 0.70$) (Table 3.4), the overall correlation of synthesized data to measured data for the 2004/2005 monitoring period produced a correlation coefficient equal to the single line method ($r^2 = 0.70$ in both cases, Table 3.5) and without the computation of negative flows.

3.3.4 Hamma Hamma River

The Hamma Hamma River gaging station had a good correlation ($r^2 = 0.96$) with the USGS gaging station located on the Duckabush River (Figure D-5). A slightly poorer correlation coefficient ($r^2 = 0.93$) was obtained in the correlation with the North Fork Skokomish River. Low flow is bimodal with the best fit line honoring the higher flow trend. At higher flows, inspection of the correlations suggests a slight downward bias for the synthesized Hamma Hamma River data.

3.3.5 John Creek

Trial correlations were made between John Creek and the precipitation dominated streams Big Beef Creek and South Fork Skokomish River and also with the Duckabush River, due to the laters proximity to John Creek. The best single-line correlation was obtained with South Fork Skokomish River ($r^2 = 0.80$). This correlation underestimated low flows and resulted in negative values, suggesting John Creek could potentially run dry at the upper Bridge where the gaging station was established. Rick Endicot with Long Live the Kings indicated that he has never observed John Creek running dry at the upper bridge during the last 12 years; however, he did indicate that the stream may run dry below the lower bridge (Endicot, 2005). To be consistent with observations at the upper bridge, the correlation plot was subdivided into low (0-500 cfs) and high (above 300 cfs) flow regime to obtain a better fit (Figure E-5).

The individual correlation coefficients were less ($r^2 = 0.57$ and 0.79 for low and high flows, respectively) than for the single line correlation ($r^2 = 0.80$), but the overall correlation of synthesized data to measured data for 2004/2005 monitoring period produced a correlation approximately equal to the single line method ($r^2 = 0.81$ for the two-line method compared to 0.8 for the single line method, Table 3.5) and produced a more plausible result without negative flows.

3.3.6 Jorsted Creek

Trial correlations were made between Jorsted Creek and precipitation dominated streams Big Beef Creek and South Fork Skokomish River. In addition, a trial correlation was made with the Duckabush River due its proximity to John Creek. The best single-line correlation was obtained with Big Beef Creek ($r^2 = 0.86$) (Figure F-5). Figure F-5 indicates high scatter for Jorsted Creek flows from about 4 to 60 cfs, potentially reflecting variability in precipitation patterns between Big Beef Creek located in Kitsap County and Jorsted Creek in Mason County.

3.3.7 Eagle Creek

Trial correlations were made between Eagle Creek and precipitation dominated streams Big Beef Creek and South Fork Skokomish River. A good single-line correlation was obtained with the South Fork Skokomish River ($r^2 = 0.86$) (Figure F-5) and no further correlation trials were performed.

3.4 Synthesized Hydrographs for the Period of Record of the Base Station

The period of flow of the study streams was extended based on the interstation correlations described in Section 3.3. Hydrographs of synthesized mean daily streamflow for the period of record for the base station are presented in the “6” series figures in Appendices A through G (i.e., Figures A-6, B-6, etc.). A qualitative presentation of the “goodness-of-fit” is presented in the inset graphs on these figures. The inset hydrographs compare mean daily discharge of the gaged flow and the synthesized flow for the period of record and, in effect, present the temporal variations between the gaged and synthesized flows. In general, the measured and synthesized hydrographs exhibit a reasonable correspondence with greatest discrepancies typically occurring during high flows events, which is consistent with the relatively greater scatter of the correlation plots at higher flows. Jorsted Creek presents an exception to this pattern, as discussed in Section 3.3.6.

3.5 Exceedance Curves

Exceedance curves show the flow value that will be exceeded a specified percentage of time on a specified date. That is, on a given date, there is, for example, a 50 percent probability that the flow will exceed 50 cfs. Since the reliability of exceedance curves increases with the period of record, the streamflow record was extended in order to create the longest record possible. The correlation techniques used are described in Sections 3.4 and 3.5. The synthesized mean daily flows were then sorted by the day of the year and the flow values calculated that would be exceeded 10 percent, 50 percent, and 90 percent of the time. These streamflow exceedance curves are presented in the "7" series figures presented in Appendices A through G.

4 Summary of Stream Gaging

4.1 Summary of Results

Results of the stream gaging are summarized in terms of mean daily flows in Table 4.1. Where nearby USGS gaging stations were available, the mean daily flows for the period of record are shown for comparison purposes. Annual averages were computed for the period from July 1 through June 30 for the one year gaging period for the study gages and for the synthesized records, except for Jorsted Creek which was averaged from August 15 through August 14. The percent of years that the 2004-2005 mean annual gaged flow on a study stream was exceeded in any given year is also shown and was computed based on the synthesized record.

Of the study streams, the greatest average annual mean daily streamflow (549 cfs) was computed for the Hamma Hamma River for the synthesized period of record. The Duckabush and Dosewallips Rivers had average mean daily streamflows of 457 and 416 cfs, respectively, for the synthesized period of record. Of the precipitation dominated streams, the greatest average annual mean daily flow was Fulton Creek at 54 cfs. John, Jorsted, and Eagle Creeks had average annual mean daily flows of 22, 22, and 20 cfs, respectively (Table 4.1).

The relatively dry gaging year is reflected in the high exceedance values shown in Table 4.1. Precipitation dominated streams (Fulton, John, Jorsted, and Eagle Creeks) were relatively consistent in the percent of years that exceed flows measured in the 2004-2005 averaging period, with 85 to 90 percent of years exceeding flows from the 2004-2005 gaged period. Similarly, snow-pack dominated streams (Dosewallips, Duckabush, and Hamma Hamma Rivers) were also relatively consistent in the percent of years that exceed the 2004-2005 average flow, with 73 to 76 percent of years exceeding the 2004-2005 gaged period, although the percent of years was less than for the precipitation dominated streams. These data suggest that for the 2004-2005 averaging periods, the larger basins, which are snow-pack dominated, were less impacted by the drought.

The relatively dry gaging year is not expected to have a significant effect on interstation correlations and hence, development of synthetic hydrographs and exceedance plots. Wetter years would have provided relatively more high flow data. High flow correlations generated during the study year would be expected to be representative of all years, to the extent that the population of storm events during the gaging period is representative of events during a wetter year, i.e., similar magnitude but at a different frequency. Long-term monitoring would provide additional data and refinement to correlations at higher flows.

Table 4.1
Comparison of Annual Mean Daily Discharge
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Stream	Gage Name[1]	Annual Averaging Period From		To	Mean Daily Discharge (cfs)	Percent of years exceeding 2004-2005 flows
Dosewallips River	USGS 12053000[2]	7/1/1931	-	6/30/1951	449	
	WRIA 16 PU (Synth w/ Duckabush)	7/1/1938	-	6/30/2005	416	
	WRIA 16 PU	7/1/2004	-	6/30/2005	385	73%
Duckabush River	USGS 12054000[3]	7/1/1938	-	6/30/2004	417	
	WRIA 16 PU (Synth w/ Duckabush)	7/1/1938	-	6/30/2005	457	
	WRIA 16 PU	7/1/2004	-	6/30/2005	398	78%
Fulton Creek	WRIA 16 PU (Synth w/ SF Skokomish[5])	7/1/1932	-	6/30/2005	54	
	WRIA 16 PU	7/1/2004	-	6/30/2005	40	85%
Hamma Hamma River	USGS 12055000[4]	7/1/1926	-	6/30/1930	461	
	WRIA 16 PU (Synth w/ Duckabush)	7/1/1938	-	6/30/2005	549	
	WRIA 16 PU	7/1/2004	-	6/30/2005	480	76%
John Creek	WRIA 16 PU (Synth w/ SF Skokomish[5])	7/1/1932	-	6/30/2005	22	
	WRIA 16 PU	7/1/2004	-	6/30/2005	16	87%
Jorsted Creek	WRIA 16 PU (Synth w/ Big Beef Creek[6])	8/15/1969	-	8/14/2004	22	
	WRIA 16 PU	8/15/2004	-	8/14/2005	14	90%
Eagle Creek	WRIA 16 PU (Synth w/ SF Skokomish[5])	7/1/1932	-	6/30/2005	25	
	WRIA 16 PU	7/1/2004	-	6/30/2005	20	85%

Notes:
1. USGS gages shown for broad comparison purposes. Locations of these gages vary from WRIA 16 gages as described below.
2. USGS Gage 12053000 on the Dosewallips River is located approximately 6.5 miles upstream from the WRIA 16 gage at the Highway 101 Bridge.
3. USGS Gage 12054000 on the Duckabush River is located approximately 3.9 miles upstream from the WRIA 16 gage.
4. USGS Gage 12055000 on the Hamma Hamma River is located near the location of the WRIA 16 gage
5. South Fork Skokomish River gage was inactive from 10/1/1984 through 9/30/1995.
6. Big Beef Creek gage was intermittently active from 6/23/1983 to 11/3/1994. These periods were not included in mean daily discharge estimates for Jorsted Creek, as including them would have introduced low-flow bias.

4.2 Data Limitations

Accuracy of the data was limited by several factors as described below. End users of the data should keep these limitations in mind.

- Rating curves were extended considerably beyond the highest measurements and such extrapolation can result in considerable misinterpretation at high flows. Except for the Duckabush River, there were no checks on the accuracy of high flow estimates.
- Correlations between streams of interest and long-term base stations were limited by the 1 year period of record. Typically 2 or more years of record are used in developing correlations (Maidment, 1993). As gaging was performed during a relatively dry year, correlation plots may not include the highest flow events, nor the population of storm events generated by a wetter year (see Section 4.1). Precipitation patterns in the Hood Canal region are variable and correlations were thus limited, with the exception of the Duckabush River, by the geographic separation between a study stream and base station.
- Hydrologic response characteristics of the basins vary, even within precipitation or snow-pack dominated types.
- Shifts in hydraulic control occurred on the Duckabush River and Eagle Creek, limiting the number of points that could be obtained to define rating curves over the project duration.
- For Eagle Creek, a number of assumptions were necessary in order to correct for tidal effects on the stage data. These assumptions include the methodology of dividing flows into two regimes for analysis, the non-significance of storage at high flows, and the use of minimum observed stage to characterize discharge in the low flow regime. The methodology is discussed more fully in Appendix G-8.

5 Fish Passage Study Area and Target Species

5.1 Study Area Streams

Three streams were evaluated in the course of this study: Fulton Creek, John Creek, and Jorsted Creek. The stream locations are presented in Figure 1.1. Fulton Creek and Jorsted Creek discharge directly to Hood Canal whereas John Creek is a tributary of the Hamma Hamma River. Each of the streams evaluated drain relatively small catchments and baseflows for these streams during the summer of 2004 were less than 4 cfs. All of the streams are unregulated (no dams) and originate on the eastern side of the Olympic Mountain range. The study sites were placed in low gradient reaches of the stream where the dominant channel units were riffle-pool and riffle-run. Gravel was abundant in all of the streams surveyed. For John and Jorsted Creek the dominant substrate in the riffle was composed of large gravel (1 – 3 inches) and cobble (3 – 6 inches). Riffle substrates in Fulton Creek were larger and consisted primarily of cobble and rubble (6 – 12 inches).

5.2 Target Species

Target species for this study were selected in consultation with the WRIA 16 Planning Unit (Table 5.1). The species identified by the Planning Unit for consideration in this study are Chinook salmon, fall- and summer-run chum salmon, pink salmon, coho salmon, steelhead trout, and coastal cutthroat trout. Summer-run chum salmon are currently listed as Threatened under the Endangered Species Act (ESA) and are subject to the regulatory oversight and protection of the United States Fish and Wildlife Service (USFWS) as well as the National Oceanic and Atmospheric Administration – National Marine Fisheries Service (NOAA-Fisheries).

Table 5.1
Species Considered in Fish Passage Study by Creek
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

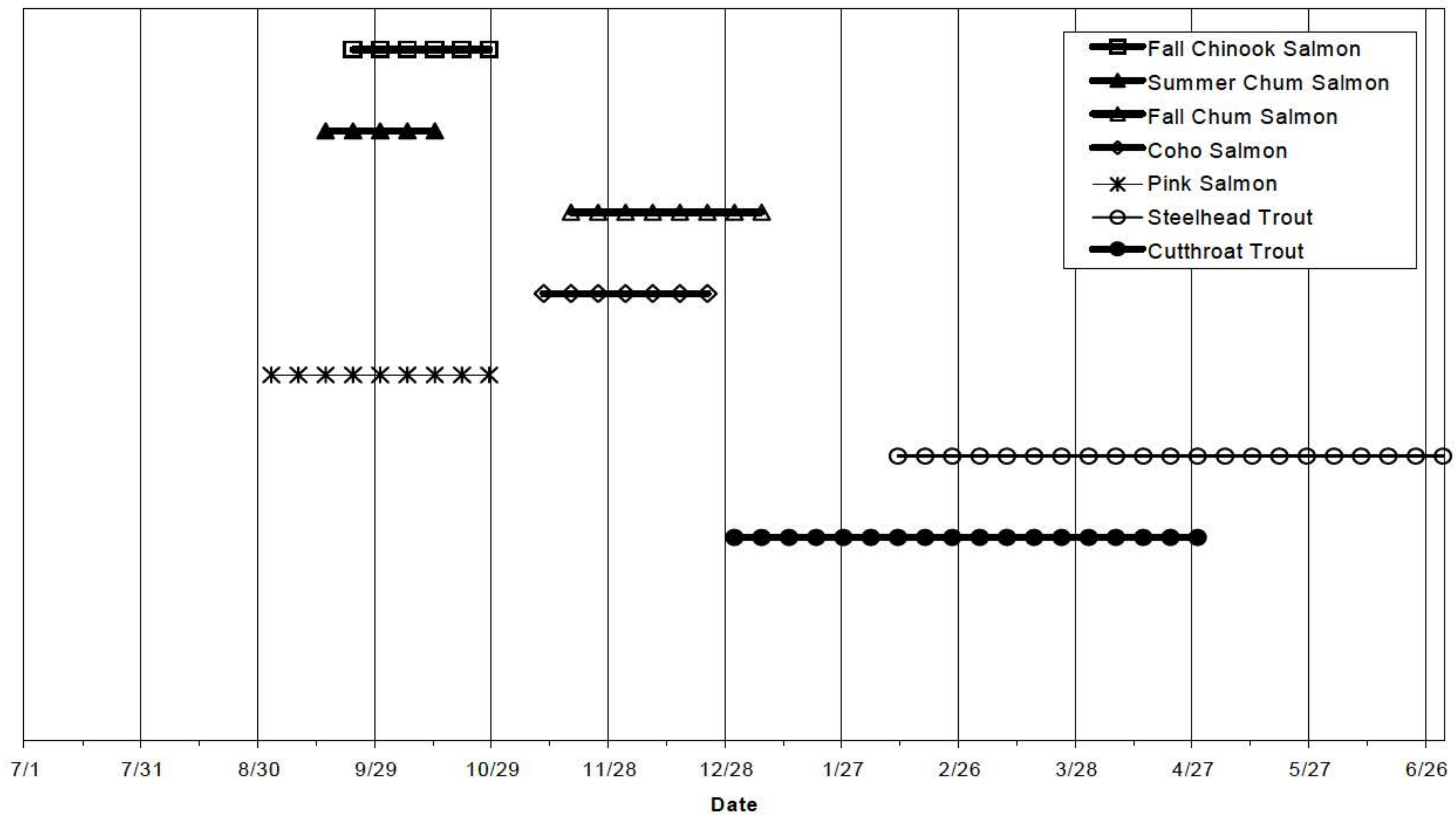
Creek	*Fall Chum*	*Summer Chum*	*Pink*	*Coho*	*Cutthroat*	*Steelhead*	*Chinook*
Fulton	X	X	X	X	X	X	
John	X	X	X	X	X	X	X
Jorsted	X		X	X	X	X	

Figure 5.1 illustrates the approximate timing for spawning by the target species in the study area. These estimates were obtained from the Salmon and Steelhead Stock Inventory (Washington Department of Fisheries and Wildlife, 1992) and the Salmonid Stock Inventory for Coastal Cutthroat Trout (Washington Department of Fisheries and Wildlife, 2000). In circumstances where periodicity was not explicitly identified for study area streams, activity windows were defined using nearby streams. Figure 5.1 does

not specifically identify adult freshwater migration. However, since the study area streams are in close proximity to Hood Canal, lengthy migratory periods are not required. Under optimal flow conditions, individual fish could easily traverse the stream from Hood Canal to upstream spawning areas in less than a day. Therefore, for the purposes of this study, adult migration is coincident with spawning activity.

All of the target species are believed to spawn in John Creek. It is believed that all of the target species, use Fulton Creek, however, chinook and summer-run chum salmon are not abundant. Summer-run chum salmon and Chinook salmon are not known to spawn in Jorsted Creek.

Figure 5.1 - Spawning Period for Target Species in WRIA 16 Streams



6 Methods of Fish Passage Study

6.1 IFIM Overview

Passage flows were determined using the Instream Flow Incremental Methodology (IFIM) to evaluate depths and velocities at numerous flows. The IFIM was designed to enable scientists and resource managers to evaluate streamflows at small incremental changes in order to identify a "desired" resource state. IFIM is a comprehensive methodology within which there are a number of methods that can be used to develop instream flow recommendations for specific purposes. Specific approaches for setting instream flows generally fall into one of three categories; 1) statistical, 2) hydraulic geometry, and 3) habitat based methods. The method applied in this study to identify adult passage flow requirements falls under the category of hydraulic geometry and is a variant of Thompson's Methodology (1972).

Thompson's Methodology is designed to identify the streamflow necessary for adult salmon and trout to successfully pass through the most restrictive portion(s) (often termed "critical riffles") of a stream en route to spawning areas. This method typically consists of three main components: 1) selection of the critical passage areas, 2) collection of bed profile and stage discharge measurements at these critical passage areas and 3) identification of applicable passage criteria for the target species. Using the Thompson Methodology, a transect is deemed passable when a combination of depths and wetted widths are greater than conditions specified by the criteria for upstream passage.

6.2 Passage Criteria

Passage criteria provide the means to determine if hydraulic conditions are suitable for the upstream passage of the target species. In this study, criteria were used to evaluate upstream passage conditions at numerous (30) different streamflows on each stream. Each simulated streamflow was classified as either suitable or unsuitable for fish passage. The passage criteria used in this analysis are discussed in greater detail in Sections 6.2.1 and 6.2.2 and were designed to be conservative and protective of fisheries resources. As such, fish are able to pass over transects at flows less than those identified in the passage analysis, although these flows may not be optimal. As suggested by Thompson (1972), recommended passage flows are the average of the lowest streamflow providing passage for each species at the transects on each study stream.

Regional differences in flow and disturbance regimes and selective pressures influence local fish population characteristics for a given species (e.g., size, weight, swimming speed, migration timing, habitat utilization, etc.). In the absence of site-specific criteria, criteria developed in streams with similar physical characteristics and in close proximity to the study area are desirable to accurately represent these regional differences. The use of inaccurate criteria or general criteria obtained in literature can result in erroneous minimum flows that range from those inadequate to protect aquatic resources, to those well in excess of what is needed to meet resource management goals.

An informal survey of instream flow practitioners was conducted to determine if site-specific or regional passage criteria had been developed for Hood Canal streams. None of the individuals contacted were aware of the existence of any such criteria. Two sets of criteria were used to evaluate the suitability of individual streamflows for fish passage. These were Thompson's original criteria, and a second set of criteria based on limited observations within the project streams (Observation Based Criteria). The rationale for selection of these criteria and their suitability thresholds are presented in the sections that follow.

6.2.1 Thompson's Criteria

A literature review and informal survey of local instream flow practitioners was unable to identify any other studies that applied Thompson's Methodology using criteria other than those originally proposed in his 1972 paper. But, as previously discussed, this search also failed to find other more site specific or regional criteria. In the absence of site-specific passage criteria it was decided that the criteria originally presented in Thompson (1972) would be most appropriate for this study. Passage criteria were initially selected in consultation with the WRIA 16 Planning Unit in a meeting that occurred on May 6, 2004.

Thompson's criteria specify that at least 25 percent of the wetted width of the channel must be greater than a species specific depth (e.g., 0.8 feet for Chinook salmon) and that at least 10 percent of the wetted width satisfying the depth criteria must be contiguous (Table 6.1). Thompson's criteria also specify that mean column velocities for discrete locations along the transect must be lower than recommended values. Minimum instream flows are generally derived from the average of passage values from all transects in a particular reach. It is generally recognized that fish do not require such large widths to successfully navigate a habitat unit, but the criteria are intentionally conservative in that they are designed to be protective of aquatic resources.

Table 6.1
Thompson's (1972) Passage Criteria for Target Species
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Species	Depth Criteria (feet)	Percent of Total Width	Percent of Width Contiguous	Velocity Criteria (fps)
Chinook Salmon	> 0.8	25	10	8.0
Coho Salmon	> 0.6	25	10	8.0
Chum Salmon	> 0.6	25	10	8.0
Pink Salmon	> 0.6	25	10	8.0
Steelhead Trout	> 0.6	25	10	8.0
Cutthroat Trout	> 0.4	25	10	4.0

6.2.2 WRIA 16 Passage Criteria

It has been our experience that these Thompson criteria are often overly conservative in providing fish passage, indicating passage flow requirements much higher than those at which salmonids have actually been observed to migrate. This was also the case in the streams studied here. The passage flow requirements based on the Thompson criteria suggested flows that rarely occur for most streams, although these streams are known to support populations of the target species, as described above. Based on this, we developed site specific criteria (the Observation Based Criteria), based on a limited set of observations made during field data collection for this project, as described below.

The Observation Based Criteria were developed with the objective of selecting recommended passage flows with greater biological relevance to the target species in the study area streams than the Thompson Criteria. The Observation Based Criteria described in this section seek to incorporate 1) behavioral observations specific to the study area and 2) empirical data from other systems regarding physiological capabilities of the target species. The passage criteria used in this study (WRIA 16 passage criteria) classify a streamflow suitable for passage if a depth of greater than 0.31 feet is achieved for a contiguous wetted width greater than 6.0 feet.

Field personnel observed numerous chum salmon and a few coho salmon pass over the study transects while collecting data for the hydraulic geometry models (see Section 6.4.1, *Field Observations*). It was clear at the time these observations were recorded, that some of the target species were passing over the transects at much shallower depths and narrower widths than were considered suitable using Thompson's criteria.

Adult chum salmon were the most commonly observed target species in the study area, most observations occurred in John Creek. Chum salmon were observed passing over the study area transects at flows approaching those that would restrict passage. Transect XS-2 on John Creek was about two or more times wider than any of the other transects surveyed. Because of its width, and correspondingly shallow depths, this was the most restrictive of the six transects surveyed. Chum salmon passed over this transect at a flow of approximately 8 cfs. The section of the transect used by chum salmon ranged in depth from 0.31 to 0.43 feet, was approximately six feet wide, and roughly 50 feet in length. Chum salmon passing through this gap did not restrict themselves to the deepest portion of this channel, but used the shallower areas as well. Passage through such shallow areas has also been observed in side channel slough habitats of the Susitna River in Alaska. Chum salmon often were observed crossing shallow bars (depth = 0.2 to 0.4 feet) that were 20 to 30 feet in length (Trihey, 2004). So the depths and widths presented by Thompson are likely greater than those actually necessary for chum salmon passage. While it is recognized that smaller fish may pass over restrictive areas at lesser depths than larger fish, evaluation of this hypothesis was beyond the scope of this study.

Other fish species were only observed passing over the transects at flows much higher than those appropriate for the development of passage criteria. Although coho salmon, pink salmon, and steelhead trout were not observed passing over the transects at "restrictive" flows, there is a behavioral and physiological basis for assuming that width and depth combinations suitable for chum salmon passage are also suitable for these species. For example, coho salmon, pink salmon, and steelhead trout are known to pass over very shallow portions of the stream en route to spawning areas. Coho salmon have been observed passing over shallow riffles with depths as low as 0.16 feet (Sandercock, 1991). Pink salmon have been observed spawning in depths as shallow as 0.32 feet (Heard, 1991) and likely pass over much shallower areas en route to spawning. From a physiological perspective, chum salmon are known to have lesser swimming abilities than other salmonids. Prolonged swimming speeds for chum salmon (“those activities lasting 15 seconds to 200 minutes which will result in fatigue") range between 2.6 and 7.7 fps (Powers and Orsborn, 1985). Coho salmon (3.4-10.6 fps) and steelhead trout (4.6-13.7 fps) have considerably higher prolonged swimming speeds. Pink salmon have prolonged swimming speeds roughly equivalent to chum salmon.

Chinook salmon have very high prolonged swimming speeds (3.4-10.8 fps) but, because of their larger body size, likely have greater depth requirements. Chinook salmon do not utilize Jorsted Creek or Fulton Creek, and did not appear to be abundant in John Creek during the course of this survey (only two unconfirmed sightings). Therefore, it was not possible to develop site specific criteria for Chinook salmon from field observations. For the purposes of this study, we assume that a depth greater than 0.31 feet for a contiguous wetted width greater than 6.0 feet is suitable for Chinook salmon passage although, in all likelihood it is not optimal.

Cutthroat trout were not observed during the course of this study but because they are small fish and are known to spawn in streams smaller than those examined in this analysis, they likely have lesser width and depth requirements than the other target species. Therefore it is reasonable to assume that instream flows of sufficient magnitude to provide passage for the other target species are also suitable for coastal cutthroat trout passage.

6.3 Transect Selection

Two transects were placed on each of the three study area streams. Study sites were located in spawning reaches of the study area streams and were therefore below natural and artificial barriers to anadromy. The Planning Unit Transect Selection Team (TST) walked extended reaches of each stream, flagged individual riffles that represented good locations for the study. Study transects were then placed in locations in the stream where passage would most likely be limiting. All transects, with the exception of Jorsted XS-3 were selected in consultation with members of the WRIA 16 Planning Unit. Transect XS-3 was installed in November of 2004 as a replacement for XS-1. Transect XS-1 was abandoned at the request of area landowners.

Each transect selected by the TST was marked with headpins using rebar driven into the ground or with nails in trees. Transects were oriented such that the line of the transect followed the contour of the shallowest portion of the riffle. A staff gage was placed at each transect location to facilitate stage (water surface elevation) measurement at different flows. Headpins and staff gages were installed at the time of selection to facilitate relocation of the transects during fall 2004, when the first set of measurements were to be taken.

Headpins for the Riffle length varied from site to site but generally ranged between ten and 30 feet. In most cases, riffle crests selected as study transects had similar characteristics to other riffle crests throughout the study reach, although they were somewhat shallower. Transect XS-2 on John Creek was unusual in that it was wider and shallower than other riffles observed on John Creek. This riffle, at roughly 50 feet in length, was also much longer than the riffles studied on other creeks. The area immediately upstream of this transect is used extensively for spawning and more adult chum salmon were observed in the vicinity of this transect than were observed for the remainder of transects combined. Because of the width of this transect, large increases in discharge are necessary to produce small changes in flow depth.

6.4 Field Methods

6.4.1 Field Observations

During each survey field personnel documented the presence or absence of target species in the stream. Field personnel also noted the presence of carcasses and potential redds. In the event that fish were observed in the stream, brief descriptions of their behavior were recorded (e.g., redd construction, holding, migration). Field personnel attempted to estimate the total number of fish observed and to identify individual fish to the species level.

Bed elevations were spot checked during the higher flow measurements to ascertain if channel changes had occurred in the period between field measurements. Other indicators of potential channel changes such as evidence of sediment deposition or bed mobilization/scour on the substrate were visually assessed during each survey.

6.5 Modeling Overview

The data requirements of this analysis include stream discharge, stream stage (water surface elevation), and channel geometry. Stage and discharge were measured on three occasions for each of the study area streams. Channel geometry was measured at the lowest of the three flow events.

6.5.1 Discharge

Discharge was measured using standard USGS protocols (Rantz, et al., 1982). Measurements were collected in close proximity to the study stream gaging stations. For each measurement field personnel recorded the date and time of the measurement as well as stream stage at the study staff gage. Flow measurements were collected at locations with the best characteristics for a good flow measurement, not on the passage analysis transects. A Swoffer 3000 velocity meter was used for all discharge measurements. The meter was calibrated using manufacturer protocols prior to use in the field.

6.5.2 Passage Transect Stage Measurements

Stream stage (water surface elevation) was measured relative to a local benchmark at each cross section using standard surveying techniques. Distance across the transect was measured using a fiberglass tape. Tapes were zeroed on the left bank (when facing upstream) and the distance to the right bank headpin was recorded so that the same stations could be re-occupied during subsequent field visits. In circumstances where stream stage was influenced by more than one hydraulic control, water surface elevations were surveyed for each distinct elevation and the distance across the tape was recorded.

Staff gages were installed in the thalweg of each transect and gage readings were used as a quality control check for survey measurements.

6.5.3 Hydraulic Simulations

The data collected at the study transects were used to develop stage-discharge models which were used for the fish passage analyses. Stage-discharge predictions were developed using the IFG4a regression model of the RHABSIM program (Thomas R. Payne & Associates, 1998). This model regresses the logarithm of discharge against the logarithm of water surface elevation minus the stage at zero flow. For each transect, 30 different discharges and stages were simulated. Simulated discharges ranged between 0.4 times the minimum measured flow and 2.5 times the maximum measured flow.

RHABSIM is capable of modeling only one stage per transect. For transects with non uniform water surface elevations across the transects, resulting from complex channel geometry, the water surface was leveled. This was accomplished by setting all of the water surfaces equal to the water surface over the thalweg. The bed elevation below each location where the water surface was adjusted, was then adjusted upward or downward by the same amount to maintain the observed depth of flow. Because of the complexity of the channel geometry along the study transects, water surface elevations in some locations may be more responsive to changes in flow than other locations. That is, as streamflow increases, depth in one section of a transect may increase quickly whereas little change in depth might be observed at another section. Therefore, the stage-discharge model may not accurately predict depth at all locations along the transect. Because field measurements used in the stage-discharge model were collected over the thalweg, the model should have relatively high accuracy in the location most likely to be used by fish for passage.

6.5.4 Passage Frequency Analysis

For each stream, Thompson's and Observation Based Criteria were used to evaluate the frequency with which the different target species would be able to migrate upstream based on the 10, 50 and 90 percent exceedance flows[2] during each species' spawning period. Hydrologic information described in Section 3 was used for this analysis. This information provided exceedance flows for each day based upon a period of simulated record typically extending back to the 1930s (Table 3.3). A similar evaluation was performed based on the actual daily flows recorded at the study stream ages from July 19, 2004 to July 18, 2005. These analyses provide insight into how frequently passage might be a problem for the different species, given the differences in their spawning periods and the variability in streamflows during these periods. This provides a cross check regarding the biological relevance of the criteria used, as well.

[2] An exceedance flow is a description of a flow level that would be equaled or exceeded a specified proportion of the time. Thus, statistically, one would expect that if one had a 90% exceedance flow of 5 cfs for a period, then the measured flow would be equal to or greater than 5 cfs in nine out of every 10 days during that period. For a 10 % exceedance flow, one would expect that this flow would be equaled or exceeded only one of every 10 days in the period. For exceedance flows calculated on the same data set, a 90% exceedance flow will be lower than a 50% exceedance flow, which in turn is less than a 10% exceedance flow.

This analysis will tend to be somewhat conservative (under-predict the frequency with which passage would be provided) in that salmonids are highly opportunistic and may take advantage of small changes in flow (such as diurnal fluctuations), or short duration pulses (associated with precipitation) to move upstream past critical areas. These short-term fluctuations would be masked in the mean daily flow records used for this analysis. Although larger flow fluctuations are more likely to be reflected in the daily record, the frequency of passage under either set of criteria may be greater than indicated.

7 Results of Fish Passage Study

7.1 Field Observations

7.1.1 John Creek

Field crews visited John Creek on the 21st of July, the 14th and 19th of September, and 3rd of November, 2004. The lowest of the measured flows (1.23 cfs) was observed during the July field survey. Water surface elevations at the high, middle, and low flows and the channel geometry for transects XS-1 and XS-2 are presented in Figures 7.1 and 7.2. None of the target species were observed at either transect XS-1 or XS-2.

During the September 14th field survey, stream discharge was approximately 4.5 cfs. Field personnel checked the staff gage at XS-1 and determined that streamflows were not substantially different from those measured in July. Consequently, detailed stage and discharge measurements were not collected during this site visit. Two chum salmon were observed in the vicinity of XS-1. Five chum salmon were observed beneath overhanging vegetation in the left bank side channel immediately downstream of XS-2. One of the chum salmon unsuccessfully attempted to cross over XS-2. Depths across the thalweg ranged between 0.26 and 0.38 feet. Field personnel did not survey upstream of XS-2, however no fish were readily observable in the reach immediately upstream of the transect.

During the September 19th field survey, stream discharge was approximately 8 cfs. Field personnel observed three redds in the vicinity of XS-1. The first was located approximately three feet upstream of the transect and the second was approximately 10 feet upstream. A third redd was located approximately three feet downstream of XS-1. Two chum salmon were observed immediately upstream of the staff gage. Spawning activity appeared to have slightly modified the channel geometry of the transect. Two chum salmon passed over the transect during the course of the survey. One obvious redd was observed approximately 30 feet upstream of XS-2 and two chum salmon occupied positions over the redd. Approximately 12 fish, with their backs out of the water, were observed at the next riffle upstream of XS-2. Other fish could be seen splashing in the stream approximately 300 feet upstream of XS-2. Three chum salmon were observed passing over XS-2 during the course of the survey. These fish passed through the deepest part of the riffle near the left bank, but were not confined to the deepest portion of this area. This part of the channel was approximately six feet in width and had a minimum depth of 0.31 feet and a maximum depth of 0.43 feet. No apparent changes in channel geometry occurred on the transect. Two fish that appeared to be Chinook salmon were observed near the study stream gaging station. These fish were large and appeared to have spots along the entire width of the caudal fin. This station is approximately 1,000 feet upstream of XS-2. Flow records for the station indicate that maximum instantaneous flow during the intervening period was 10.5 cfs. Measured flow on the 19th was 8 cfs. The predicted water surface elevation at XS-2 for these two flow events differed by only 0.03 feet, so these fish apparently moved upstream under conditions similar to those observed on the 19th.

Figure 7.1 - Channel Geometry and Water Surface Elevation, John Creek XS-1

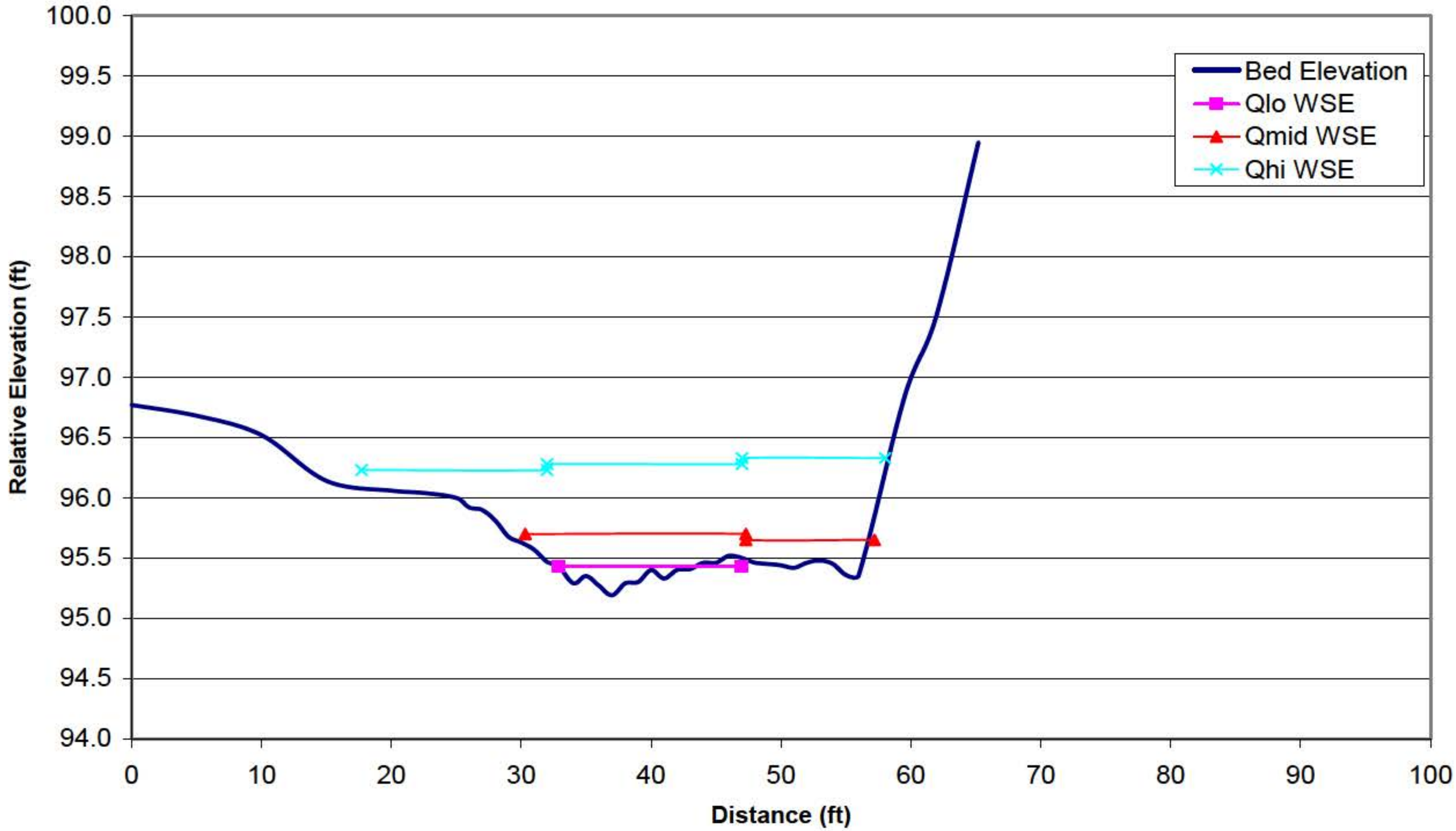
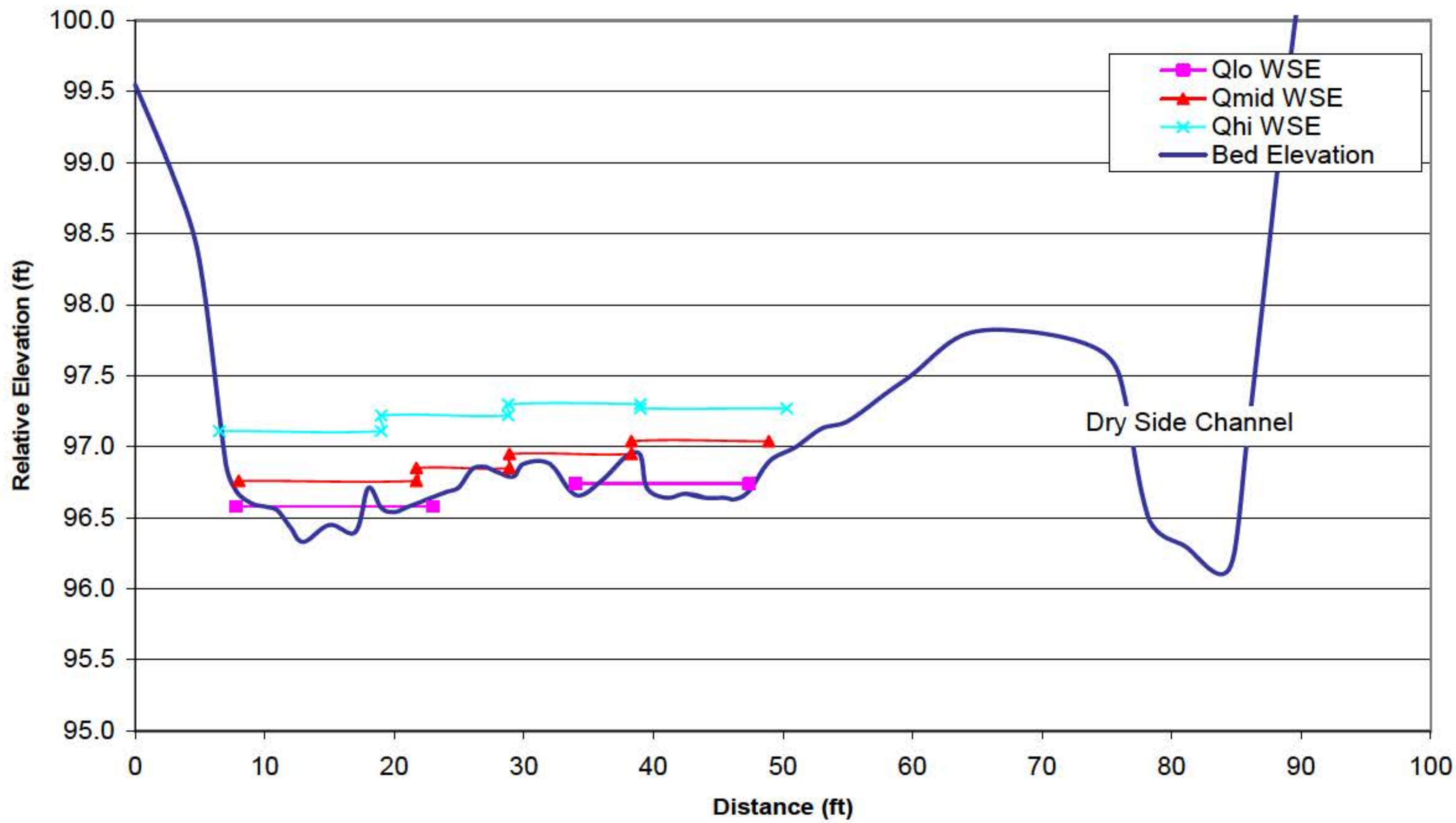


Figure 7.2 - Channel Geometry and Water Surface Elevation, John Creek XS-2



During the November 3rd field survey, stream discharge was approximately 58 cfs. The stream was very turbid. Numerous chum salmon and possibly one coho salmon passed over the transect XS-1 during the survey. Evidence of intensive spawning activity was observed in the immediate vicinity of XS-1 and the channel geometry was modified slightly as a result. Stream velocities were very high in the center of the channel and several chum salmon were observed holding on the lateral margins of the channel. Perhaps as many as 100 chum salmon were observed immediately upstream of transect XS-2. Stream velocities were considerably lower at XS-2 than at XS-1 and fish were actively spawning. Numerous chum salmon and possibly one coho salmon passed over XS-2 during the course of the survey. Fish were no longer coming up the left bank side channel but instead, were using the right bank side channel.

7.1.2 Fulton Creek

Field measurements at Fulton Creek were collected on the 21st of July, the 14th of September, and the 19th of December, 2004. Measured flows were 1.16, 16.21, and 39.15 cfs respectively. The channel geometry and water surface elevations for the field measurements are presented in Figures 7.3 and 7.4. None of the target species were observed during the July 21st field survey.

During the September 14, 2004 field survey, personnel measured water surface elevation on the study transects and measured a streamflow of 16 cfs near the study gaging station. None of the target species were observed during the course of the survey however, one possible redd was observed upstream of XS-1.

Field personnel collected flow data on Fulton Creek on December 19, 2004 when streamflow was measured to be 39 cfs. Surveys included target species observations, water surface elevation measurements at the transects, stream discharge measurements, and channel geometry assessments. Two chum salmon crossed over XS-1 near the right bank during the course of the survey. Water depths along this part of the transect ranged between 0.3 and 0.5 feet. Stream velocities were less than 1.0 fps and the fish passed through the 20-foot long riffle with relative ease. One coho salmon was observed downstream of XS-2 beneath a large piece of wood. Approximately 12 chum salmon, one coho salmon, and one unidentified trout were observed upstream of XS-2. The channel geometry assessment was performed to determine if changes in channel geometry occurred since the time of the last survey. These assessments consisted of bed elevation spot checks at various points along the transect and were conducted using the surveying techniques described previously. Visual surveys were also conducted to identify evidence of scouring or localized sediment deposition. The dominant substrate along XS-1 and XS-2 is fairly large, relative to what was observed in the other study area streams, and consisted primarily of cobble (3 – 6 inches) and rubble (6 – 12 inches). Both the bed elevation spot checks and the abundance of algae on the rocks indicated that few channel changes occurred on the transects. Some clean gravels were observed near the right bank of XS-1 and could potentially be attributed to spawning activity. Some sand deposition was observed on transect XS-2 between stations 2.5 and 8.0.

Figure 7.3 - Channel Geometry and Water Surface Elevation, Fulton Creek XS-1

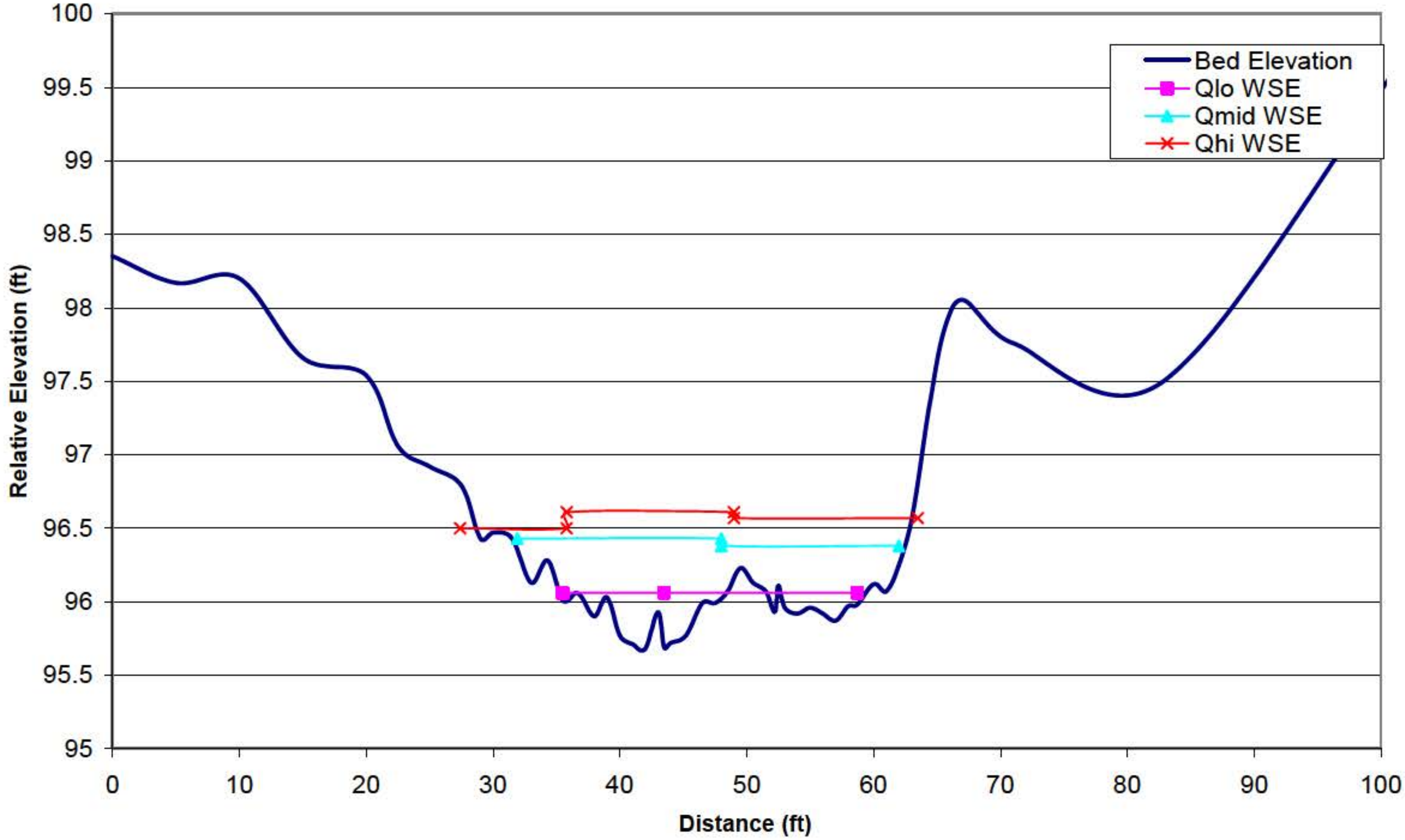
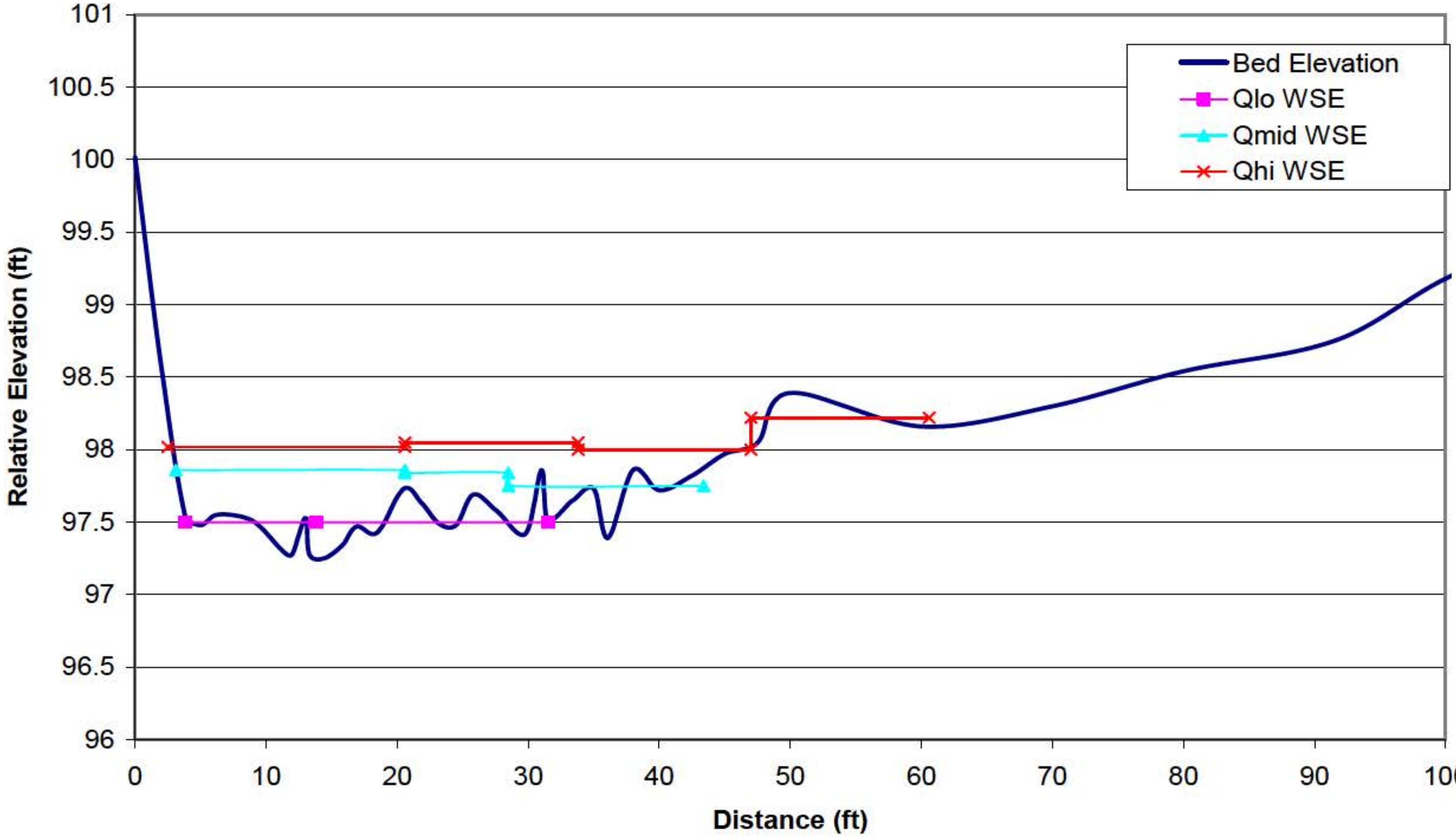


Figure 7.4 - Channel Geometry and Water Surface Elevation, Fulton Creek XS-2



7.1.3 Jorsted Creek

Field personnel visited Jorsted Creek on the 21st of July, 19th of September, 3rd and 12th of November, and the 19th and 23rd of December. Field measurements were collected at transect XS-1 during the July survey but were not collected during subsequent events at the request of a nearby landowner. A third transect was installed approximately 300 feet upstream of XS-2. Figures 7.5 and 7.6 present the relative elevation of the water surfaces at high, medium, and low flows.

Channel geometry and water surface elevation were measured at XS-2 during the July 21st field effort. Streamflow was measured as approximately 3.5 cfs. None of the target species were observed in the stream during the July and September field surveys.

Streamflow was approximately 32 cfs during the November 3, 2004 field survey and the water column was very turbid. No fish were observed during the survey, however, several potential redds were observed in the vicinity of transects XS-2 and XS-3. Because of the extended period between field surveys, field personnel used surveying equipment to spot check relative bed elevations at various locations along transect XS-2 to determine if major changes in channel geometry had occurred. These spot checks indicated that little, if any changes had occurred since the last survey. However, the absence of algae on the substrate in the thalweg indicated that some scouring had occurred, perhaps due to spawning activity or elevated streamflows. Regardless, the channel geometry was essentially the same as during the previous surveys. Algae was largely absent on the substrate in the thalweg of XS-3.

During the November 12, 2004 survey, streamflow was approximately 8 cfs. None of the target species were observed in the vicinity of XS-2, but two chum salmon were observed just downstream of XS-3. These fish did not attempt to cross the transect while field personnel were on site. Chum salmon were observed constructing a redd in close proximity to the study stream gage (downstream of XS-2). Some localized bank erosion was observed at XS-2. This channel adjustment did not appear to affect stream stage at the staff gage.

On December 19, 2004, streamflow in Jorsted Creek was approximately 29 cfs. Because this flow was similar to the flow measured on November 3, 2004, field personnel did not collect measurements. Four chum salmon were observed over a gravel patch just downstream of XS-3. No attempt was made by the fish to cross over the transect during the time that field personnel were on site. Numerous salmon carcasses were observed in a rootwad near XS-3. A coho salmon was observed on the lateral margins of the stream near XS-2.

Field personnel collected data at transect XS-3 on December 23, 2004 at a streamflow of approximately 17 cfs. Three chum salmon were observed downstream of the transect and appeared to be holding over a patch of gravel. Approximately four chum salmon were observed in close proximity to the study gaging station.

Figure 7.5 - Channel Geometry and Water Surface Elevation, Jorsted Creek XS-2

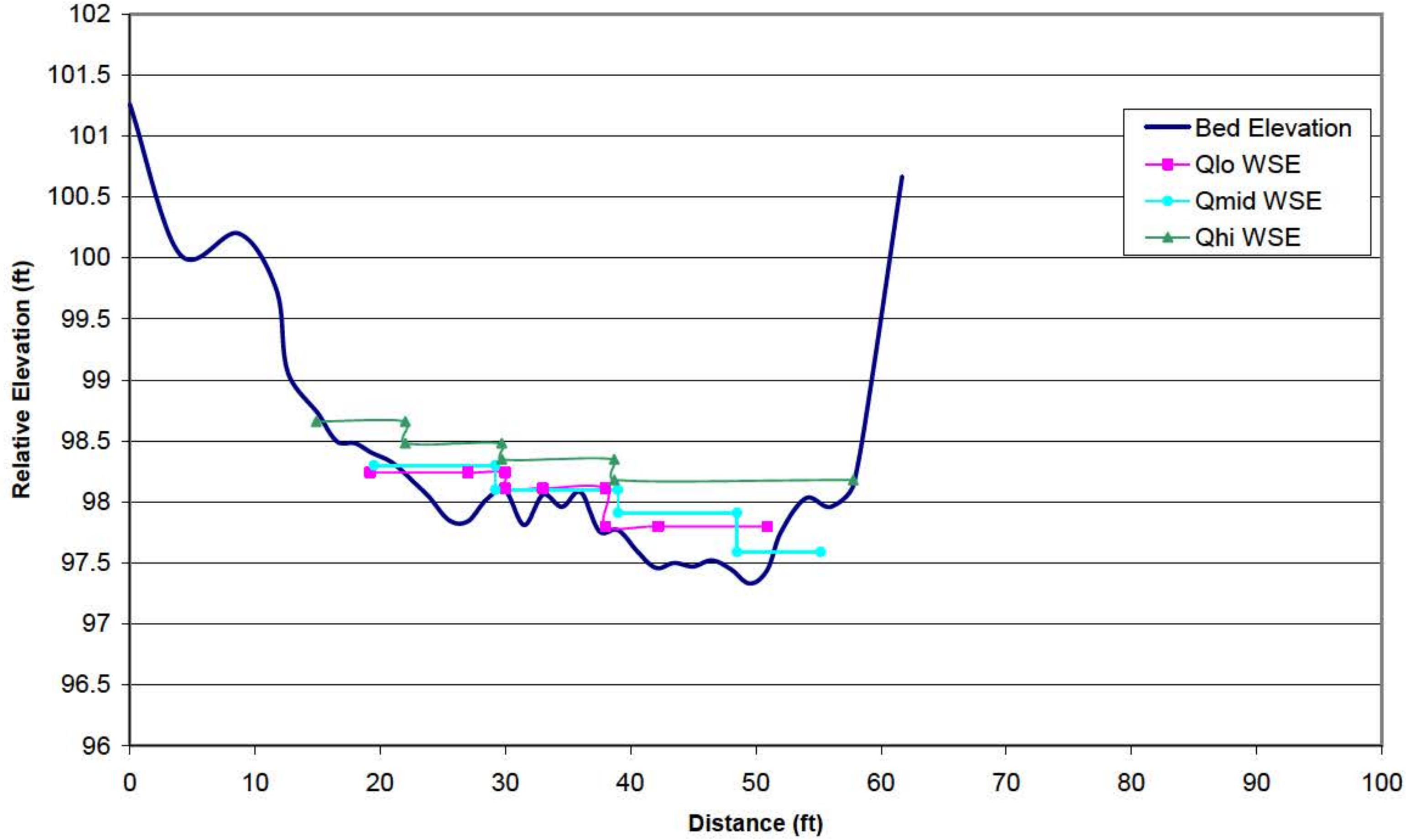
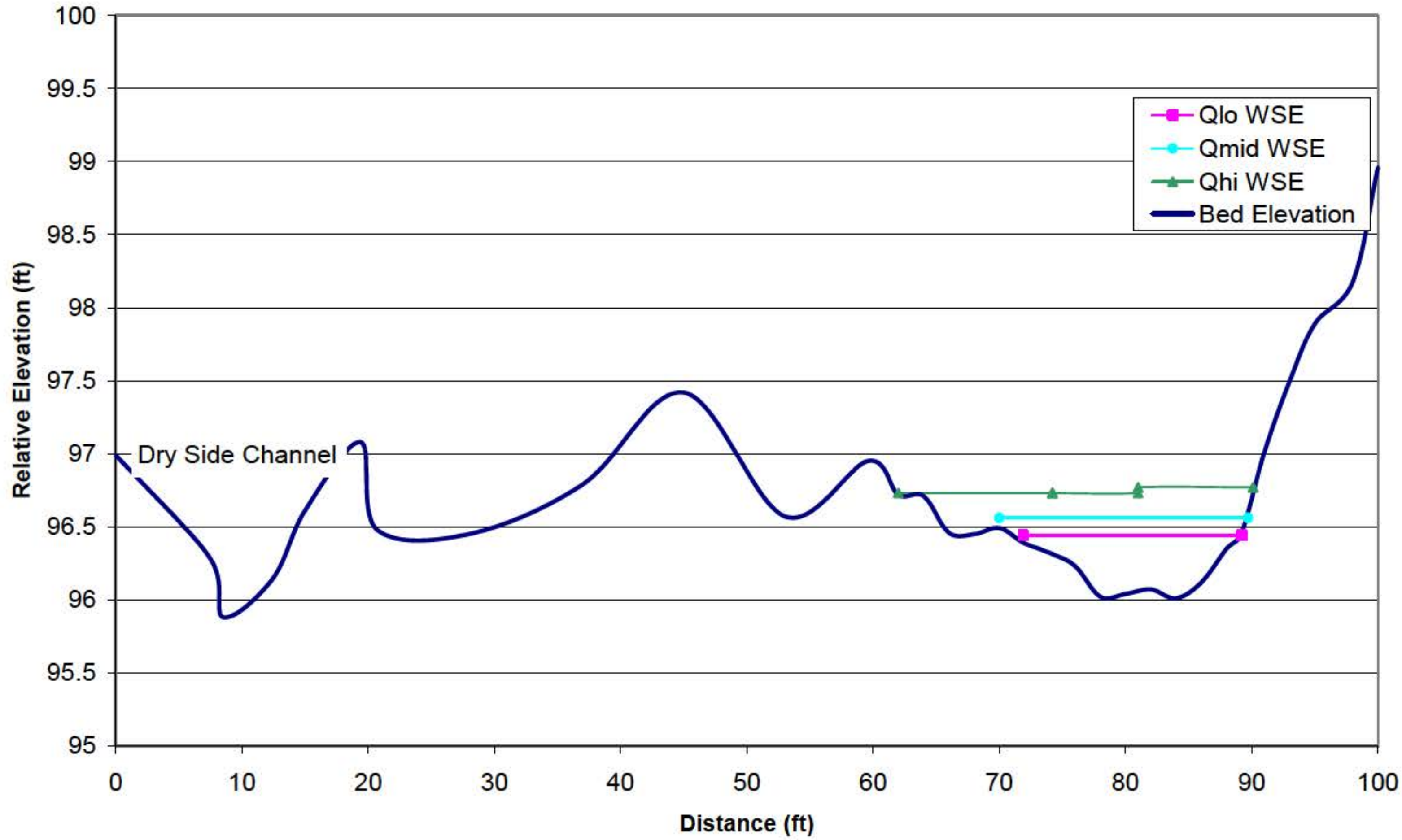


Figure 7.6 - Channel Geometry and Water Surface Elevation, Jorsted Creek XS-3



7.2 Stage-Discharge Modeling

Modeling of the stage discharge relationships was successful and acceptable water surface simulations were obtained for all study sites. The IFG-4a regression method was used for all study sites. One transect at the John Creek study site had a mean error of 5.54 percent (Table 7.1). All remaining transects had mean errors of less than 2.7 percent. The Instream Flow Group (Milhous et al., 1989) describes a stage discharge relationship with a mean error of less than 10 percent as "good", and one with a mean error of less than 5 percent as "excellent".

Table 7.1
Stage-Discharge Model Calibration Values and Summary Statistics
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

	Fulton Creek		John Creek		Jorsted Creek	
Transect	XS-1	XS-2	XS-1	XS-2	XS-2	XS-3
Measured Flow (Low)	1.16	1.16	1.23	1.23	3.50	8.20
Measured Flow (Middle)	16.21	16.21	7.99	7.99	8.20	16.79
Measured Flow (High)	39.15	39.15	58.08	58.08	32.50	32.50
Calibration WSE (Low)	96.06	97.50	95.43	96.58	97.80	96.44
Calibration WSE (Middle)	96.43	97.84	95.70	96.75	97.91	96.56
Calibration WSE (High)	96.61	98.02	96.28	97.11	98.18	96.73
Predicted WSE (Low)	96.06	97.50	95.43	96.58	97.80	96.44
Predicted WSE (Middle)	96.43	97.83	95.69	96.76	97.92	96.57
Predicted WSE (High)	96.61	98.03	96.29	97.10	98.18	96.73
Mean Error for Stage-Discharges	1.47	1.99	2.18	5.54	2.61	2.60
Standard Deviation for Stage-Discharges	0.87	1.18	0.98	2.21	1.09	1.22
Absolute Difference in WSEs (Low)	0.00	0.00	0.00	0.00	0.00	0.00
Absolute Difference in WSEs (Middle)	0.00	0.01	0.01	0.01	0.01	0.01
Absolute Difference in WSEs (High)	0.00	0.01	0.01	0.01	0.00	0.00

WSE = water surface elevation

A review of measurements taken at the transects indicated that the depth and width criteria were almost always satisfied at flows much lower than those required to generate velocities of 4 fps, the velocity that impairs passage. In the remainder of this section, velocities are not discussed.

7.3 Fish Passage Modeling

This analysis was completed for each transect, and then, as described in Thompson's method, the average of the resulting flows was calculated to determine the recommended flow for that sub-reach of the stream.

This recommended passage flow is intended to describe the flows required for passage in the stream through the shallower habitats present, in the absence of other structural barriers to passage (i.e., drops, dams, weirs, or substantial debris jams).

7.3.1 John Creek

The fish passage analysis was performed for cutthroat trout, chum salmon, coho salmon, pink salmon, steelhead trout, and Chinook salmon using Thompson's criteria. This analysis indicates that 15.0 cfs is required to provide sufficient wetted width and depth for suitable cutthroat trout passage, 42.5 cfs for chum salmon, coho salmon, pink salmon, and steelhead trout, and 105.0 cfs for Chinook salmon (Table 7.2). Results for individual transects are presented in Appendix H-1.

Table 7.2
Recommended Passage Flows (cfs) using Thompson's Criteria
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Species	John Creek	Fulton Creek	Jorsted Creek
Chinook Salmon	105.0	NA	NA
Chum Salmon	42.5	40.0	26.3
Coho Salmon	42.5	40.0	26.3
Pink Salmon	42.5	40.0	26.3
Steelhead Trout	42.5	40.0	26.3
Cutthroat Trout	15.0	15.0	7.8

NA = Not applicable

Application of the WRIA 16 passage criteria indicate that 7.5 cfs is suitable for fish passage on John Creek (Table 7.3). The passage flows developed for transects XS-1 and XS-2, using the Observation Based Criteria, are 7.0 and 8.0 cfs, respectively. In both cases, more than 16 percent of the total wetted was considered suitable for passage. The 7.5 cfs passage flow for John Creek is consistent with our September 19, 2004 on-site observations.

Table 7.3
Recommended Passage Flows (cfs) using Observation Based Criteria
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Species	John Creek	Fulton Creek	Jorsted Creek
Chinook Salmon	7.5	NA	NA
Chum Salmon	7.5	10.0	5.5
Coho Salmon	7.5	10.0	5.5
Pink Salmon	7.5	10.0	5.5
Steelhead Trout	7.5	10.0	5.5
Cutthroat Trout	7.5	10.0	5.5

NA = Not applicable

Passage Frequency Analysis

The results of the passage frequency analysis for John Creek are presented in Table 7.4 and Figure 7.7. The results of the passage frequency analysis based on Thompson's Criteria, show that in John Creek reliable passage only would be available to cutthroat, fall chum, and coho salmon in wetter periods (10 percent exceedance). Passage would be available less than 50 percent of the time some of the time for steelhead and pink salmon, during wetter periods. At the 50 percent exceedance flows (normal flows), conditions would be suitable for passage for only cutthroat trout passage. No other species would have any available passage opportunities in normal or dry (90 percent exceedance flows) conditions.

The passage frequency analysis using the Observation Based Criteria indicates that conditions would be more favorable for passage. Nearly all species would be able to migrate upstream most of the time under wetter conditions (10 percent exceedance flows). Under normal conditions, fall chum and coho salmon and steelhead and cutthroat trout would have conditions suitable for passage most of the time. Chinook and pink salmon would have a few opportunities (less than 20 percent of the time) for upstream migration, while summer chum salmon would have little or no passage opportunities. In dry conditions (90 percent exceedance flows), flows would allow upstream passage for fall chum and coho salmon about 40 percent of the time, while steelhead and cutthroat trout would have passage opportunities less than 10 percent of the time. The other species would have few or no opportunities in dry conditions.

7.3.2 Fulton Creek

Passage analyses on Fulton Creek were performed for cutthroat trout, chum salmon, coho salmon, pink salmon, and steelhead trout. Using Thompson's criteria, recommended passage flows are 15.0 cfs for cutthroat trout and 40.0 cfs for chum salmon, coho salmon, pink salmon, and steelhead trout (Table 7.2). Chinook salmon are not thought to utilize

Fulton Creek. Roughly twice as much flow is necessary at transect XS-2 to produce wetted widths equal to those at transect XS-1 (see Appendix H-2). This is due in part to the channel geometry at the transect XS-2 which was installed along a riffle crest diagonal to the direction of flow.

The Observation Based Criteria indicate that streamflows are suitable for fish passage at approximately 10.0 cfs (Table 7.3). More than 30 percent of the total wetted width for each transect was considered passable at the minimum suitable passage flows. The total wetted width suitable for passage at both transects was greater than twelve feet, twice the specified contiguous width criteria. Chum salmon were observed passing over transect XS-1 with no difficulty at a flow of 39.0 cfs during our December 19, 2004 site visit. Water depths in the location where the fish passed over the transect ranged between 0.3 and 0.5 feet.

Passage Frequency Analysis

Based upon Thompson's criteria, flows in Fulton Creek would provide reliable passage for only cutthroat trout most of the time under all flow conditions (Table 7.5, Figure 7.8). Fall Chum and Coho salmons would be able to migrate most of the time in wet and normal conditions (10 and 50 percent exceedance flows, respectively). Steelhead would be provided passage most of the time in wet conditions and about half the time in normal conditions. Flows favorable for passage for pink salmon and summer chum salmon would be available less than half the time in wet conditions. Passage opportunities would be limited, if at all available, for any species except cutthroat trout under dry conditions (90 percent exceedance flows).

Table 7.4
Number and Percentage of Days Passage is Provided in John Creek*
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Thompson Criteria

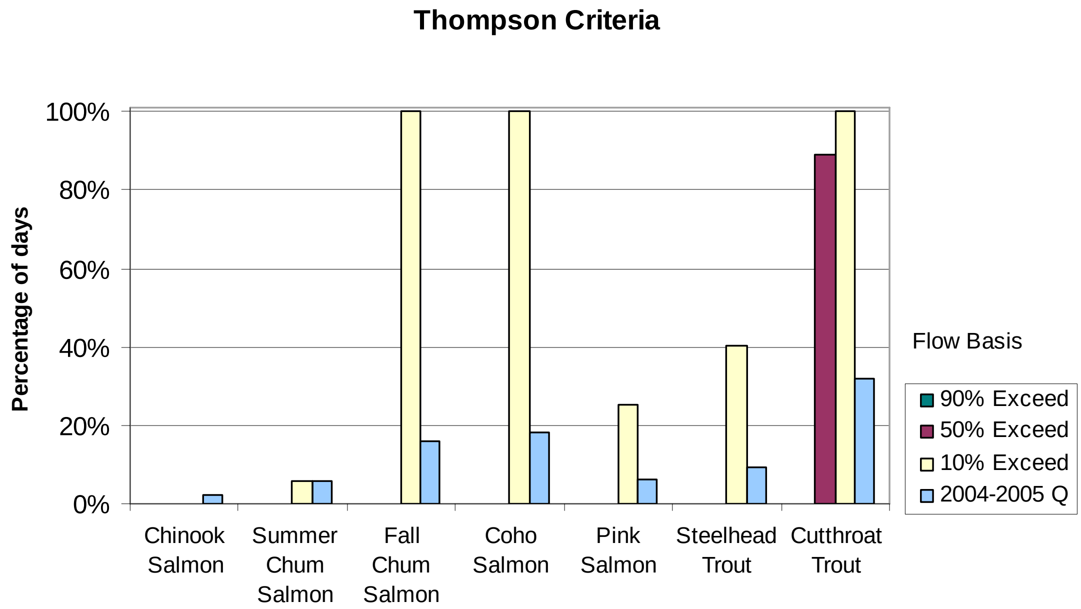
Species	Spawning Period	No of days in period	90% Exceedance		50% Exceedance		10% Exceedance		Daily Discharge	
			No.	%	No.	%	No.	%	No.	%
Chinook Salmon	Sep23-Nov3	42	0	0%	0	0%	0	0%	1	2%
Summer Chum Salmon	Sep16-Oct20	35	0	0%	0	0%	2	6%	2	6%
Fall Chum Salmon	Nov18-Jan12	56	0	0%	0	0%	56	100%	9	16%
Coho Salmon	Nov11-Dec29	49	0	0%	0	0%	49	100%	9	18%
Pink Salmon	Sep2-Nov3	63	0	0%	0	0%	16	25%	4	6%
Steelhead Trout	Feb10-Jun30	141	0	0%	0	0%	57	40%	13	9%
Cutthroat Trout	Dec30-May4	126	0	0%	112	89%	126	100%	40	32%

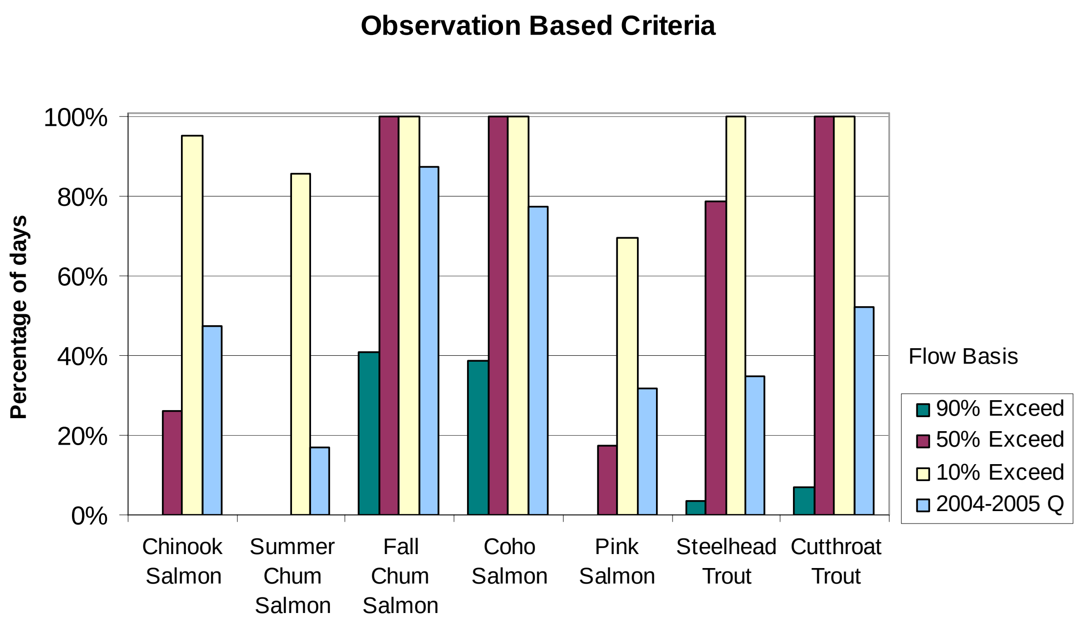
Observation Based Criteria

Species	Spawning Period	No of days in period	90% Exceedance		50% Exceedance		10% Exceedance		Daily Discharge	
			No.	%	No.	%	No.	%	No.	%
Chinook Salmon	Sep23-Nov3	42	0	0%	11	26%	40	95%	20	48%
Summer Chum Salmon	Sep16-Oct20	35	0	0%	0	0%	30	86%	6	17%
Fall Chum Salmon	Nov18-Jan12	56	23	41%	56	100%	56	100%	49	88%
Coho Salmon	Nov11-Dec29	49	19	39%	49	100%	49	100%	38	78%
Pink Salmon	Sep2-Nov3	63	0	0%	11	17%	44	70%	20	32%
Steelhead Trout	Feb10-Jun30	141	5	4%	111	79%	141	100%	49	35%
Cutthroat Trout	Dec30-May4	126	9	7%	126	100%	126	100%	66	52%

*Evaluation based on 10, 50 and 90 percent exceedance flow and daily discharge from July 19, 2004 to July 18, 2005

Figure 7.7 - Percentage of Days Passage is Provided in John Creek*





*Evaluation based on 10, 50 and 90 percent exceedance flow and daily discharge from July 19, 2004 to July 18, 2005.

Table 7.5
Number and Percentage of Days Passage is Provided in Fulton Creek*
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Thompson Criteria

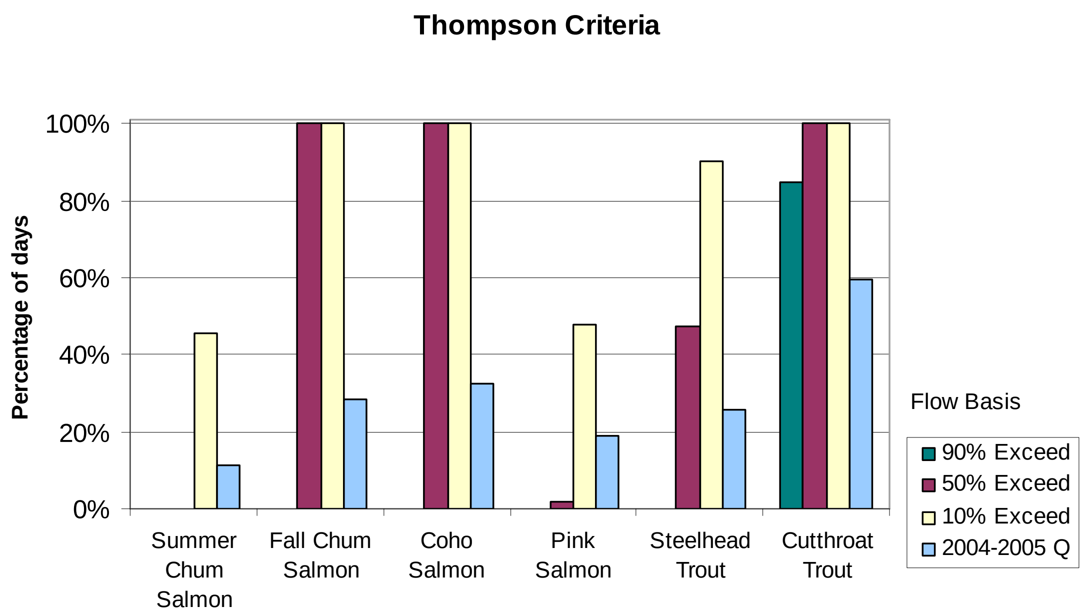
Species	Spawning Period	No of days in period	90% Exceedance		50% Exceedance		10% Exceedance		Daily Discharge	
			No.	%	No.	%	No.	%	No.	%
Summer Chum Salmon	Sep16-Oct20	35	0	0%	0	0%	16	46%	4	11%
Fall Chum Salmon	Nov18-Jan12	56	0	0%	56	100%	56	100%	16	29%
Coho Salmon	Nov11-Dec29	49	0	0%	49	100%	49	100%	16	33%
Pink Salmon	Sep2-Nov3	63	0	0%	1	2%	30	48%	12	19%
Steelhead Trout	Feb10-Jun30	141	0	0%	67	48%	127	90%	36	26%
Cutthroat Trout	Dec30-May4	126	107	85%	126	100%	126	100%	75	60%

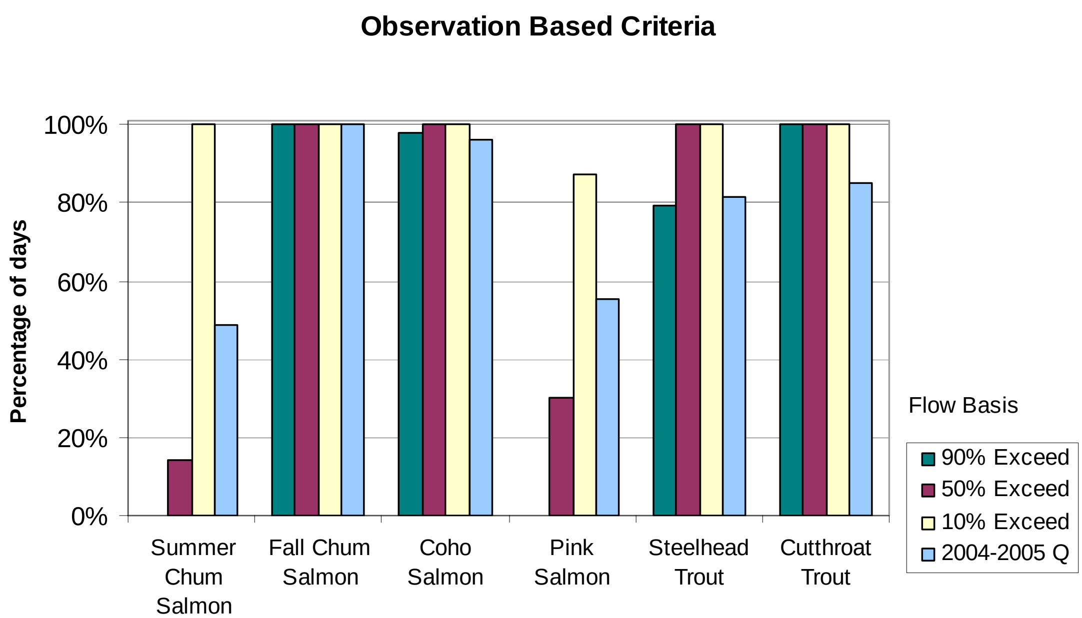
Observation Based Criteria

Species	Spawning Period	No of days in period	90% Exceedance		50% Exceedance		10% Exceedance		Daily Discharge	
			No.	%	No.	%	No.	%	No.	%
Summer Chum Salmon	Sep16-Oct20	35	0	0%	5	14%	35	100%	17	49%
Fall Chum Salmon	Nov18-Jan12	56	56	100%	56	100%	56	100%	56	100%
Coho Salmon	Nov11-Dec29	49	48	98%	49	100%	49	100%	47	96%
Pink Salmon	Sep2-Nov3	63	0	0%	19	30%	55	87%	35	56%
Steelhead Trout	Feb10-Jun30	141	112	79%	141	100%	141	100%	115	82%
Cutthroat Trout	Dec30-May4	126	126	100%	126	100%	126	100%	107	85%

*Evaluation based on 10, 50 and 90 percent exceedance flow and daily discharge from July 19, 2004 to July 18, 2005

Figure 7.8 - Percentage of Days Passage is Provided in Fulton Creek*





*Evaluation based on 10, 50 and 90 percent exceedance flow and daily discharge from July 19, 2004 to July 18, 2005.

The Observation Based Criteria indicate that conditions would be much more favorable for passage in Fulton Creek than indicated by the Thompson Criteria. These criteria indicate that passage would be available the majority of time for all species except pink salmon and summer chum salmon. For these two species, wetter periods (10 percent exceedance flows) would provide suitable flows for passage most of the time, a limited number of passage opportunities would be present in normal conditions (50 percent exceedance flows), and few if any passage opportunities would be available under dry conditions (90 percent exceedance flows).

7.3.3 Jorsted Creek

Thompson's criteria were used to evaluate the suitability of streamflows for fish passage at two transects on Jorsted Creek. Cutthroat trout, chum salmon, coho salmon, pink salmon, and steelhead trout were the species of interest for this creek. This analysis indicates that streamflows greater than 7.8 cfs are suitable for cutthroat trout passage and streamflows greater than 26.3 cfs are suitable for the remainder of the target species for this stream (Table 7.2). Suitability for transect XS-3 was driven by the center section of the thalweg which was slightly shallower than the margins of the thalweg. Once depths over this section of the channel exceeded the specified depth criteria, the both the percent contiguous and percent passable criteria were simultaneously satisfied. For more information regarding suitable passage flows at each transect see Appendix H-3.

The Observation Based Criteria used in this analysis indicate that streamflows greater than 5.5 cfs are suitable for fish passage. Minimum suitable passage flows at the two transects differed by only 2.0 cfs. Suitability at transect XS-3 was driven by the contiguous width requirement. As much as 6.0 feet of the wetted channel exceeded depth criteria at a streamflow of 4.5 cfs but only 4.0 feet of the wetted width were contiguous. Although a 5.5 cfs passage flow appears reasonable, we did not observe fish passing over restrictive riffles in Jorsted Creek so we can not validate the recommended flow.

Passage Frequency Analysis

The passage frequency analysis based on Thompson's criteria indicates that passage flows would only be available for a few species under wet and normal conditions (10 and 90 percent exceedance flows), and few if any passage opportunities are available for any species, except cutthroat trout, under dry conditions (Table 7.6, Figure 7.9). Under wet conditions, suitable passage flows would be available nearly all the time for fall chum, coho, and cutthroat trout, and about 50 percent of the time for steelhead. Pink salmon would have few migration opportunities, even in wet conditions. In normal conditions, the frequency of suitable flows for passage is high for fall chum and cutthroat trout, slightly lower for coho salmon, and low for steelhead.

The passage analysis using the Observation Based Criteria indicate passage would be available most of the time for fall chum salmon, coho salmon, steelhead, and cutthroat trout in all flow conditions. Suitable flows would occur less frequently in dry conditions (90 percent exceedance flows). Pink salmon would have suitable flows for passage about 40 percent for the time wetter conditions and few opportunities under normal or dry conditions.

Table 7.6
Number and Percentage of Days Passage is Provided in Jorsted Creek*
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

Thompson Criteria

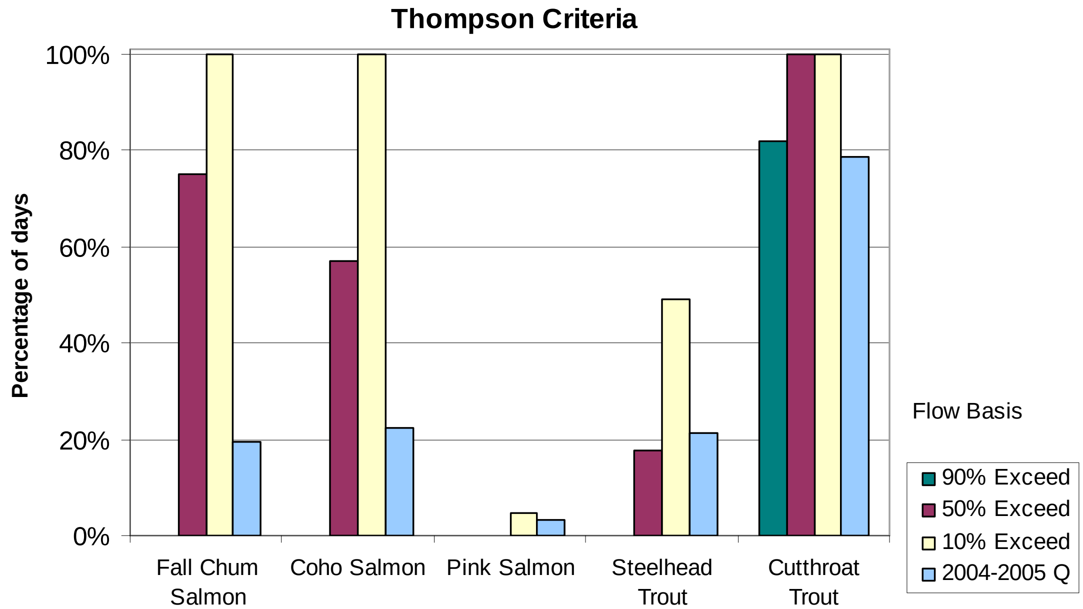
Species	Spawning Period	No of days in period	90% Exceedance		50% Exceedance		10% Exceedance		Daily Discharge	
			No.	%	No.	%	No.	%	No.	%
Fall Chum Salmon	Nov18-Jan12	56	0	0%	42	75%	56	100%	11	20%
Coho Salmon	Nov11-Dec29	49	0	0%	28	57%	49	100%	11	22%
Pink Salmon	Sep2-Nov3	63	0	0%	0	0%	3	5%	2	3%
Steelhead Trout	Feb10-Jun30	141	0	0%	25	18%	69	49%	30	21%
Cutthroat Trout	Dec30-May4	126	103	82%	126	100%	126	100%	99	79%

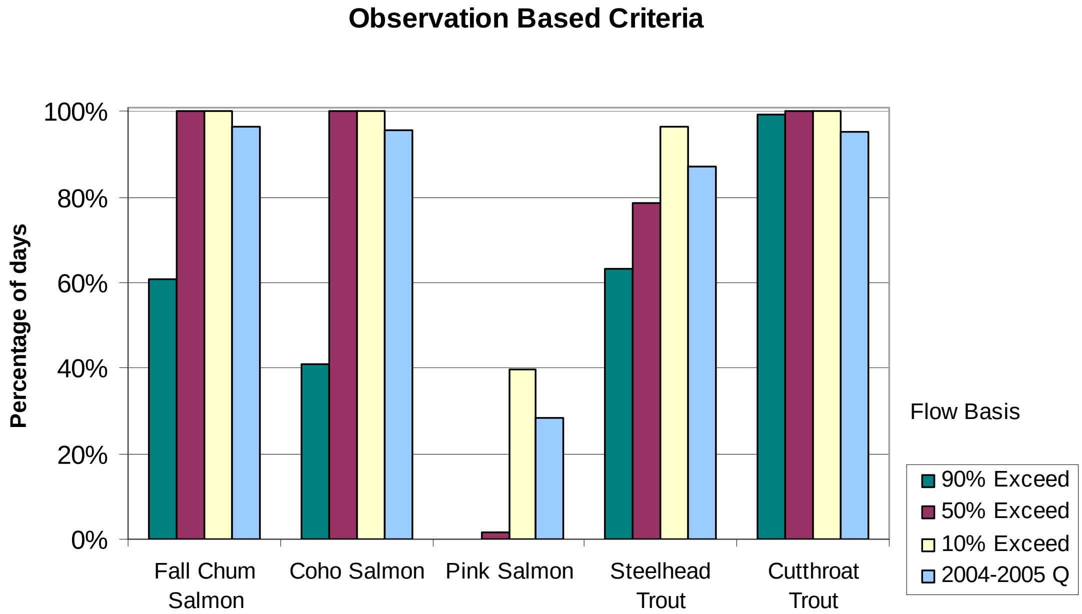
Observation Based Criteria

Species	Spawning Period	No of days in period	90% Exceedance		50% Exceedance		10% Exceedance		Daily Discharge	
			No.	%	No.	%	No.	%	No.	%
Fall Chum Salmon	Nov18-Jan12	56	34	61%	56	100%	56	100%	54	96%
Coho Salmon	Nov11-Dec29	49	20	41%	49	100%	49	100%	47	96%
Pink Salmon	Sep2-Nov3	63	0	0%	1	2%	25	40%	18	29%
Steelhead Trout	Feb10-Jun30	141	89	63%	111	79%	136	96%	123	87%
Cutthroat Trout	Dec30-May4	126	125	99%	126	100%	126	100%	120	95%

*Evaluation based on 10, 50 and 90 percent exceedance flow and daily discharge from August 5, 2004 to July 18, 2005

Figure 7.9 - Percentage of Days Passage is Provided in Jorsted Creek*





*Evaluation based on 10, 50 and 90 percent exceedance flow and daily discharge from August 5, 2004 to July 18, 2005.

8 Fish Passage Study Discussion

This study evaluated passage flows in John, Fulton, and Jorsted creeks using the Thompson Methodology (1972) and Thompson's passage criteria. Passage flows were also evaluated using criteria based on a limited number of site specific observations (Observation Based Criteria), observations from other systems, and the physical and physiological characteristics of the target species. These species included Chinook salmon, fall- and summer-run chum salmon, pink salmon, coho salmon, steelhead trout, and coastal cutthroat trout. Each species, except Chinook salmon and summer chum salmon, are thought to use each stream. Chinook salmon are thought to use only John Creek and sporadically use Fulton Creek. Summer chum salmon are not thought to use Jorsted Creek.

The different passage flows resulting from the two criteria sets reflect differences in the minimum depth required for passage. The broad, open nature of the channel in the area where these riffles are located, means that substantial changes in flow are required to provide modest increases in depth. For, example, a 24 cfs increase in flow was required to increase the depth in Jorsted Creek by 0.2 to 0.3 feet.

Limited site-specific observations and the passage frequency analysis indicate that the Thompson criteria may be overly conservative, requiring greater depth and widths than are actually needed by the fish for passage in the study streams. Fish have been observed crossing these transects where conditions do not meet the Thompson criteria. We have observed this in other rivers as well where the Thompson criteria were applied. Additionally, the frequency analysis based on the Thompson criteria indicates that the target species, except cutthroat trout, would only be able to use these streams in wet conditions. However, these species are thought to use these streams (except as noted above) in most years. If these streams supported upstream passage as infrequently as indicated by these criteria, then these species would not be expected to utilize these streams.

The Thompson requirement that 25 percent of the channel width have depths greater than the specified depth may not be necessary in small streams. This criterion requires a passage width of many feet, whereas a salmonid of any species is only a few inches wide, and can utilize much narrower slots for passage. Thompson's width requirements are likely intended to provide sufficient width that the fish can readily locate a passable area and to increase the likelihood that there is a continuous thread of passage throughout each riffle. The study streams are small with single channels. Fish are able to traverse the entire channel width in a few seconds with minimal effort. The riffles in these streams also tend to be short, so prolonged passage efforts are not required.

The Observation Based Criteria provide a more realistic estimate of the flow levels required to provide passage in these streams than the Thompson criteria. These criteria were based in part on site specific observations of summer chum and coho salmon crossing these transects at flows near those estimated from the analysis. Since chum salmon are the largest of the target species (except chinook salmon (Salo 1991)), the flows that provide passage for this species, will provide passage for the other species, as well. The frequency analysis based on these criteria suggest that suitable passage flows occur regularly, except under dry conditions. This better fits the known utilization of these streams by the target species.

In setting passage flow requirements, the short distance that fish have to travel should be considered. Each of the subject streams is only a little more than a mile from their mouths to the base of the foothills, where passage characteristics change. Most of the spawning habitat is contained in this short reach. Thus fish may only have to pass over a couple of critical riffles to reach their spawning area.

9 Conclusions of Fish Passage Study

The Observation Based Criteria indicate that minimum passage flows are 7.5, 10 and 5.5 cfs for John, Fulton, and Jorsted Creeks, respectively. These criteria provide a more appropriate estimate of the flows required for upstream passage in the study streams than do the Thompson criteria. A buffer (25 to 33 percent) should be allowed to ensure that passage is provided to most returning adults. The flows suggested by the Thompson criteria, however, appear to be unrealistic in the context of the study streams.

The results of this analysis and the conclusions presented above are based on a limited set of observations in the study streams. We recommend that both hydrologic and regular spawning surveys be implemented to validate the results of this analysis. Additional observations would help refine the Observation Based Criteria and, in the case of chinook salmon, assist in the development of criteria that incorporate regional behaviors. These should include observations of all the target species crossing critical riffles in the study streams and be accompanied by measurements of the depths in the specific areas the fish passed through the riffle as well as the size of the fish. The Observation Based Criteria likely approach the lower range of depths that are passable for some of the larger bodied target species and additional observations to confirm the appropriateness of the recommended flows would be useful. Periodic monitoring of riffle characteristics over time may also be helpful in better defining passage requirements. Over time geomorphic changes (sedimentation or incision) may occur that may modify passage requirements. Long-term streamflow monitoring would confirm the results of the hydrologic simulations performed to date, and allow refinement of the hydrologic models and the passage analysis. Finally, results of this study are specific to fish passage in the study streams. While the Observation Based Criteria used in this study have a biological basis, they should not be applied to other streams in the basin without consideration of current behavior of the target species (e.g., is fish passage an issue?) as well as other physical and biological factors that may affect passage success. These factors include migration timing, distance to suitable spawning habitat, and channel complexity (i.e., multiple threaded channel versus single thread). For evaluation of other streams in the WRIA, a scoping effort would be necessary to identify existing data on aquatic resources in the basin and to develop appropriate strategies for setting, achieving and protecting instream flows.

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11 Limitations

Work for this project was performed and this report prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. It is intended for the exclusive use of WRIA 16 Planning Unit for specific application to the referenced property. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

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Table 3.2
Mean Daily Discharges
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
6/25/2004				289	2.5		8.0
6/26/2004	414	388	3.5	273	2.4		8.2
6/27/2004	368	335	3.2	253	2.4		7.9
6/28/2004	338	312	3.1	240	2.4		7.8
6/29/2004	342	316	2.9	233	2.3		7.7
6/30/2004	347	320	2.8	230	2.3		7.8
7/1/2004	344	315	2.7	224	2.3		7.8
7/2/2004	331	300	2.7	218	2.4		7.9
7/3/2004	311	277	3.6	210	2.5		8.6
7/4/2004	296	259	3.2	200	2.4		8.7
7/5/2004	282	245	2.9	189	2.3		8.7
7/6/2004	301	254	2.7	186	2.3		8.7
7/7/2004	294	247	2.7	180	2.3		8.4
7/8/2004	254	215	2.6	169	2.3		8.5
7/9/2004	245	210	2.6	164	2.3		8.5
7/10/2004	245	207	2.9	159	2.3		8.5
7/11/2004	231	195	3.0	153	2.3		8.6
7/12/2004	225	183	2.6	146	2.3		8.7
7/13/2004	232	184	2.4	142	2.2		8.8
7/14/2004	247	191	2.2	141	2.2		8.9
7/15/2004	243	187	2.1	137	2.2		8.8
7/16/2004	240	184	2.0	134	2.2		8.5
7/17/2004	231	175	1.9	130	2.1		8.1
7/18/2004	237	173	1.9	127	2.1		8.4
7/19/2004	235	168	1.8	125	2.1		8.2
7/20/2004	219	162	1.8	122	2.1		7.8
7/21/2004	201	152	1.8	118	2.1		7.8
7/22/2004	194	144	1.7	114	2.1		7.6
7/23/2004	197	142	1.6	111	2.1		7.3
7/24/2004	203	142	1.6	109	2.0		7.0
7/25/2004	207	142	1.6	107	2.0		6.8
7/26/2004	194	135	1.6	105	2.0		6.6
7/27/2004	183	129	1.5	102	2.0		6.4
7/28/2004	183	126	1.5	99	2.0		6.4
7/29/2004	181	124	1.4	97	2.0		6.4
7/30/2004	180	121	1.4	95	2.0		6.3
7/31/2004	173	117	1.4	93	2.0		6.3
8/1/2004	167	113	1.4	91	2.0		6.5
8/2/2004	163	110	1.3	89	2.0		7.0
8/3/2004	160	108	1.3	87	2.0		6.9

Table 3.2
Mean Daily Discharges
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
8/4/2004	168	117	1.5	88	2.0		7.2
8/5/2004	160	110	1.7	87	2.0	3.2	7.0
8/6/2004	222	271	29	160	6.0	4.7	16
8/7/2004	245	300	23	232	4.6	3.4	10
8/8/2004	177	182	10.0	160	3.1	3.3	7.5
8/9/2004	162	143	6.4	135	2.6	3.2	7.1
8/10/2004	160	127	4.8	121	2.4	3.1	6.6
8/11/2004	156	116	3.9	113	2.3	3.1	6.5
8/12/2004	152	109	3.3	106	2.2	3.1	6.3
8/13/2004	153	104	2.9	101	2.2	3.0	6.0
8/14/2004	152	101	2.6	96	2.1	3.0	6.2
8/15/2004	153	98	2.4	93	2.1	3.0	6.0
8/16/2004	151	96	2.3	91	2.1	3.0	6.1
8/17/2004	146	93	2.2	89	2.1	3.0	6.3
8/18/2004	143	91	2.0	86	2.1	3.0	6.3
8/19/2004	138	89	2.0	84	2.1	2.9	6.1
8/20/2004	137	87	1.9	82	2.0	2.9	5.9
8/21/2004	136	86	1.9	82	2.0	2.9	5.9
8/22/2004	172	104	2.7	83	2.1	3.0	6.5
8/23/2004	141	93	2.6	81	2.1	2.9	6.3
8/24/2004	166	98	2.8	83	2.3	3.2	7.8
8/25/2004	302	246	8.1	105	3.6	3.2	9.6
8/26/2004	278	287	5.0	142	2.9	3.0	7.9
8/27/2004	188	163	4.3	120	2.6	2.9	6.9
8/28/2004	161	131	4.5	108	2.5	2.9	6.7
8/29/2004	149	113	4.0	101	2.4	2.8	6.8
8/30/2004	142	103	3.5	95	2.3	2.8	6.6
8/31/2004	139	95	3.1	90	2.2	2.8	6.4
9/1/2004	140	93	3.0	87	2.2	2.7	6.3
9/2/2004	129	94	2.7	84	2.2	2.7	5.9
9/3/2004	118	86	2.5	81	2.2	2.7	5.8
9/4/2004	114	81	2.3	79	2.1	2.7	5.9
9/5/2004	110	77	2.2	77	2.1	2.6	5.9
9/6/2004	105	75	2.1	75	2.1	2.6	5.9
9/7/2004	102	73	2.0	73	2.1	2.6	5.9
9/8/2004	105	71	1.9	71	2.1	2.6	5.9
9/9/2004	112	74	1.9	70	2.1	2.6	6.0
9/10/2004	106	75	2.4	72	2.5	3.3	9.0
9/11/2004	263	235	17	171	5.7	3.2	12
9/12/2004	164	151	8.7	135	3.3	2.7	7.5

Table 3.2
Mean Daily Discharges
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
9/13/2004	170	199	25	155	4.8	3.0	10.0
9/14/2004	182	207	19	169	4.5	2.8	8.4
9/15/2004	203	268	18	182	5.3	2.8	10.0
9/16/2004	186	215	15	178	5.5	2.9	9.7
9/17/2004	227	216	14	194	6.2	3.1	9.7
9/18/2004	198	191	14	203	6.7	3.8	12
9/19/2004	178	177	16	210	6.9	3.6	12
9/20/2004	160	164	15	195	5.8	3.1	9.0
9/21/2004	147	148	12	175	5.0	2.9	8.0
9/22/2004	147	138	10	165	4.8	2.9	7.6
9/23/2004	153	135	9.0	156	4.5	2.8	7.5
9/24/2004	144	126	7.8	146	4.2	2.6	7.1
9/25/2004	142	118	6.8	136	3.9	2.6	6.9
9/26/2004	137	114	6.0	129	3.7	2.5	6.9
9/27/2004	133	111	5.5	124	3.5	2.5	6.9
9/28/2004	131	106	4.9	118	3.4	2.5	6.9
9/29/2004	131	103	4.6	114	3.4	2.5	6.6
9/30/2004	125	102	4.3	111	3.3	2.5	6.4
10/1/2004	122	102	4.1	107	3.4	2.4	6.0
10/2/2004	119	99	3.7	103	3.3	2.4	5.9
10/3/2004	116	97	3.5	100	3.2	2.4	6.0
10/4/2004	116	94	3.4	97	3.1	2.4	6.2
10/5/2004	116	93	3.7	96	3.3	2.5	6.6
10/6/2004	141	105	4.4	97	3.5	2.5	6.7
10/7/2004	124	99	4.2	95	3.3	2.4	6.7
10/8/2004	207	222	30	152	6.1	3.1	11
10/9/2004	262	306	33	246	9.4	3.9	13
10/10/2004	218	256	21	258	9.1	3.3	10.0
10/11/2004	178	188	15	204	7.4	2.9	8.3
10/12/2004	163	159	12	177	6.4	2.9	7.6
10/13/2004	158	144	10	161	5.8	2.9	7.3
10/14/2004	151	132	8.8	149	5.6	2.9	7.0
10/15/2004	145	124	8.1	140	5.5	2.8	6.9
10/16/2004	146	121	7.6	134	5.4	2.9	7.0
10/17/2004	269	542	110	469	22	7.4	18
10/18/2004	284	485	84	586	22	8.3	19
10/19/2004	527	1,520	313	1,959	83	24	48
10/20/2004	454	1,010	126	1,306	45	19	30
10/21/2004	320	549	60	760	26	15	25
10/22/2004	273	419	44	600	24	14	23

Table 3.2
Mean Daily Discharges
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
10/23/2004	247	344	35	510	21	12	17
10/24/2004	218	282	27	434	16	11	14
10/25/2004	223	294	36	431	16	12	16
10/26/2004	285	469	65	659	22	12	18
10/27/2004	257	385	44	588	17	11	14
10/28/2004	236	326	31	493	14	10	13
10/29/2004	221	290	26	433	12	10	14
10/30/2004	274	444	48	598	20	12	19
10/31/2004	242	340	36	506	15	10	13
11/1/2004	240	370	44	525	24	14	22
11/2/2004	1,021	1,952	321	1,934	128	39	60
11/3/2004	573	897	141	1,154	67	33	38
11/4/2004	421	563	65	789	34	24	26
11/5/2004	354	437	41	632	21	19	21
11/6/2004	320	382	29	543	16	15	18
11/7/2004	376	418	23	512	13	12	16
11/8/2004	356	398	18	469	10	11	15
11/9/2004	310	337	16	423	8.7	12	15
11/10/2004	279	297	13	387	7.6	9.9	14
11/11/2004	257	271	12	356	7.1	8.2	13
11/12/2004	240	254	11	329	6.5	7.7	13
11/13/2004	230	242	9.6	308	6.0	7.6	13
11/14/2004	240	253	9.5	301	6.3	7.6	13
11/15/2004	291	316	10	325	6.2	7.1	14
11/16/2004	263	289	12	321	5.9	6.2	13
11/17/2004	236	264	12	323	5.8	5.8	13
11/18/2004	245	300	19	350	8.6	6.8	21
11/19/2004	232	287	19	354	8.9	6.0	16
11/20/2004	216	255	17	323	7.8	5.7	14
11/21/2004	210	240	15	298	7.1	5.6	13
11/22/2004	208	234	13	280	6.5	5.3	13
11/23/2004	202	227	12	265	5.9	5.1	12
11/24/2004	310	594	23	342	12	7.0	18
11/25/2004	781	1,309	85	956	42	13	31
11/26/2004	403	566	58	600	25	11	21
11/27/2004	322	427	39	483	18	9.6	17
11/28/2004	268	361	28	414	14	8.4	14
11/29/2004	253	327	22	370	12	7.9	14
11/30/2004	241	306	19	340	10	8.0	13
12/1/2004	226	287	16	314	8.5	6.8	12

Table 3.2
Mean Daily Discharges
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
12/2/2004	215	271	14	291	7.6	6.3	11
12/3/2004	211	261	13	273	7.0	5.9	11
12/4/2004	211	262	14	273	9.0	6.9	16
12/5/2004	206	262	21	290	11	6.6	16
12/6/2004	207	269	31	303	20	9.4	28
12/7/2004	243	341	103	379	71	25	54
12/8/2004	490	754	392	1,135	236	98	147
12/9/2004	375	562	132	798	82	68	81
12/10/2004	1,880	3,836	433	4,272	251	125	219
12/11/2004	1,936	3,000	325	3,503	198	148	181
12/12/2004	869	1,178	129	1,563	77	83	89
12/13/2004	724	1,167	151	1,413	51	60	75
12/14/2004	1,185	2,578	392	3,047	118	65	104
12/15/2004	911	1,427	150	1,913	70	59	75
12/16/2004	697	942	79	1,280	39	48	57
12/17/2004	598	778	54	1,024	25	36	46
12/18/2004	600	765	45	937	18	30	39
12/19/2004	610	738	39	882	15	26	33
12/20/2004	532	608	30	769	12	22	28
12/21/2004	470	513	24	677	10	18	25
12/22/2004	429	452	20	608	9.2	16	23
12/23/2004	397	406	17	552	8.3	15	21
12/24/2004	376	373	15	507	7.6	13	20
12/25/2004	376	386	26	514	13	16	32
12/26/2004	382	423	64	622	28	18	38
12/27/2004	358	384	51	566	24	17	31
12/28/2004	341	352	37	502	18	16	27
12/29/2004	330	332	29	459	14	15	25
12/30/2004	317	310	24	422	12	14	23
12/31/2004	302	290	21	388	10	13	21
1/1/2005	298	283	19	368	9.9	12	20
1/2/2005	284	266	17	340	8.7	11	19
1/3/2005	268	248	15	315	7.9	10	18
1/4/2005	259	235	14	294	7.4	9.8	17
1/5/2005	251	223	13	277	6.9	9.2	17
1/6/2005	247	215	12	263	6.6	8.9	16
1/7/2005	262	231	15	270	8.6	11	25
1/8/2005	271	243	18	271	10	11	26
1/9/2005	264	241	17	258	10	11	26
1/10/2005	249	222	15	242	9.2	10	24

Table 3.2
Mean Daily Discharges
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Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
1/11/2005	239	208	13	229	8.5	10	24
1/12/2005	231	199	12	220	8.2	9.7	21
1/13/2005	214	190	11	210	7.8	9.3	20
1/14/2005	201	181	11	202	7.4	8.9	18
1/15/2005	196	176	10	197	7.3	8.9	18
1/16/2005	213	199	19	220	14	12	27
1/17/2005	1,238	2,544	505	2,614	253	66	157
1/18/2005	2,103	3,354	348	3,407	162	78	120
1/19/2005	1,835	2,455	246	2,751	97	69	79
1/20/2005	1,378	1,646	165	2,058	53	54	57
1/21/2005	1,131	1,243	112	1,676	33	44	45
1/22/2005	1,347	1,570	125	1,896	34	43	50
1/23/2005	1,430	1,617	130	2,134	46	43	52
1/24/2005	1,038	1,001	77	1,468	31	38	40
1/25/2005	859	758	51	1,132	22	34	32
1/26/2005	769	666	39	961	17	31	28
1/27/2005	724	643	31	887	14	28	24
1/28/2005	647	534	25	772	11	24	22
1/29/2005	591	472	22	699	9.8	21	19
1/30/2005	555	426	19	638	8.8	19	17
1/31/2005	541	417	17	598	7.9	17	16
2/1/2005	505	380	15	552	7.2	15	15
2/2/2005	485	350	13	511	6.6	14	14
2/3/2005	465	329	12	479	6.2	13	14
2/4/2005	476	341	12	462	6.0	12	13
2/5/2005	457	321	11	434	5.5	11	13
2/6/2005	446	310	14	417	7.2	14	20
2/7/2005	425	289	14	385	7.3	12	19
2/8/2005	401	271	14	358	6.8	11	15
2/9/2005	384	256	13	337	6.5	11	14
2/10/2005	369	244	14	319	6.4	10	13
2/11/2005	360	236	16	306	6.7	10	13
2/12/2005	352	231	19	300	6.9	9.7	12
2/13/2005	339	222	18	292	6.6	9.2	12
2/14/2005	324	210	16	277	6.1	8.9	12
2/15/2005	309	199	14	263	5.7	8.6	11
2/16/2005	301	191	13	250	5.4	8.4	11
2/17/2005	294	185	12	239	5.1	8.1	10
2/18/2005	285	178	11	229	4.8	7.9	10
2/19/2005	278	172	9.7	219	4.6	7.7	9.9

Table 3.2
Mean Daily Discharges
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Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
2/20/2005	268	165	8.9	209	4.4	7.5	9.4
2/21/2005	260	159	8.2	200	4.1	7.1	9.2
2/22/2005	253	153	7.6	192	4.0	7.1	9.1
2/23/2005	247	149	7.1	185	3.8	6.8	8.9
2/24/2005	242	144	6.9	179	3.7	6.6	8.8
2/25/2005	239	141	6.7	175	3.6	6.4	8.8
2/26/2005	235	138	6.5	171	3.5	6.2	8.8
2/27/2005	231	134	6.4	166	3.4	6.1	8.6
2/28/2005	242	146	9.6	175	4.0	6.9	11
3/1/2005	264	212	36	302	8.5	9.4	18
3/2/2005	259	212	30	344	7.7	7.6	14
3/3/2005	249	200	24	327	6.8	7.1	12
3/4/2005	237	176	19	284	6.0	6.7	11
3/5/2005	230	163	16	255	5.4	6.5	10
3/6/2005	223	155	13	235	5.1	6.3	9.6
3/7/2005	246	179	12	233	4.8	6.1	9.4
3/8/2005	259	183	11	235	4.5	6.0	9.1
3/9/2005	288	206	10	238	4.2	5.8	8.9
3/10/2005	291	201	9.6	232	4.0	5.7	8.7
3/11/2005	273	185	8.8	221	3.9	5.6	8.7
3/12/2005	274	183	8.1	216	3.7	5.4	8.7
3/13/2005	251	165	7.4	205	3.5	5.4	8.2
3/14/2005	235	152	6.7	194	3.4	5.3	8.2
3/15/2005	226	143	6.3	186	3.3	5.2	8.3
3/16/2005	228	145	6.9	188	3.8	5.9	11
3/17/2005	220	142	6.4	187	3.4	5.3	8.0
3/18/2005	211	132	5.8	177	3.3	5.2	7.8
3/19/2005	222	155	17	192	6.1	7.9	14
3/20/2005	861	1,580	718	2,123	143	40	80
3/21/2005	740	888	249	1,455	87	42	59
3/22/2005	509	503	82	782	38	33	38
3/23/2005	424	373	48	585	23	28	25
3/24/2005	371	306	34	484	16	24	21
3/25/2005	333	264	26	417	12	20	19
3/26/2005	539	684	205	874	58	37	67
3/27/2005	673	749	182	1,088	66	44	73
3/28/2005	577	552	102	816	41	40	51
3/29/2005	505	443	68	664	30	37	46
3/30/2005	443	371	51	576	23	32	35
3/31/2005	405	327	43	514	19	31	32

Table 3.2
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Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
4/1/2005	533	690	215	1,093	59	41	62
4/2/2005	509	521	110	855	45	39	50
4/3/2005	620	640	242	1,002	90	52	79
4/4/2005	570	535	134	856	61	50	59
4/5/2005	522	482	102	715	40	46	50
4/6/2005	602	639	159	966	45	43	48
4/7/2005	544	522	96	825	31	39	39
4/8/2005	503	457	65	710	22	34	33
4/9/2005	446	370	45	584	16	30	28
4/10/2005	409	324	37	511	14	27	26
4/11/2005	450	415	103	649	24	29	36
4/12/2005	417	348	68	586	21	27	32
4/13/2005	396	319	56	539	21	26	32
4/14/2005	375	299	49	508	19	24	28
4/15/2005	362	288	51	499	20	27	34
4/16/2005	686	1,072	314	1,528	98	51	97
4/17/2005	644	730	133	1,091	54	46	64
4/18/2005	534	515	72	757	30	40	44
4/19/2005	478	418	49	619	20	34	35
4/20/2005	454	384	38	560	15	30	27
4/21/2005	482	428	33	566	12	27	23
4/22/2005	555	496	31	602	10	23	21
4/23/2005	619	543	27	633	9.0	21	20
4/24/2005	682	599	24	671	8.0	18	19
4/25/2005	699	594	20	652	7.2	16	18
4/26/2005	734	619	18	652	6.5	15	17
4/27/2005	765	633	16	659	6.1	13	16
4/28/2005	724	588	14	633	5.6	12	15
4/29/2005	617	491	15	599	6.2	13	17
4/30/2005	576	456	15	580	5.6	11	14
5/1/2005	545	409	12	529	5.2	10	14
5/2/2005	598	475	12	557	5.2	10	13
5/3/2005	625	512	15	571	5.0	9.5	13
5/4/2005	592	471	14	552	5.0	9.3	13
5/5/2005	587	462	14	544	4.7	8.7	13
5/6/2005	603	432	12	515	4.5	8.3	12
5/7/2005	559	395	11	485	4.3	7.9	11
5/8/2005	504	347	9.5	452	4.2	7.7	11
5/9/2005	481	333	8.9	431	4.1	7.6	11
5/10/2005	617	483	15	494	5.5	8.6	13

Table 3.2
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Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
5/11/2005	587	438	14	467	4.9	7.4	12
5/12/2005	536	387	12	438	4.7	7.1	11
5/13/2005	519	366	11	421	4.5	6.9	11
5/14/2005	553	381	10	419	4.3	6.6	11
5/15/2005	628	460	10	443	4.4	6.7	11
5/16/2005	572	410	11	425	5.0	6.7	11
5/17/2005	485	359	12	405	6.4	6.7	12
5/18/2005	948	2,069	231	1,969	38	15	28
5/19/2005	1,244	2,374	415	2,494	83	27	39
5/20/2005	1,064	1,534	161	1,825	49	26	28
5/21/2005	854	1,047	79	1,302	28	21	26
5/22/2005	834	1,208	118	1,566	37	25	35
5/23/2005	748	900	82	1,309	32	25	27
5/24/2005	680	699	52	1,004	21	22	23
5/25/2005	640	592	37	831	15	19	20
5/26/2005	653	568	28	740	12	17	17
5/27/2005	693	564	21	681	9.5	15	16
5/28/2005	729	567	18	640	8.1	13	15
5/29/2005	733	560	15	607	7.2	12	14
5/30/2005	696	509	13	567	6.5	11	13
5/31/2005	653	464	12	530	6.0	11	13
6/1/2005	592	427	12	492	6.2	10	13
6/2/2005	534	369	15	453	6.1	9.8	13
6/3/2005	495	330	16	420	5.6	9.3	12
6/4/2005	480	313	16	393	5.2	8.8	12
6/5/2005	456	295	15	370	5.0	8.4	11
6/6/2005	434	299	19	363	4.9	8.0	11
6/7/2005	415	286	20	350	5.3	8.4	11
6/8/2005	437	293	23	340	5.9	8.1	11
6/9/2005	413	281	24	325	5.6	7.6	11
6/10/2005	407	271	21	312	5.3	7.2	11
6/11/2005	426	291	28	302	5.3	7.0	11
6/12/2005	417	297	45	289	5.2	6.7	10.0
6/13/2005	402	267	34	279	5.0	6.4	12
6/14/2005	396	256	27	271	4.8	6.2	12
6/15/2005	389	253	38	260	4.5	6.0	10
6/16/2005	374	242	38	250	4.4	6.0	9.4
6/17/2005	439	283	37	273	4.9	6.4	11
6/18/2005	402	253	29	257	4.3	5.7	9.9
6/19/2005	368	229	23	242	4.0	5.4	9.5

Table 3.2
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Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
6/20/2005	363	217	19	234	3.8	5.2	9.2
6/21/2005	382	221	16	231	3.7	5.2	9.1
6/22/2005	379	219	14	227	3.6	5.2	8.6
6/23/2005	349	203	12	217	3.5	5.1	9.2
6/24/2005	336	192	11	209	3.3	4.9	9.5
6/25/2005	328	185	9.7	204	3.3	4.9	9.9
6/26/2005	313	178	8.9	199	3.2	4.8	11
6/27/2005	315	178	10	197	3.3	4.9	10
6/28/2005	301	170	9.6	192	3.2	4.7	11
6/29/2005	304	165	8.7	187	3.0	4.6	11
6/30/2005	310	164	8.0	184	2.9	4.5	10
7/1/2005	301	158	7.5	179	2.9	4.4	9.7
7/2/2005	285	153	9.5	174	2.9	4.4	9.2
7/3/2005	272	146	9.3	169	2.8	4.3	8.8
7/4/2005	270	140	8.3	163	2.7	4.2	9.0
7/5/2005	277	138	7.8	161	2.7	4.3	9.0
7/6/2005	342	164	8.3	171	2.8	4.4	10
7/7/2005	286	144	7.4	162	2.6	4.1	9.8
7/8/2005	320	172	15	190	4.8	5.8	13
7/9/2005	323	187	18	216	4.3	4.7	8.9
7/10/2005	270	156	15	189	3.7	4.4	8.7
7/11/2005	276	167	15	196	3.7	4.5	10
7/12/2005	298	180	15	204	3.4	4.2	9.3
7/13/2005	270	159	13	193	3.3	4.1	8.3
7/14/2005	250	144	11	186	3.1	4.0	8.5
7/15/2005	249	137	10	180	3.0	4.0	7.7
7/16/2005	245	132	9.4	175	3.0	4.0	7.8
7/17/2005	233	124	8.2	168	2.8	3.9	7.9
7/18/2005	232	119	7.3	162	2.7	3.9	7.9
7/19/2005						3.9	
7/20/2005						3.9	
7/21/2005						3.9	
7/22/2005						3.9	
7/23/2005						3.8	
7/24/2005						3.8	
7/25/2005						3.8	
7/26/2005						3.8	
7/27/2005						3.7	
7/28/2005						3.7	
7/29/2005						3.7	

Table 3.2
Mean Daily Discharges
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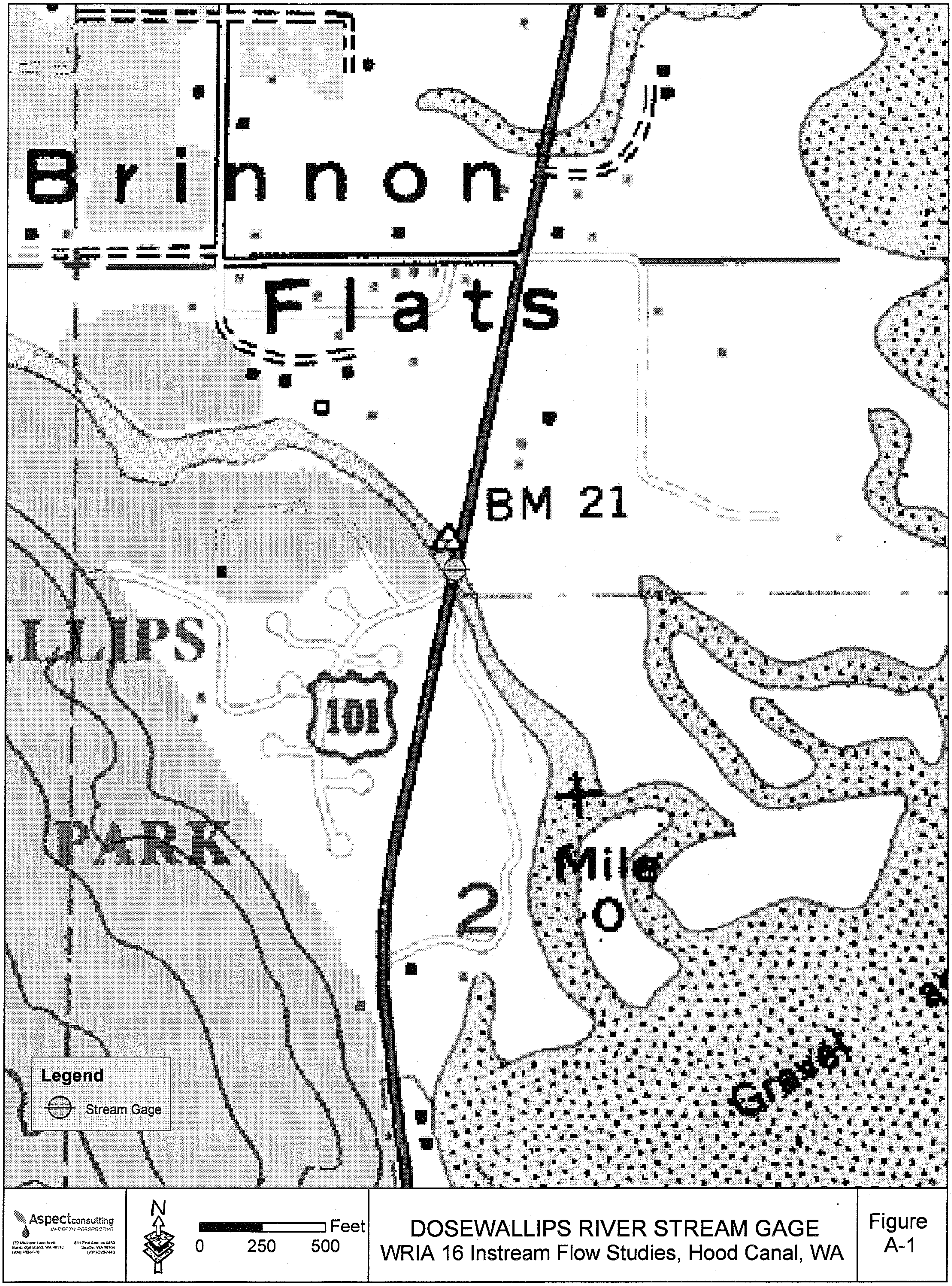
Date	Mean Daily Discharge (cfs)						
	Dosewallips	Duckabush	Fulton	Hamma Hamma	John	Jorsted	Eagle
7/30/2005						3.6	
7/31/2005						3.6	
8/1/2005						3.7	
8/2/2005						3.6	
8/3/2005						3.6	
8/4/2005						3.6	
8/5/2005						3.5	
8/6/2005						3.5	
8/7/2005						3.5	
8/8/2005						3.5	
8/9/2005						3.5	
8/10/2005						3.5	
8/11/2005						3.4	
8/12/2005						3.4	
8/13/2005						3.3	
8/14/2005						3.3	
8/15/2005						3.3	
8/16/2005						3.3	
8/17/2005						3.3	
8/18/2005							

Period:	7/1/04 - 6/30/05	7/1/04 - 6/30/05	7/1/04 - 6/30/05	7/1/04 - 6/30/05	7/1/04 - 6/30/05	8/15/04 - 8/14/05	7/1/04 - 6/30/05
Average Mean Daily Flow:	385	398	40	480	16	14	20

APPENDIX A

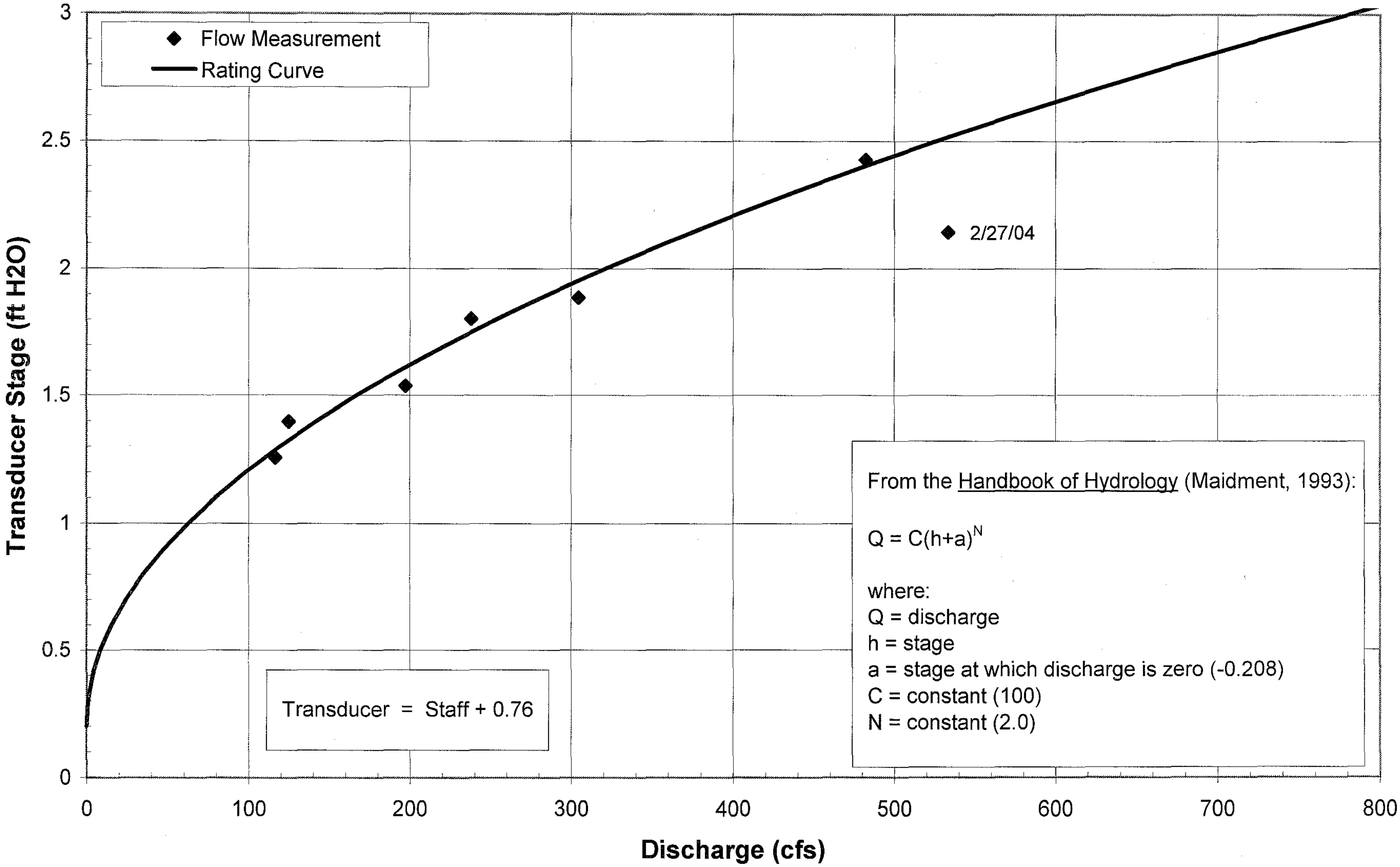
Dosewallips River



DOSEWALLIPS RIVER STREAM GAGE
WRIA 16 Instream Flow Studies, Hood Canal, WA

Figure A-1

Aspect consulting
IN-DEPTH PERSPECTIVE

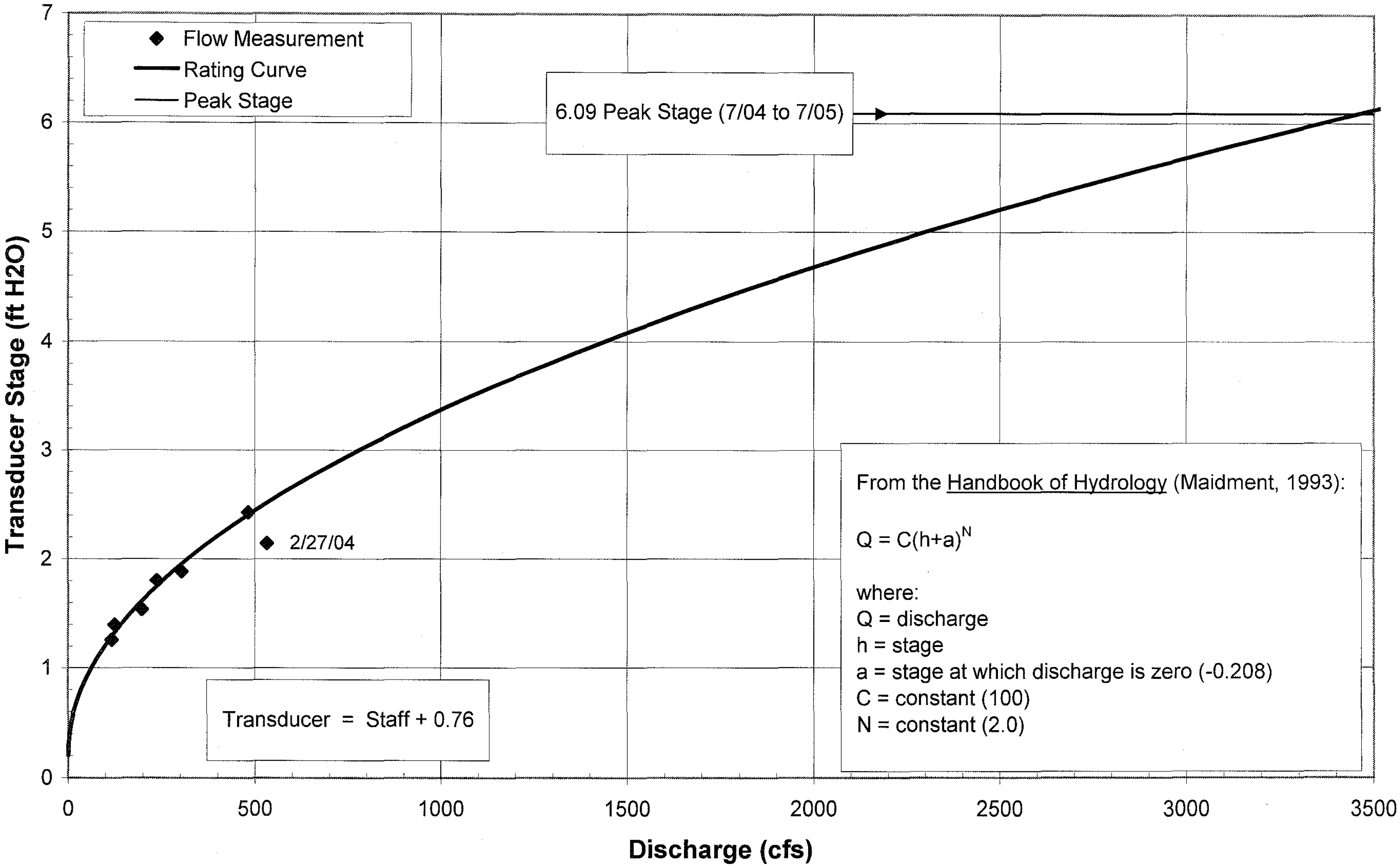


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve - Dosewallips River
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure A-2



Aspect consulting IN-DEPTH PERSPECTIVE

Discharge Rating Curve (extrapolated) - Dosewallips River

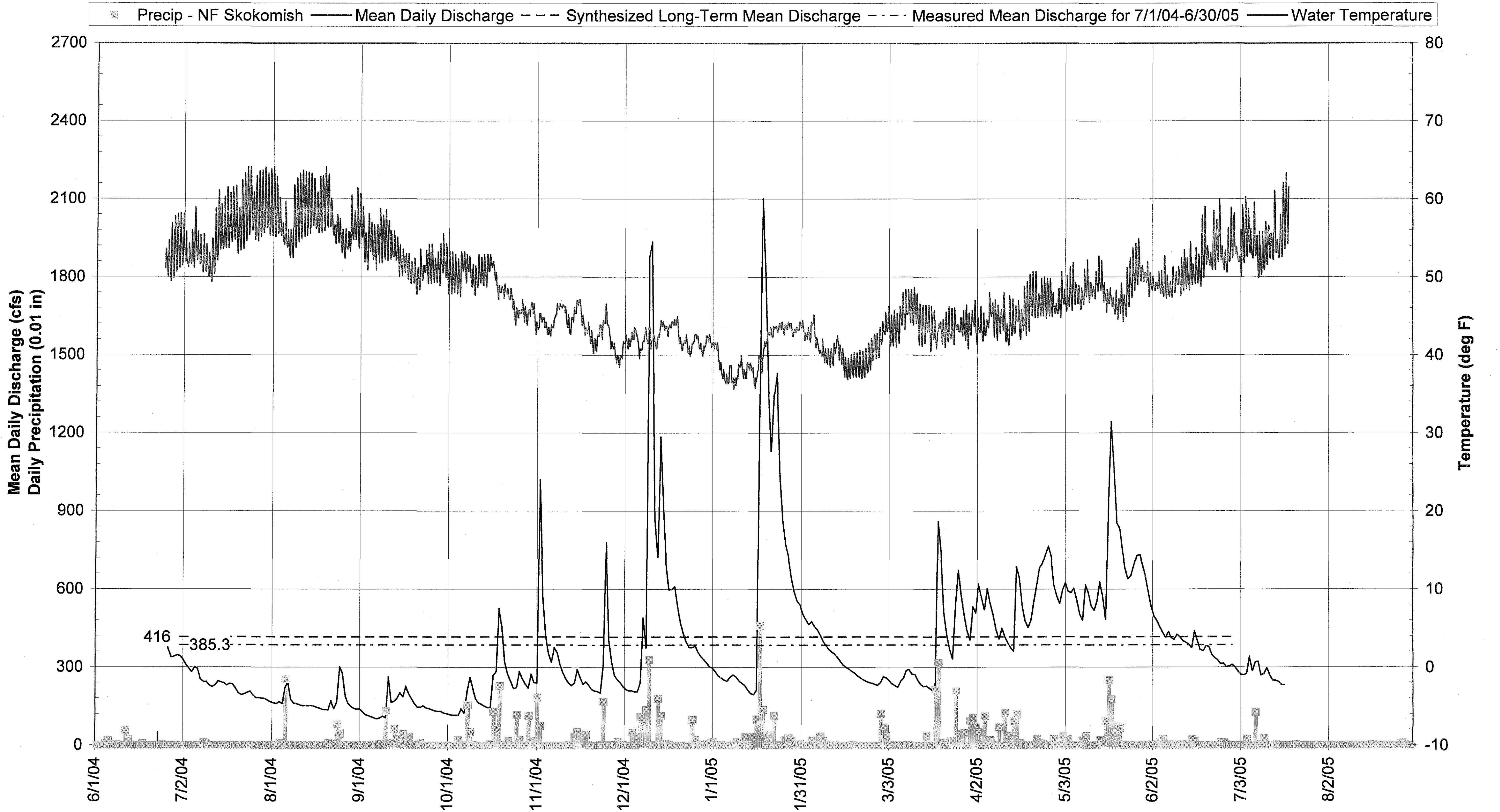
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure A-3

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Precipitation data from NF Skokomish, Staircase Rapids station.
Temperature data were obtained and plotted at 15-minute intervals.
Discharge data were obtained at 15-minute intervals and averaged to mean daily discharge.



Aspect consulting IN-DEPTH PERSPECTIVE

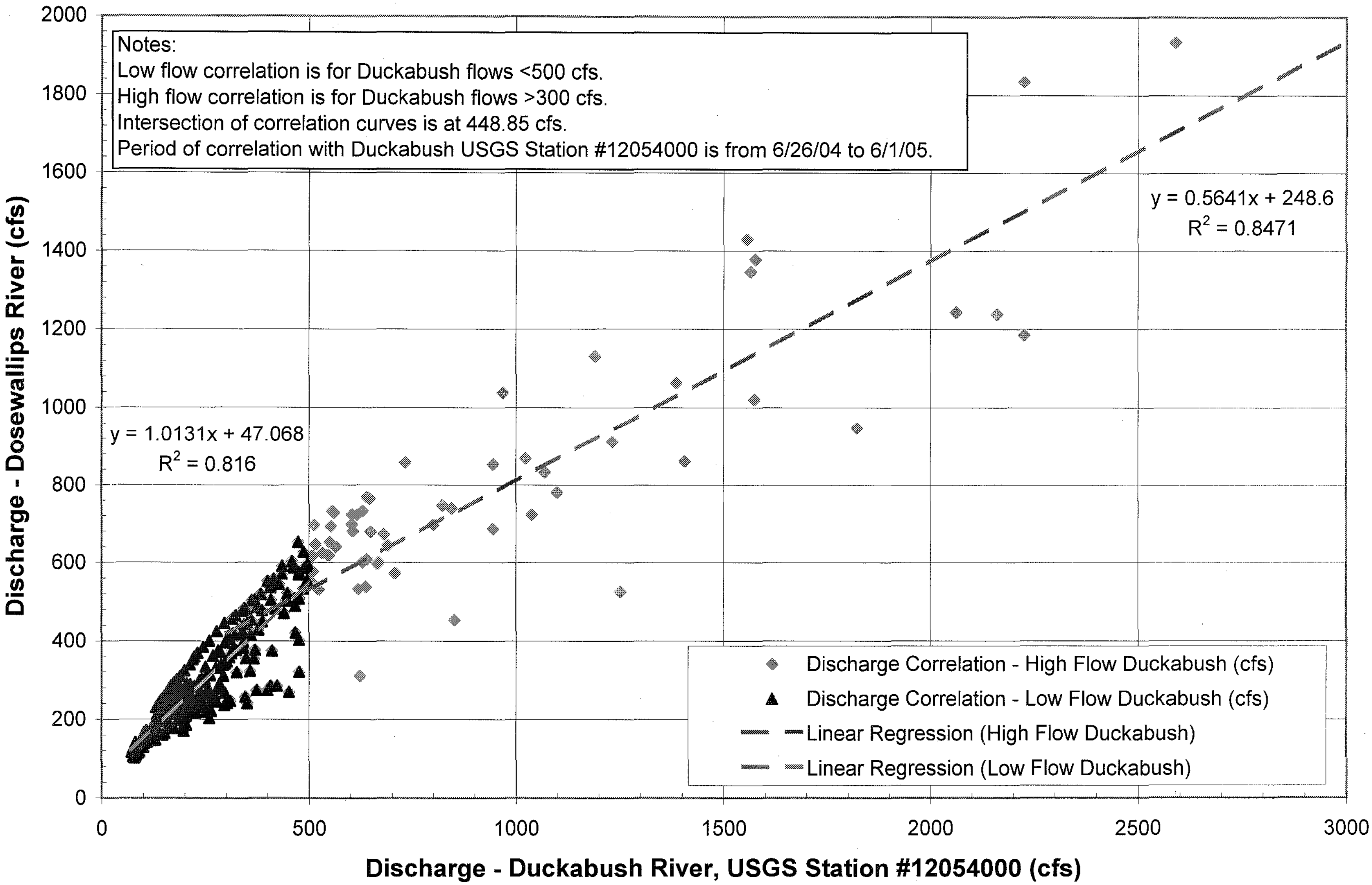
Mean Daily Discharge, Temperature, and Precipitation - Dosewallips River

WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure A-4

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Mean Daily Discharge.xls



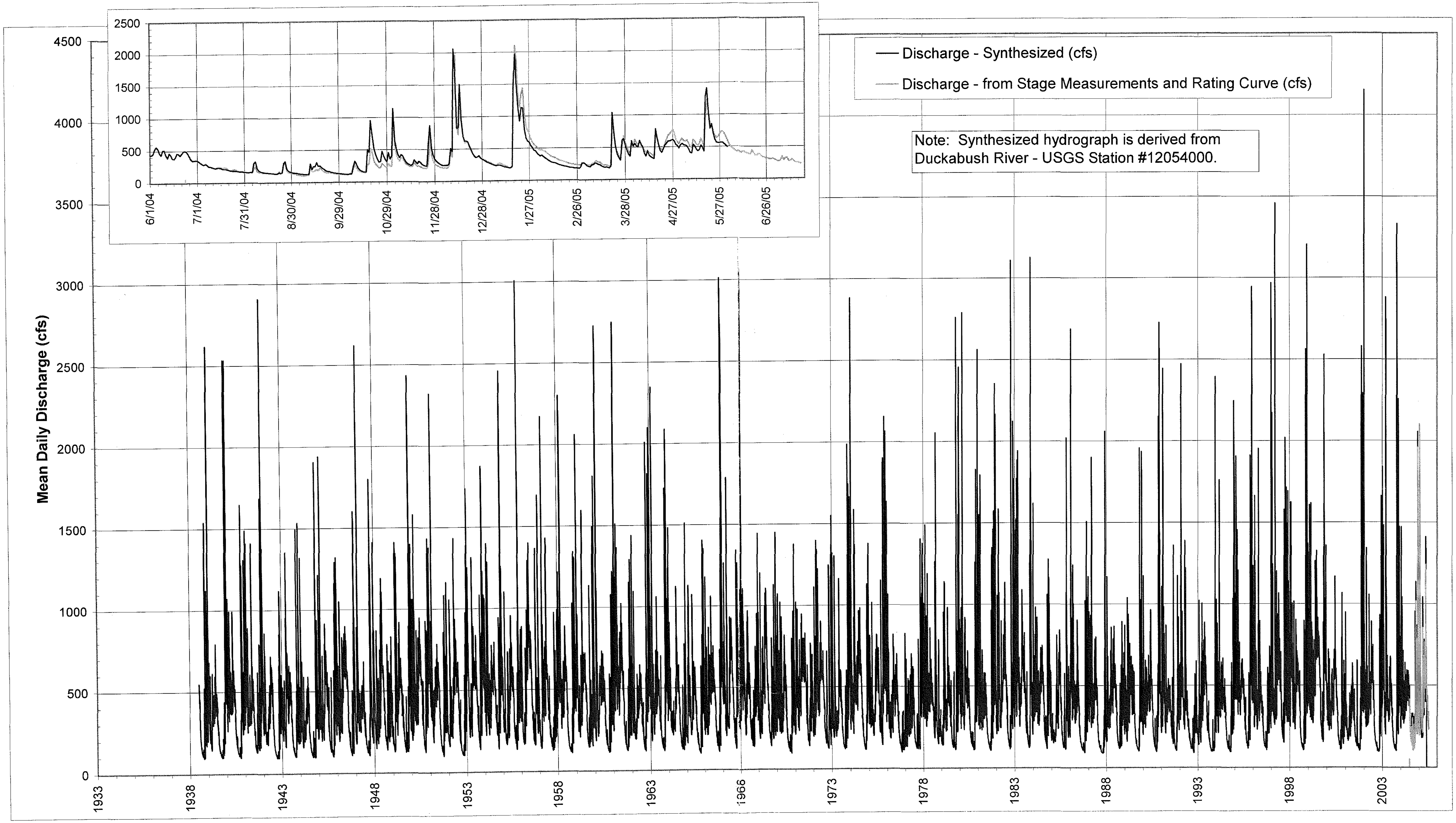
Discharge Correlation Between Dosewallips River and the Duckabush River

WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Discharge Correlations.xls

Figure A-5



Aspect consulting
IN-DEPTH PERSPECTIVE

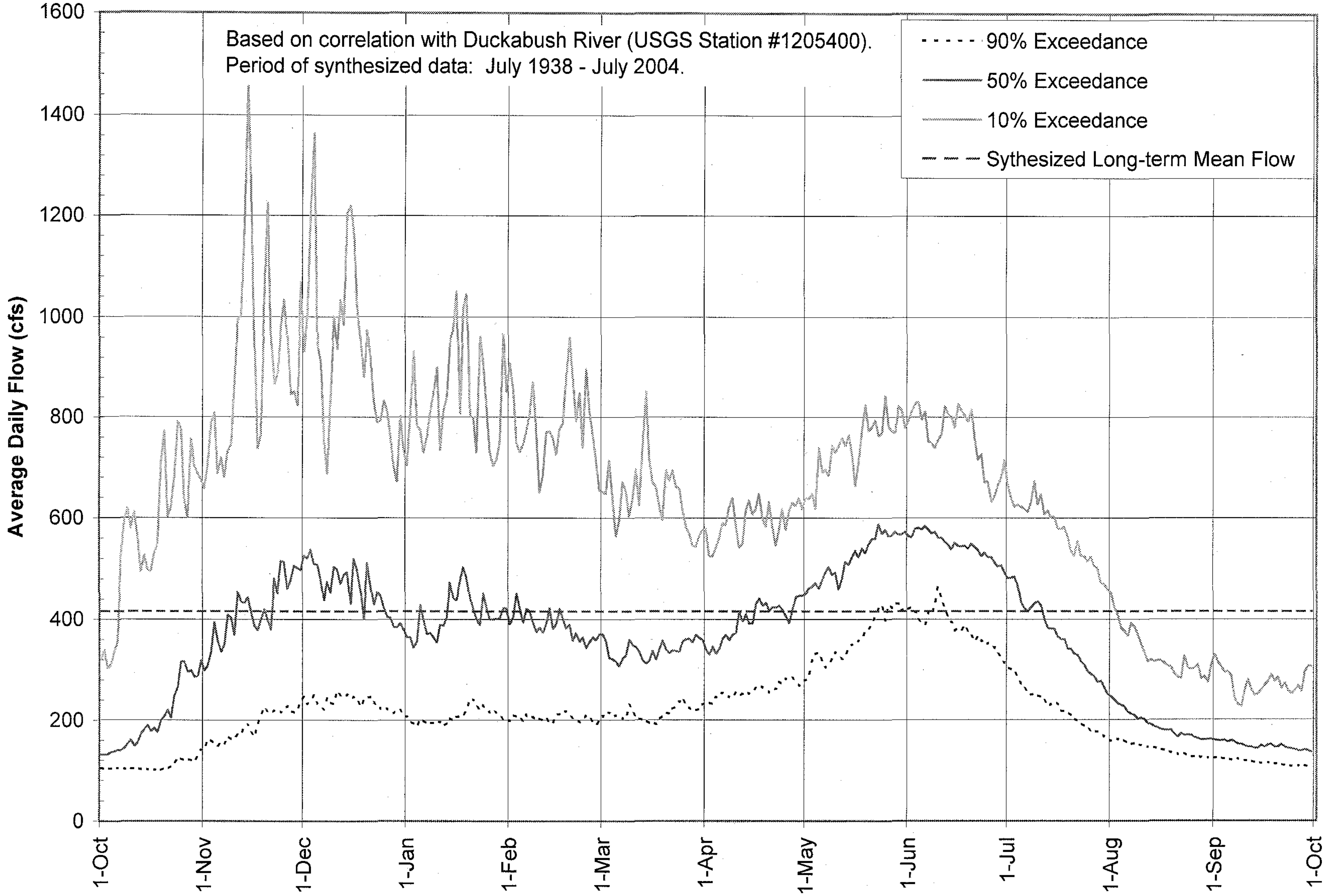
P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Synthesized Hydrograph of Dosewallips River

WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure A-6



Aspect consulting IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Streamflow Exceedance Curves - Dosewallips River

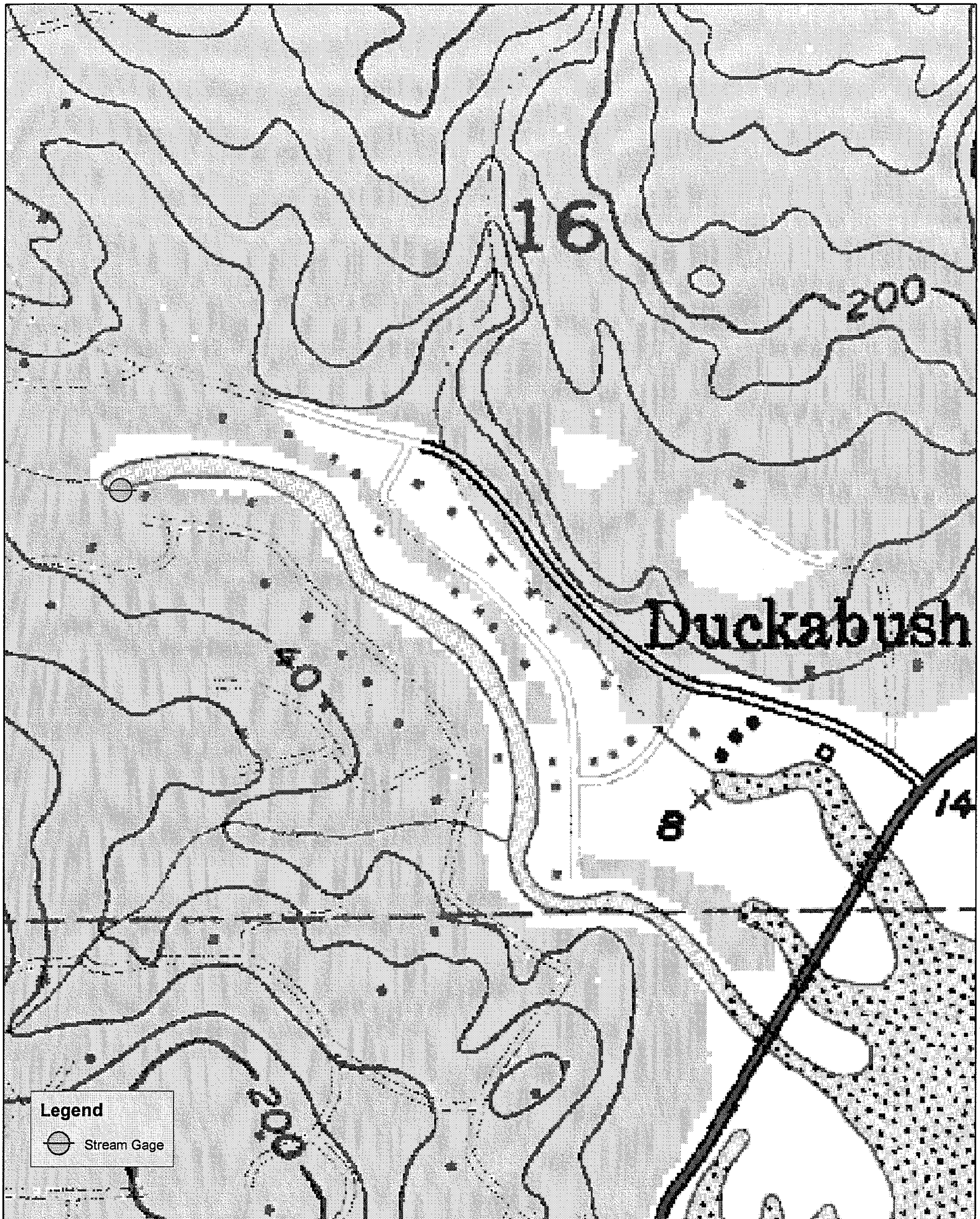
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure A-7

APPENDIX B

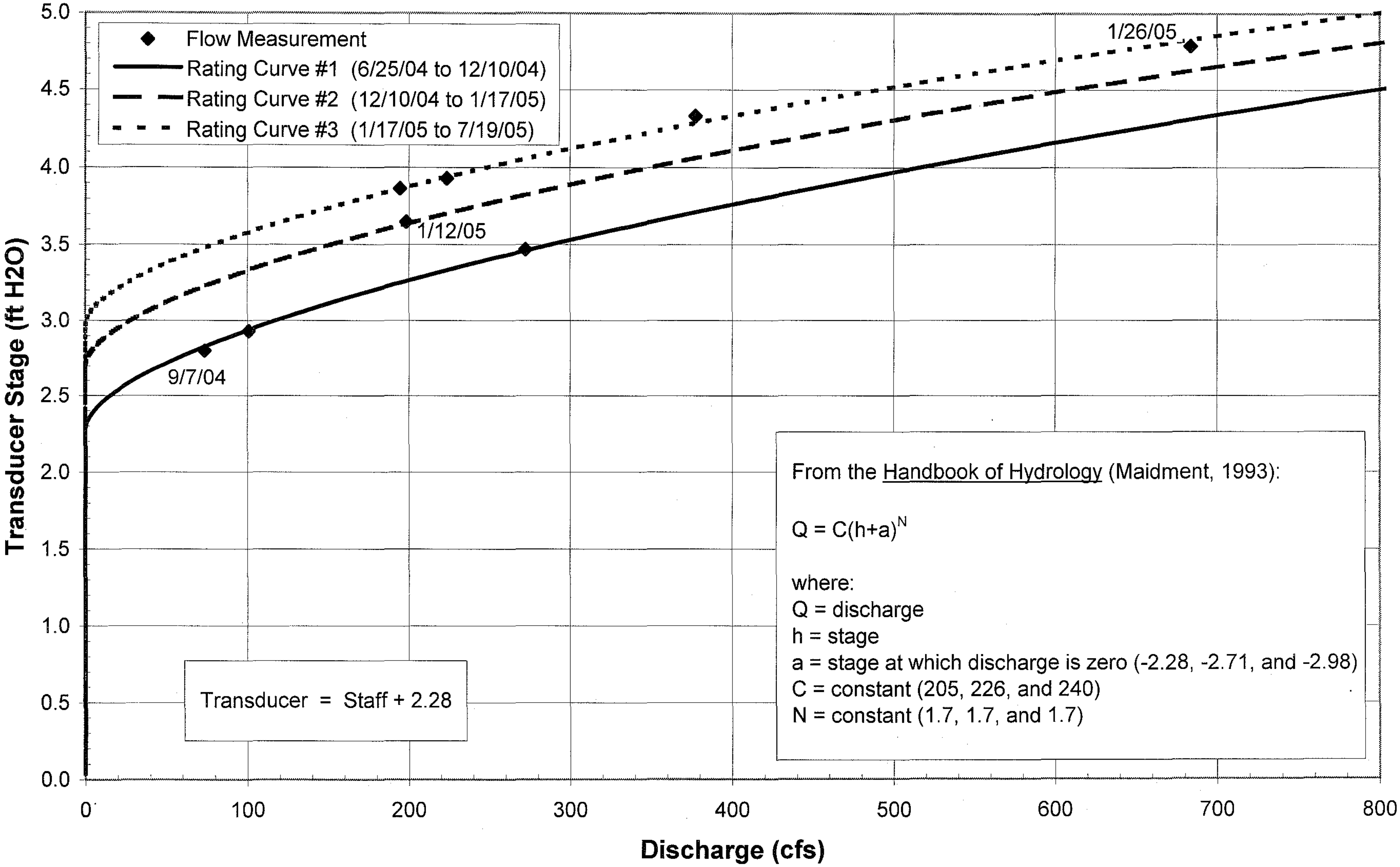
Duckabush River



Aspect consulting
IN-DEPTH PERSPECTIVE

DUCKABUSH RIVER STREAM GAGE
WRIA 16 Instream Flow Studies, Hood Canal, WA

Figure
B-1

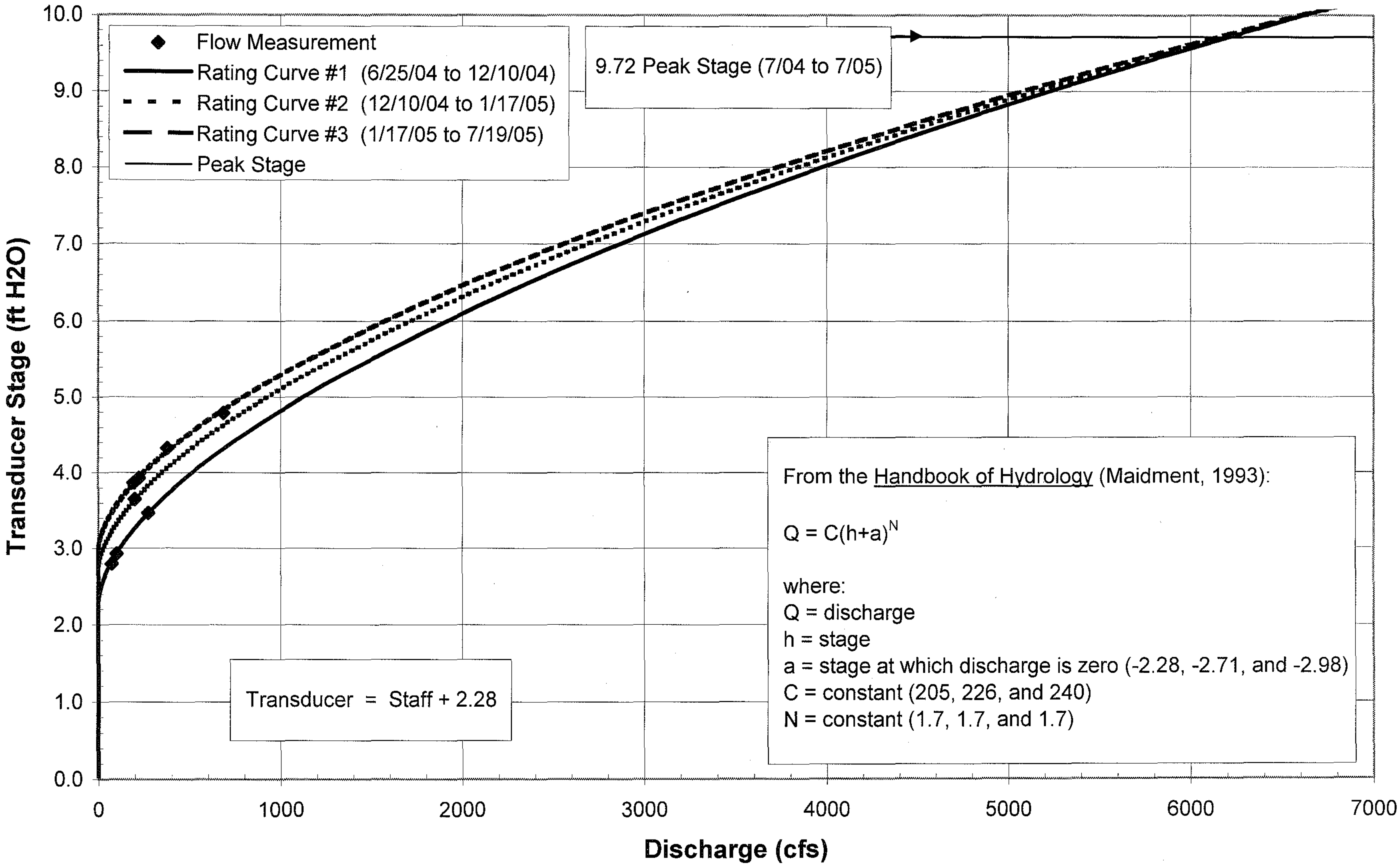


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve - Duckabush River
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure B-2



Aspect consulting *IN-DEPTH PERSPECTIVE*

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

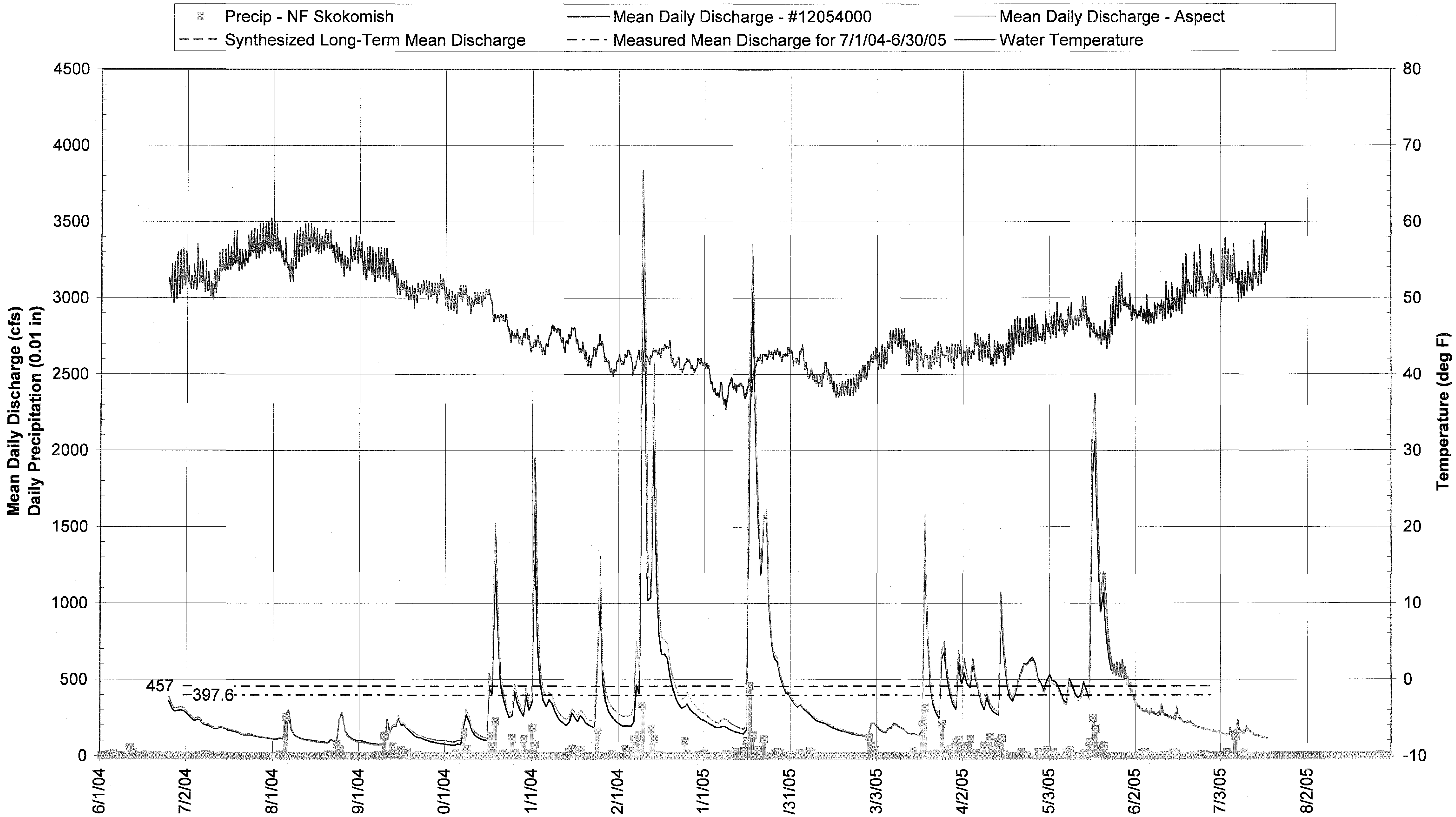
Discharge Rating Curve (extrapolated) - Duckabush River

WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure B-3

Precipitation data from NF Skokomish, Staircase Rapids station.
Temperature data were obtained and plotted at 15-minute intervals.
Discharge data were obtained at 15-minute intervals and averaged to mean daily discharge.

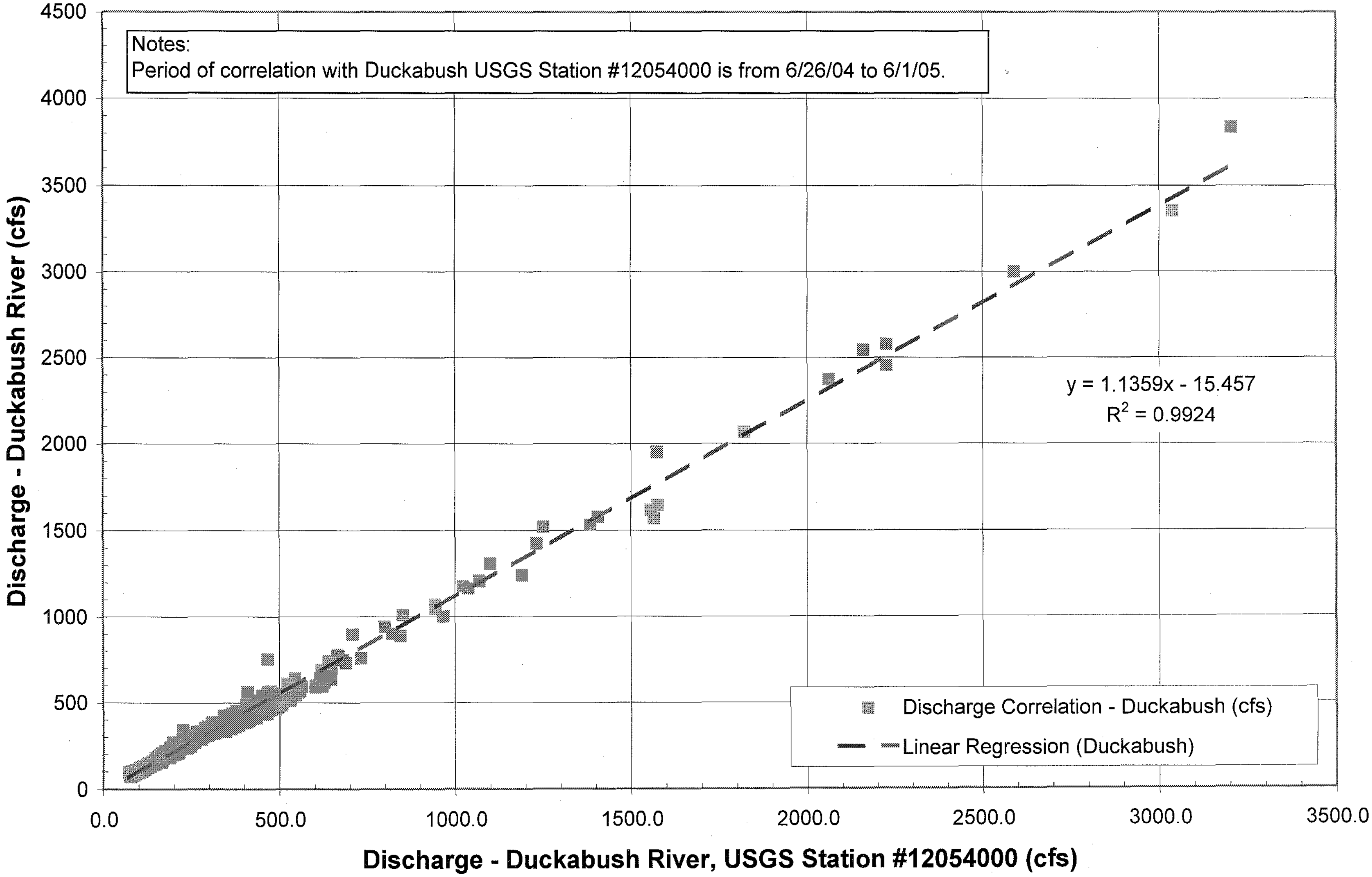


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Mean Daily Discharge.xls

Mean Daily Discharge, Temperature, and Precipitation - Duckabush River
WRIA16 Instream Flow Studies
Jefferson and Mason Countiesn, WA

Figure B-4



Discharge Correlation Between Duckabush River and the Duckabush River

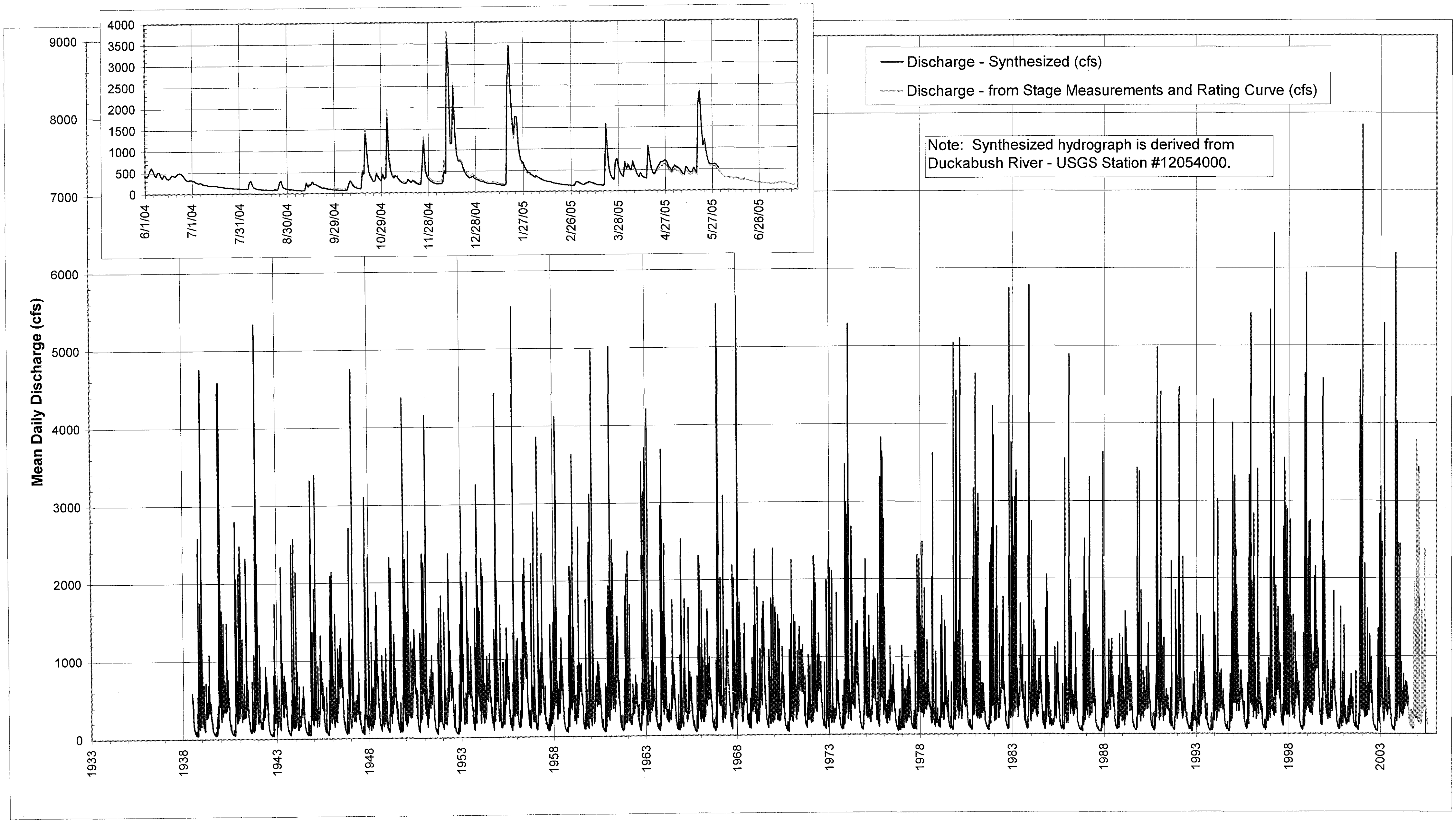
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure B-5

Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Discharge Correlations.xls



Aspect consulting
IN-DEPTH PERSPECTIVE

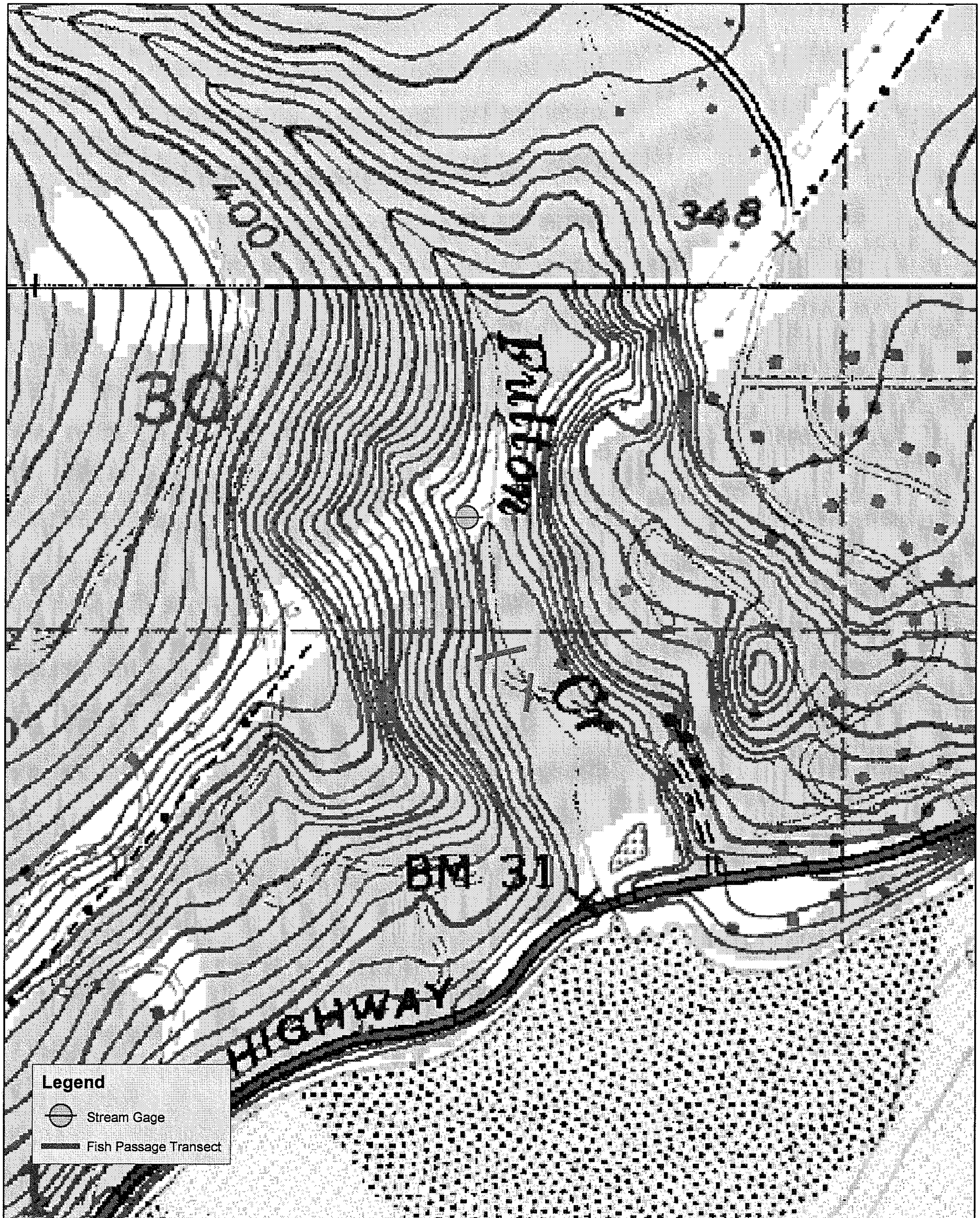
Synthesized Hydrograph of Duckabush River
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure B-6

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

APPENDIX C

Fulton Creek

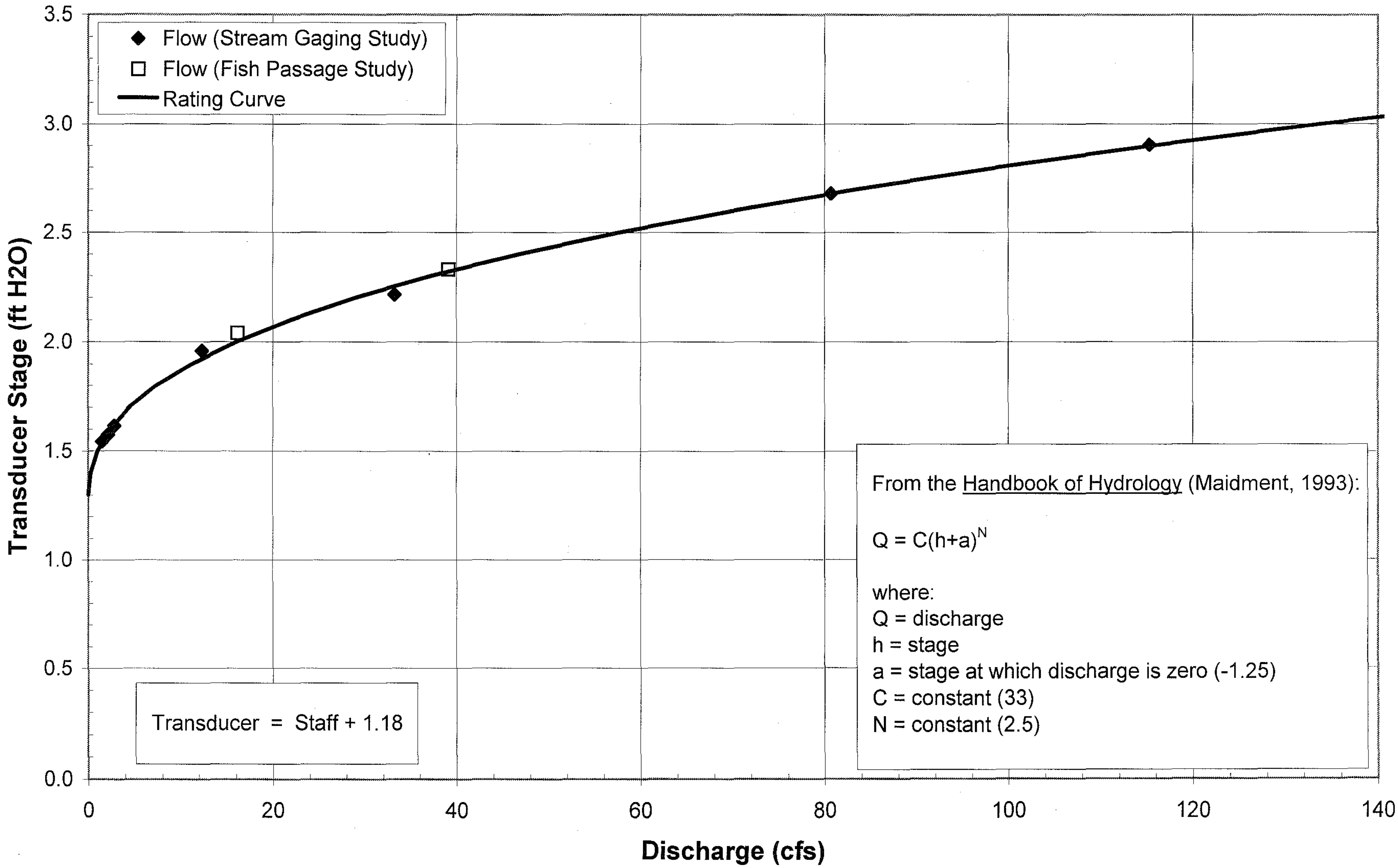


Aspect consulting
IN-DEPTH PERSPECTIVE

N
0 250 500 Feet

FULTON CREEK STREAM GAGE
AND FISH PASSAGE TRANSECTS
WRIA 16 Instream Flow Studies, Hood Canal, WA

Figure
C-1

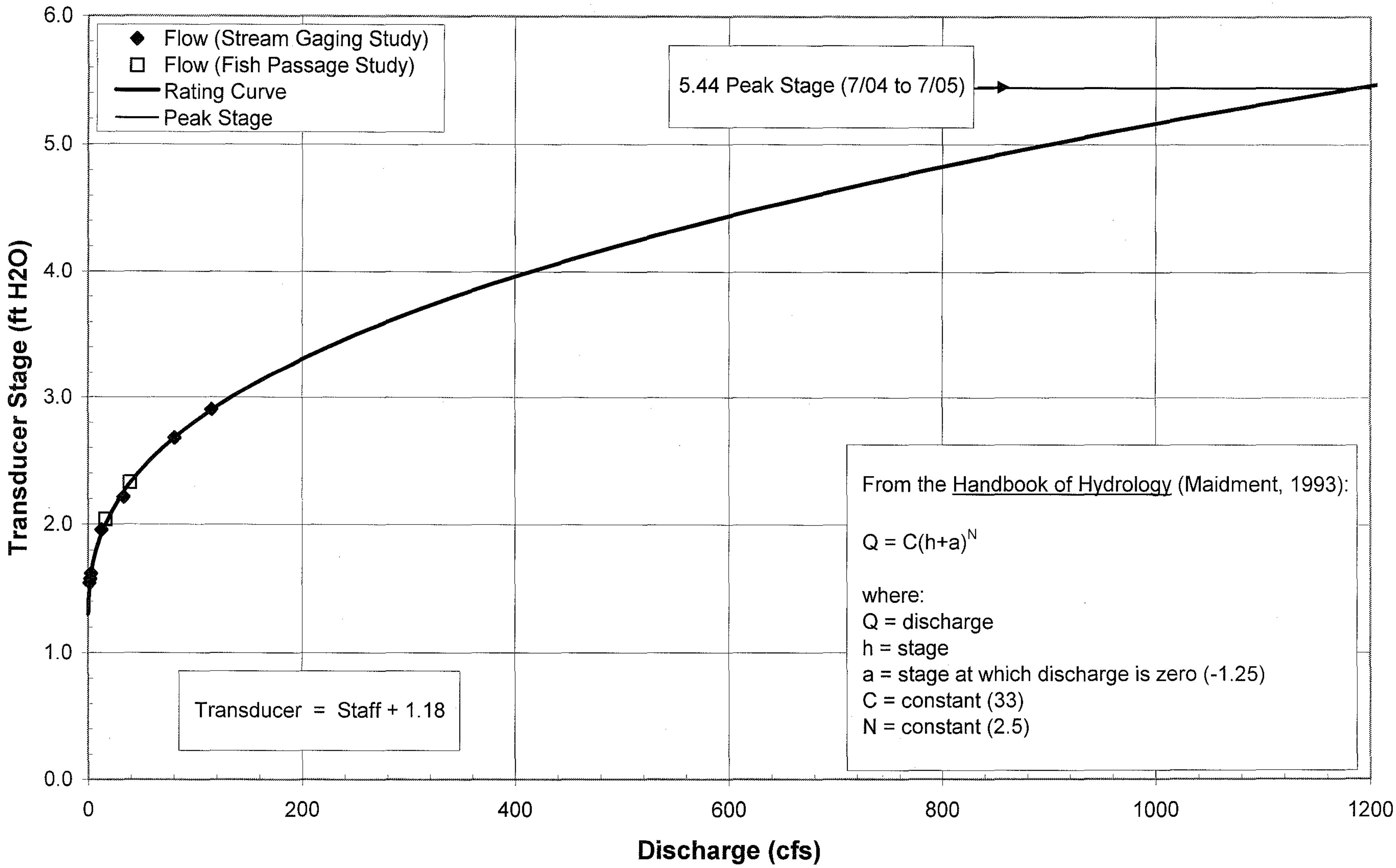


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve - Fulton Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure C-2



Aspect consulting IN-DEPTH PERSPECTIVE

Discharge Rating Curve (extrapolated) - Fulton Creek

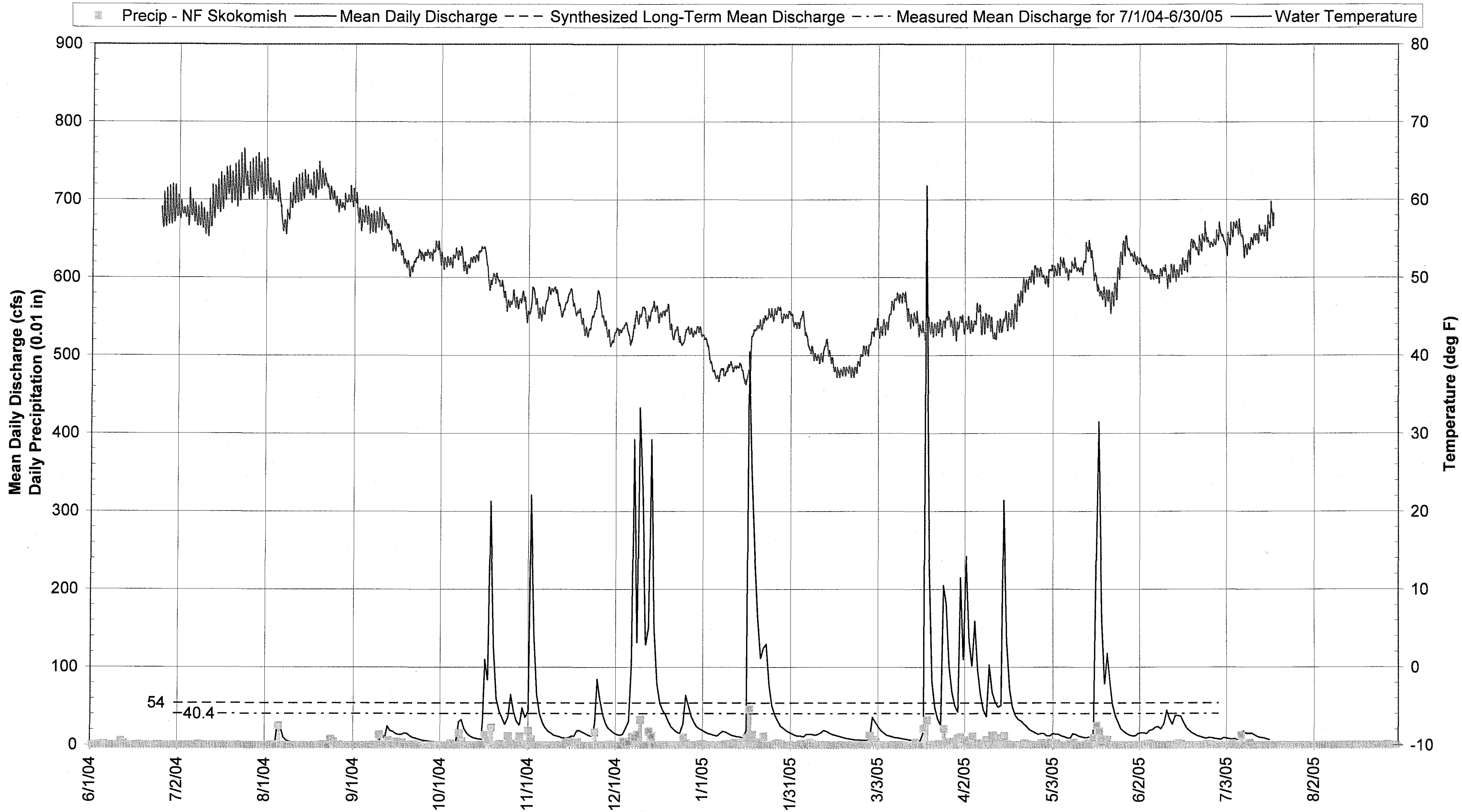
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure C-3

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Precipitation data from NF Skokomish, Staircase Rapids station.
Temperature data were obtained and plotted at 15-minute intervals.
Discharge data were obtained at 15-minute intervals and averaged to mean daily discharge.

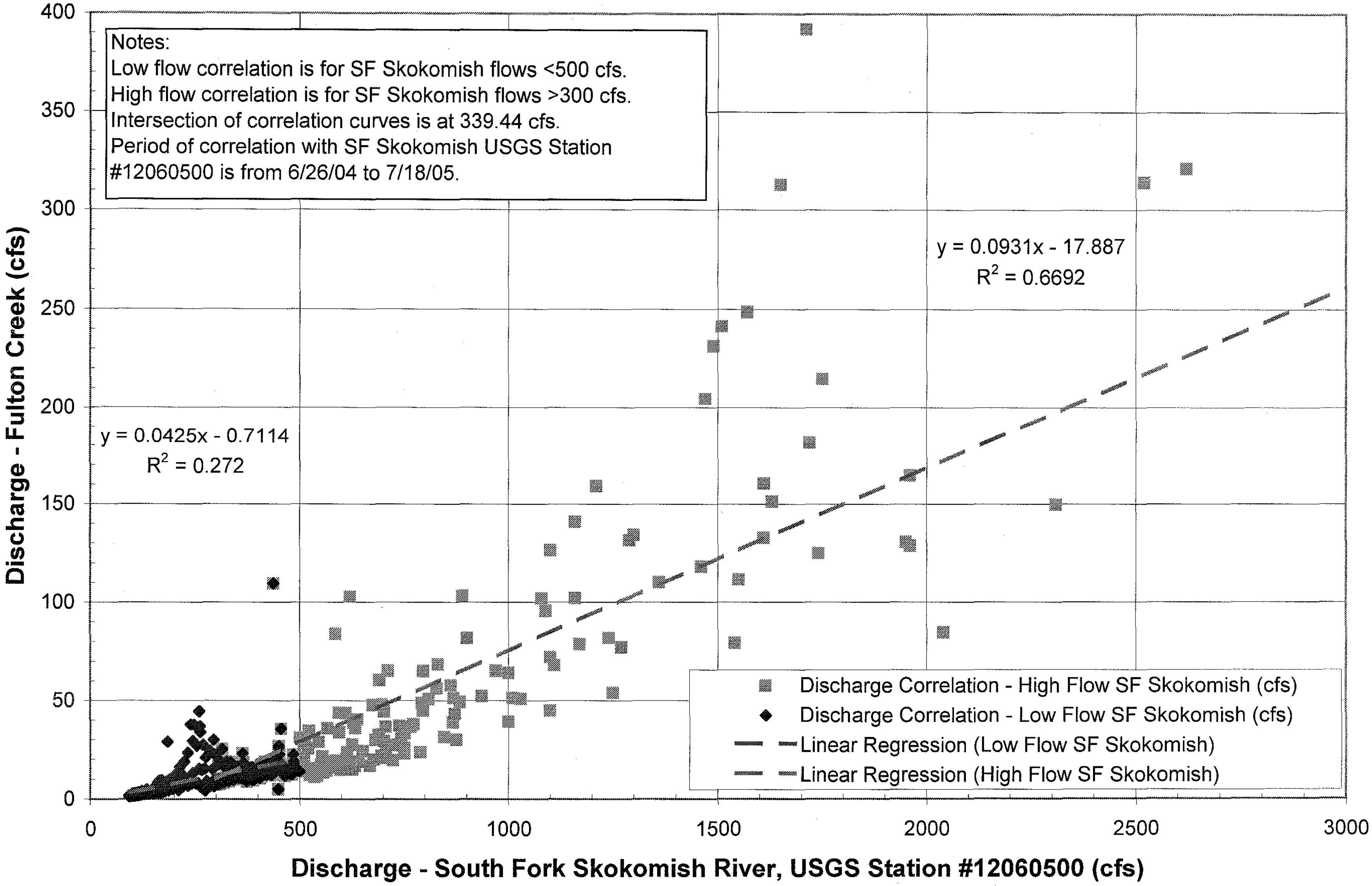


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Mean Daily Discharge.xls

Mean Daily Discharge, Temperature, and Precipitation - Fulton Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure C-4



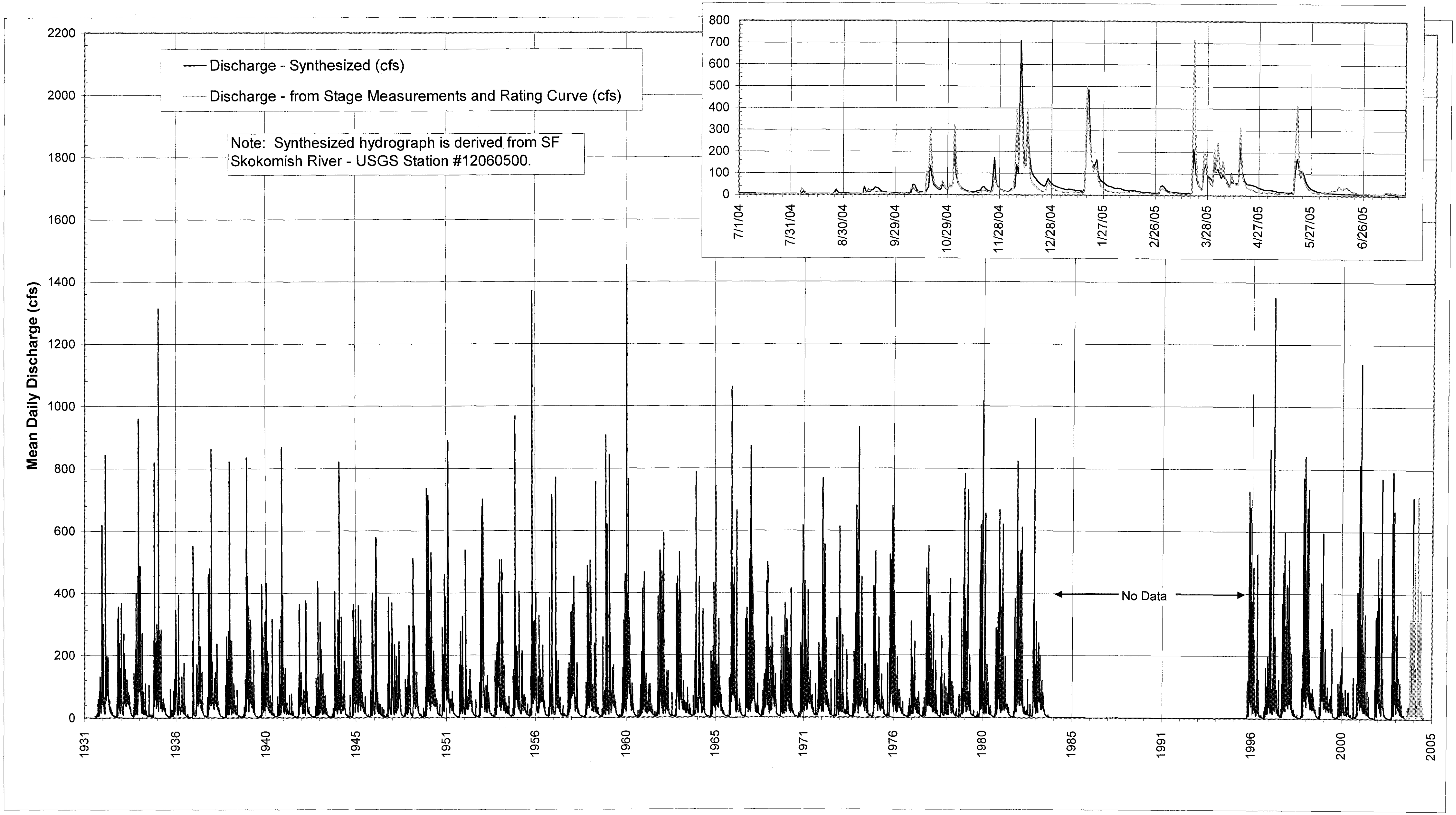
Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Discharge Correlations.xls

Discharge Correlation Between Fulton Creek and the South Fork Skokomish River

WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure C-5

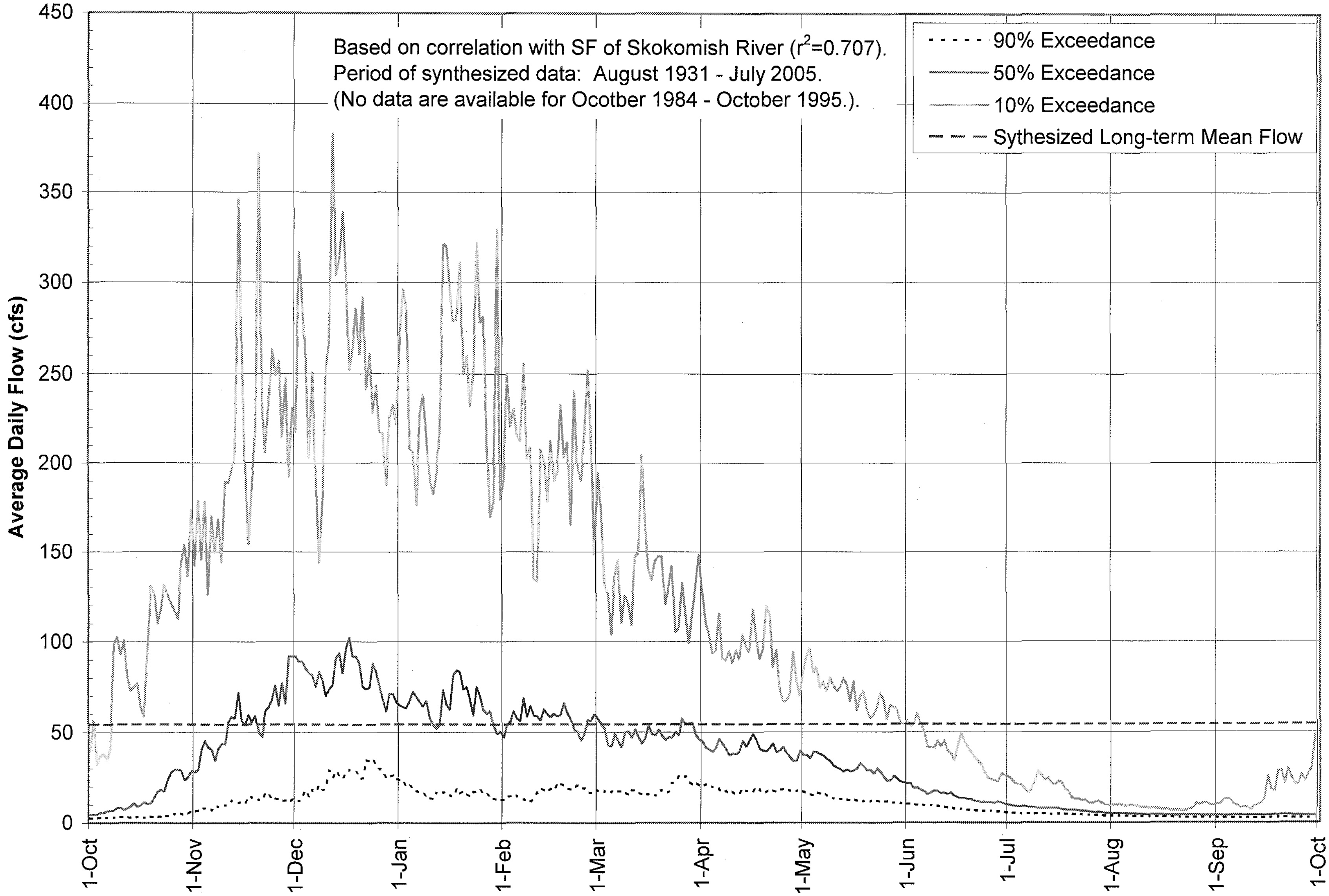


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Synthesized Hydrograph of Fulton Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure C-6



Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Streamflow Exceedance Curves - Fulton Creek

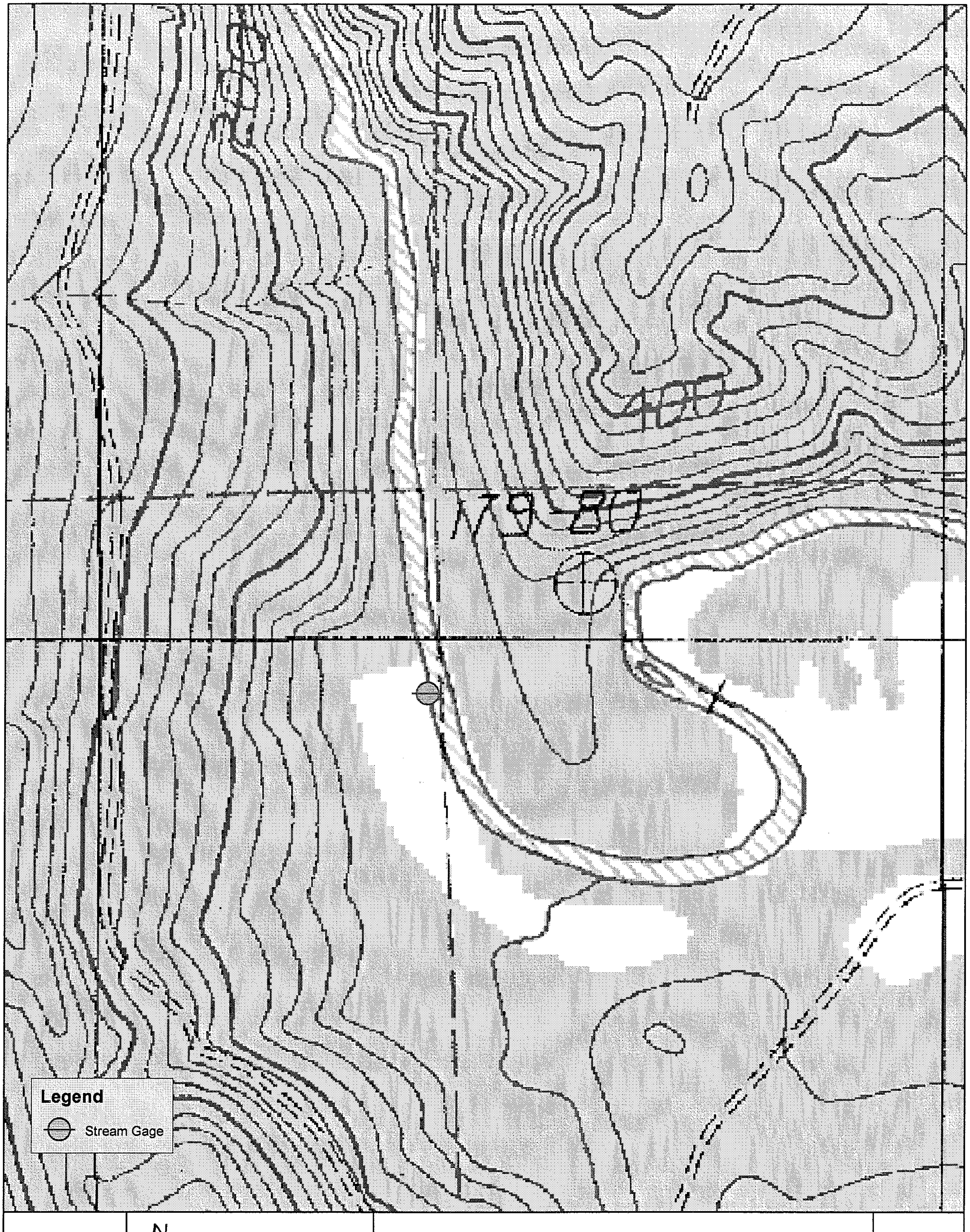
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure C-7

APPENDIX D

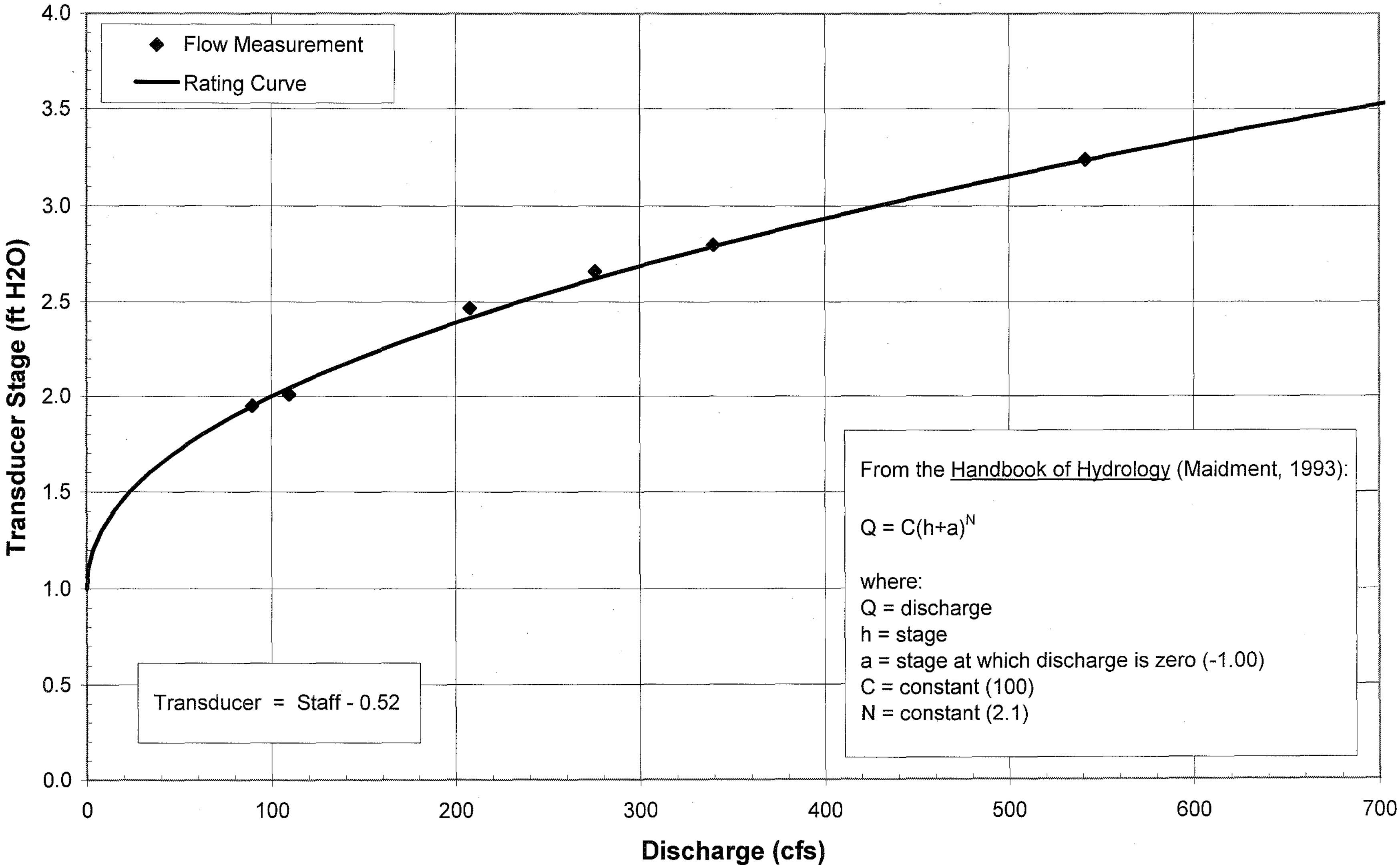
Hamma Hamma River



Aspect consulting

HAMMA HAMMA RIVER STREAM GAGE
WRIA 16 Instream Flow Studies, Hood Canal, WA

Figure D-1

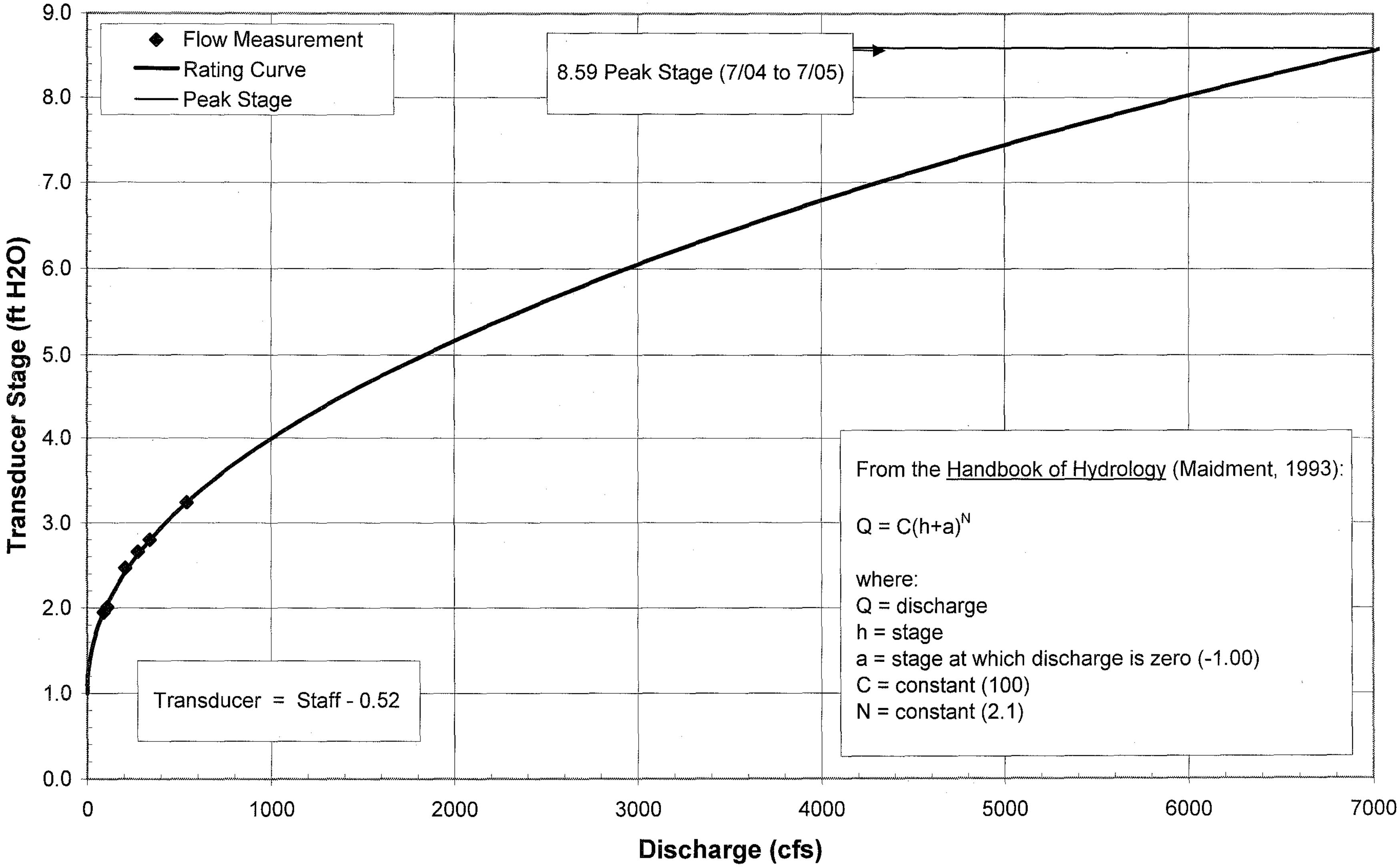


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve - Hamma Hamma River
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure D-2



Aspect consulting *IN-DEPTH PERSPECTIVE*

Discharge Rating Curve (extrapolated) - Hamma Hamma River

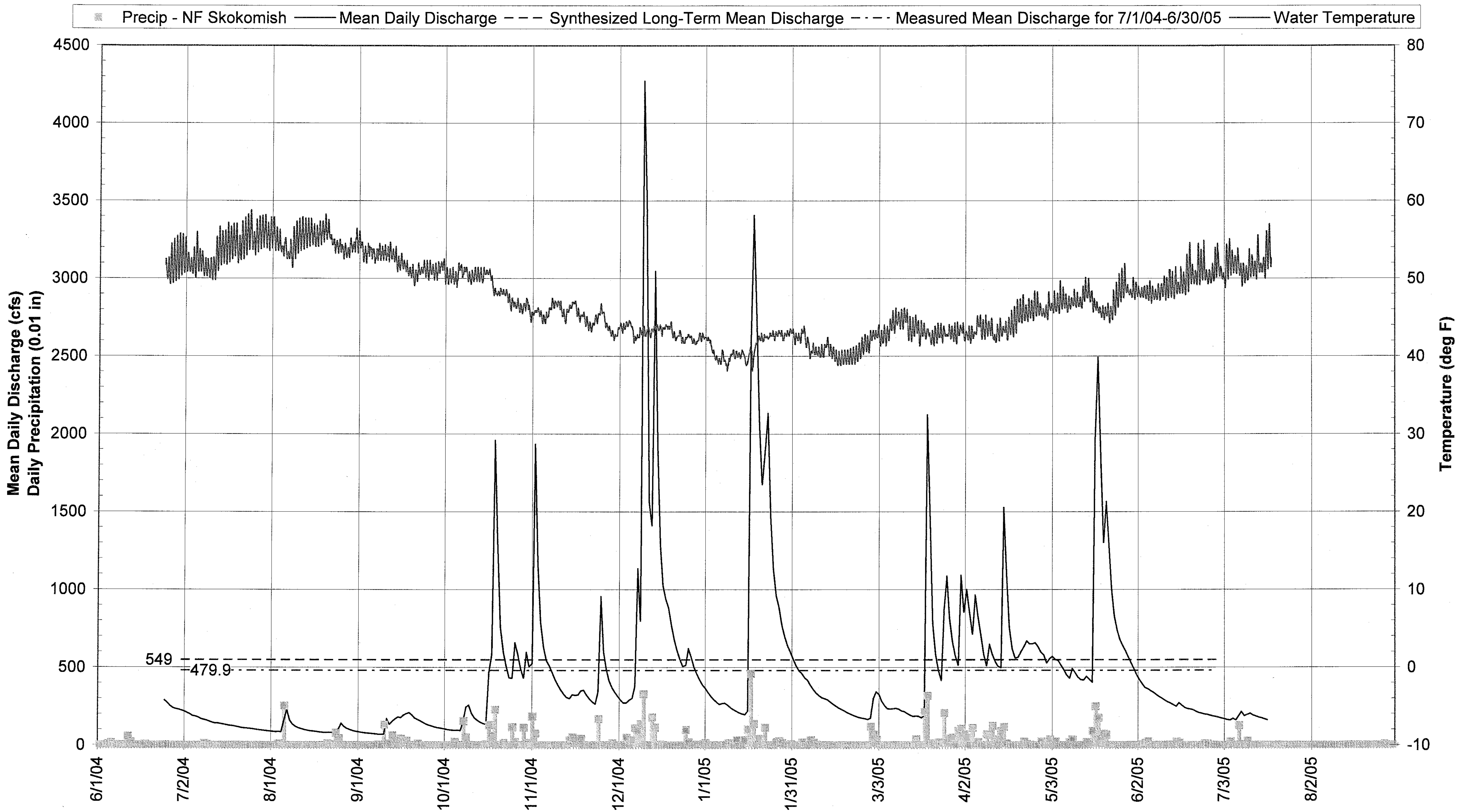
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure D-3

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Precipitation data from NF Skokomish, Staircase Rapids station.
Temperature data were obtained and plotted at 15-minute intervals.
Discharge data were obtained at 15-minute intervals and averaged to mean daily discharge.

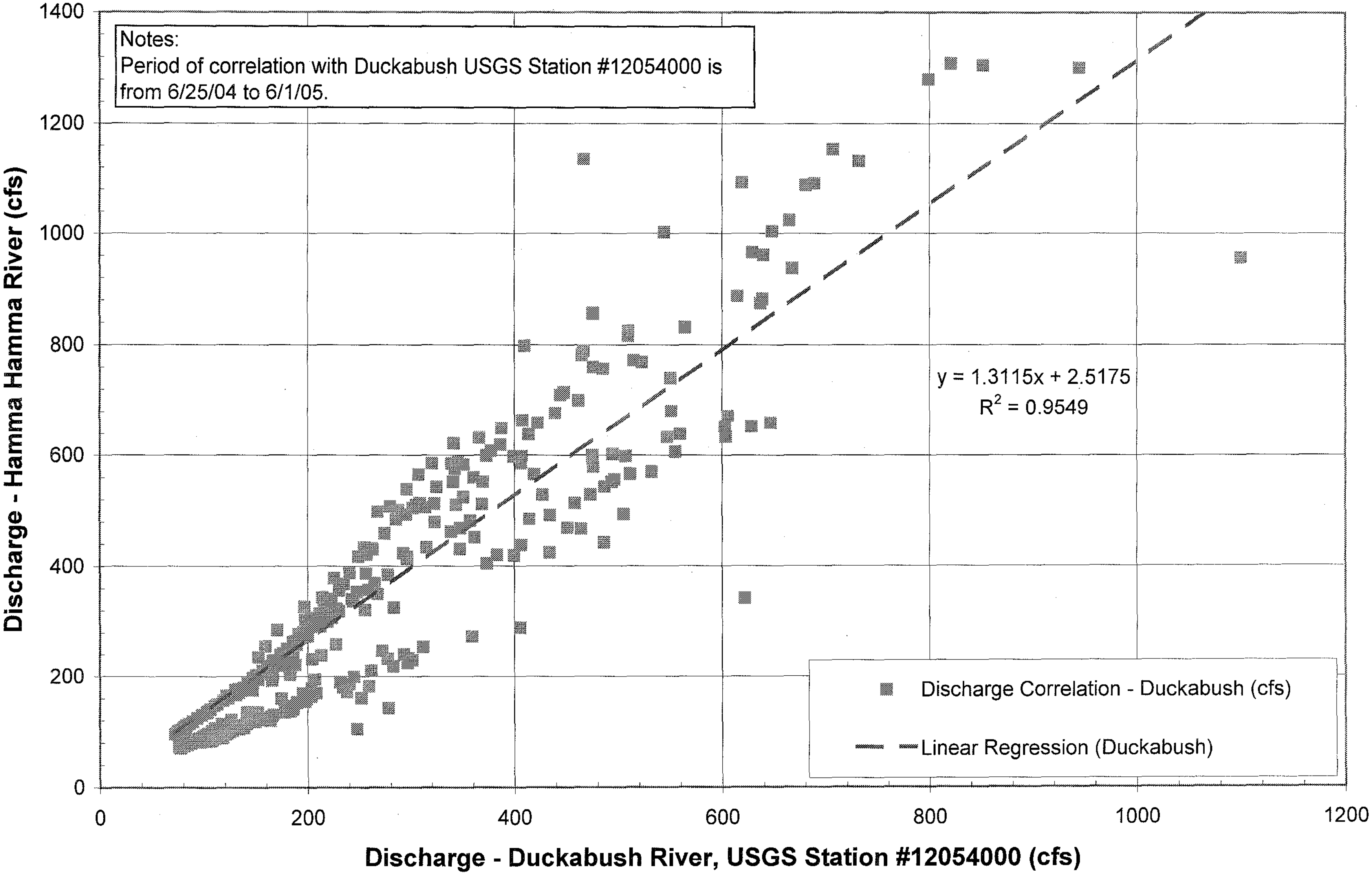


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Mean Daily Discharge.xls

Mean Daily Discharge, Temperature, and Precipitation - Hamma Hamma River
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure D-4



Discharge Correlation Between Hamma Hamma River and the Duckabush River

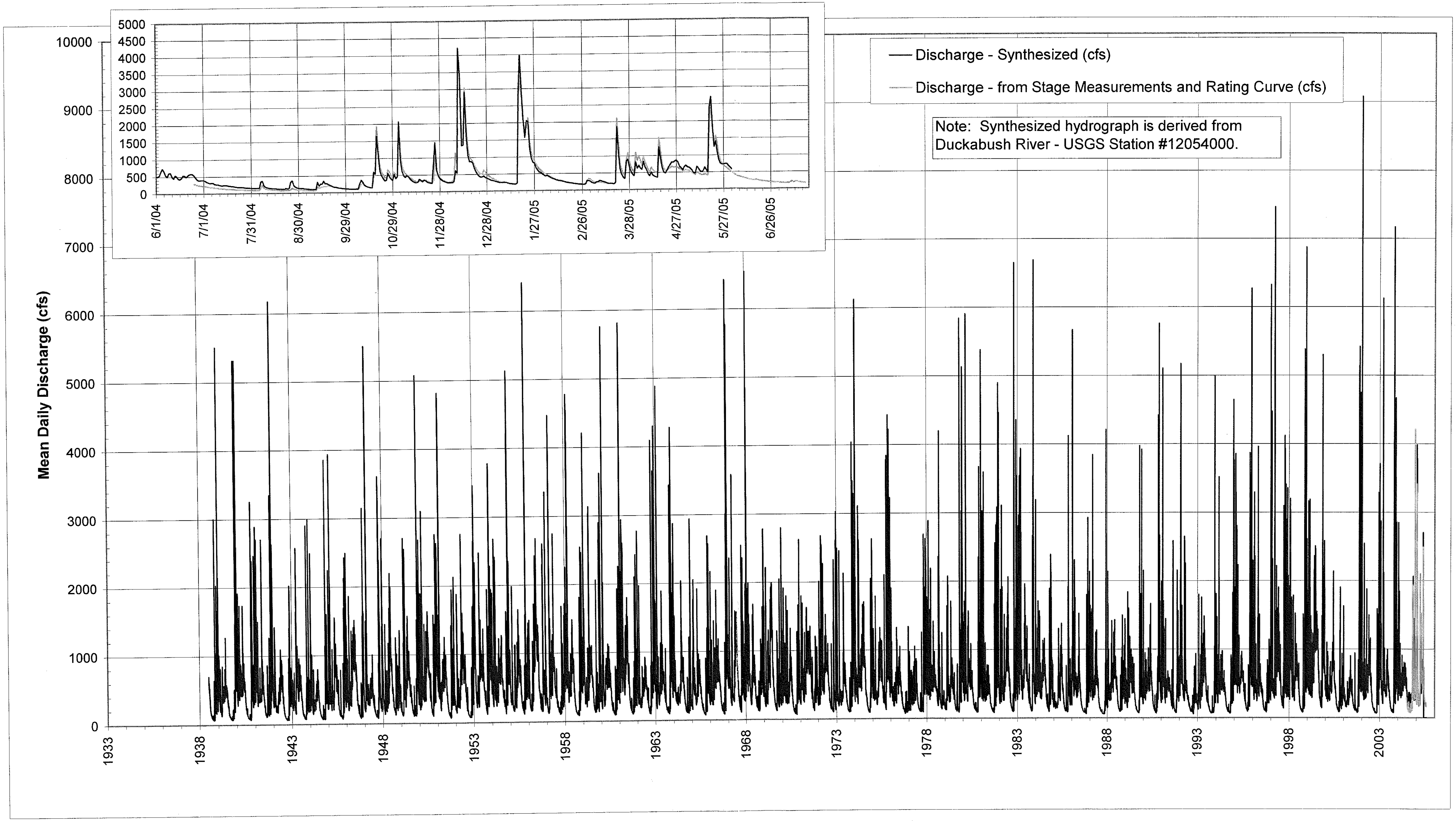
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Discharge Correlations.xls

Figure D-5

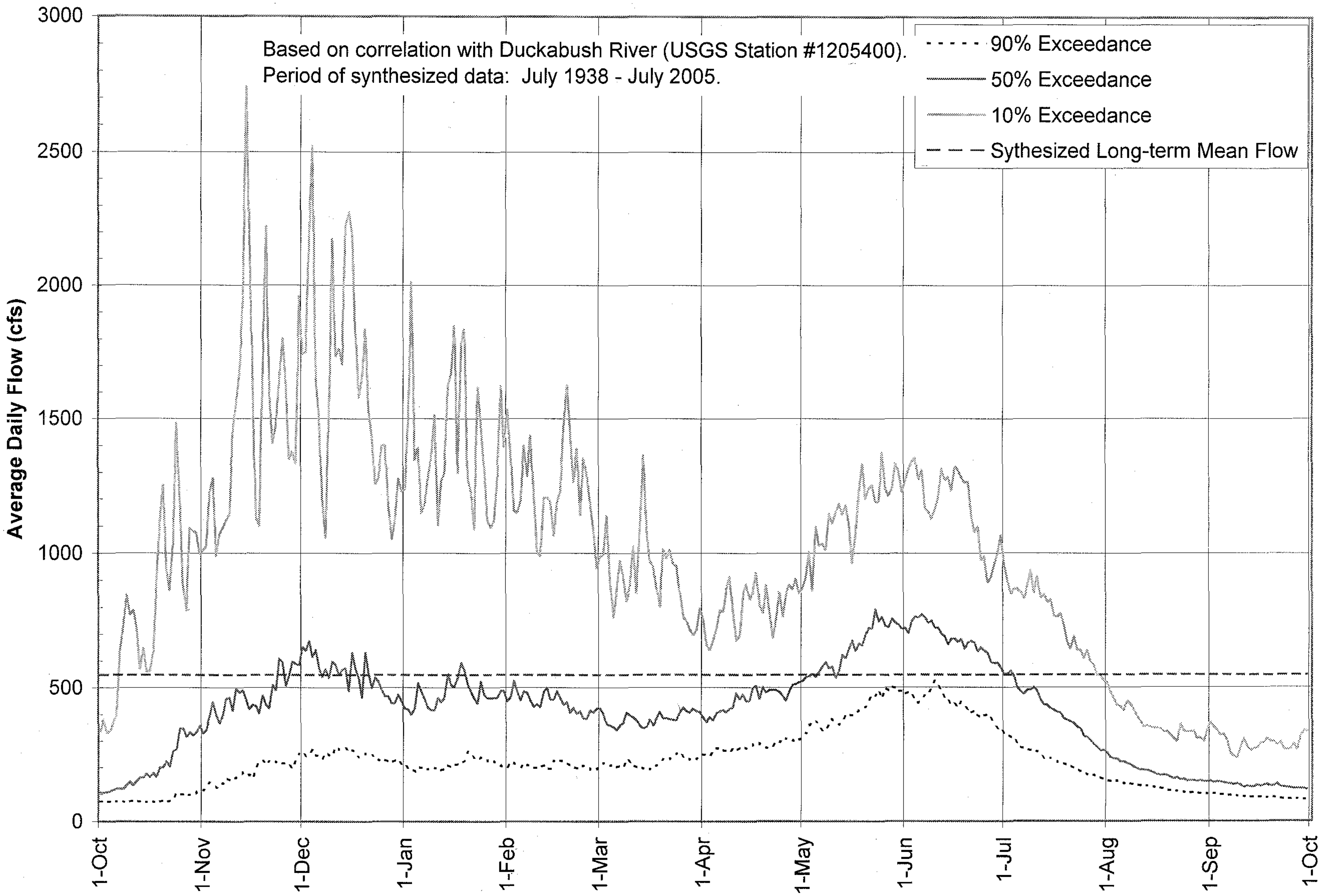


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Synthesized Hydrograph of Hamma Hamma River
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure D-6



Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

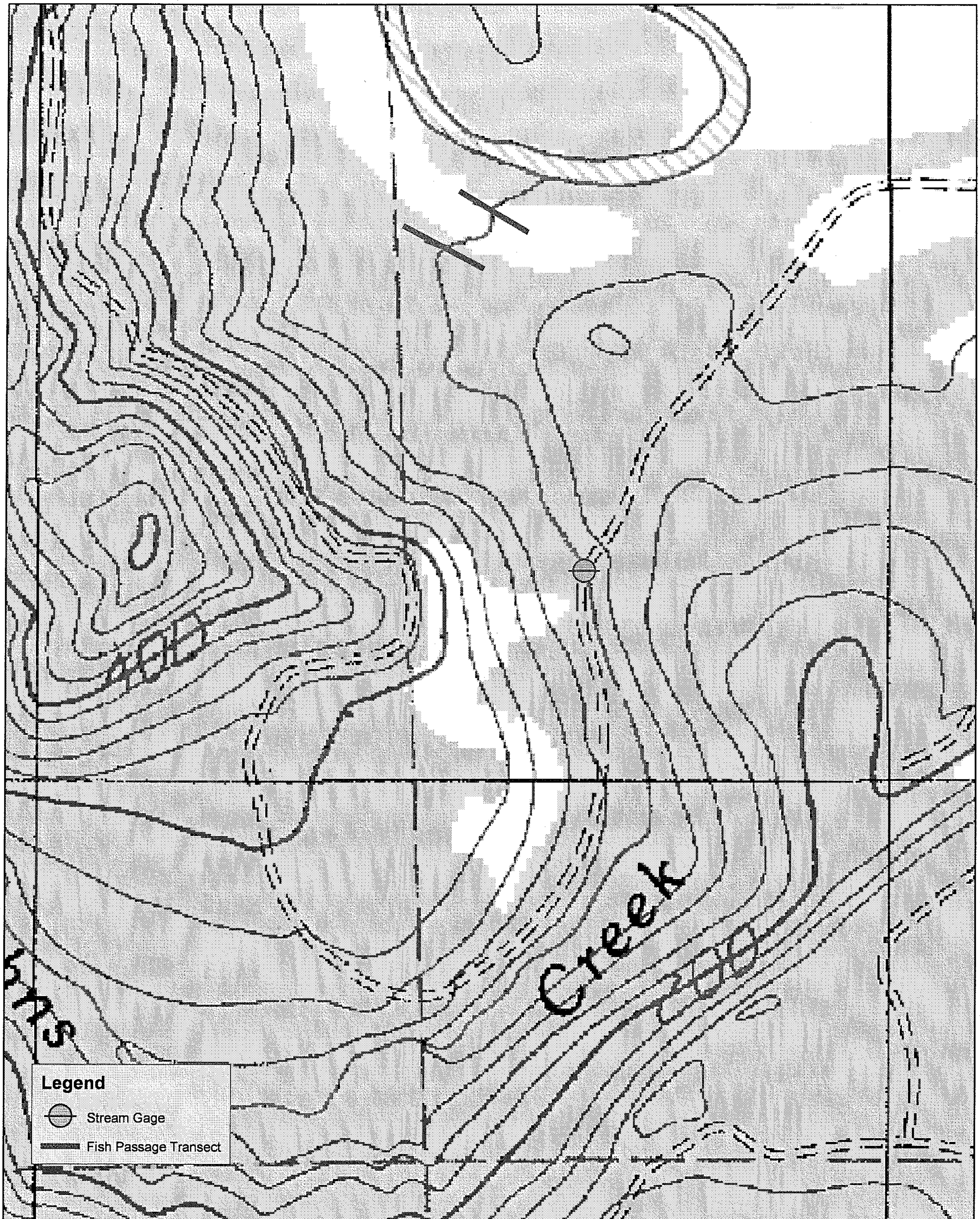
Streamflow Exceedance Curves - Hamma Hamma River

WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure D-7

APPENDIX E

John Creek

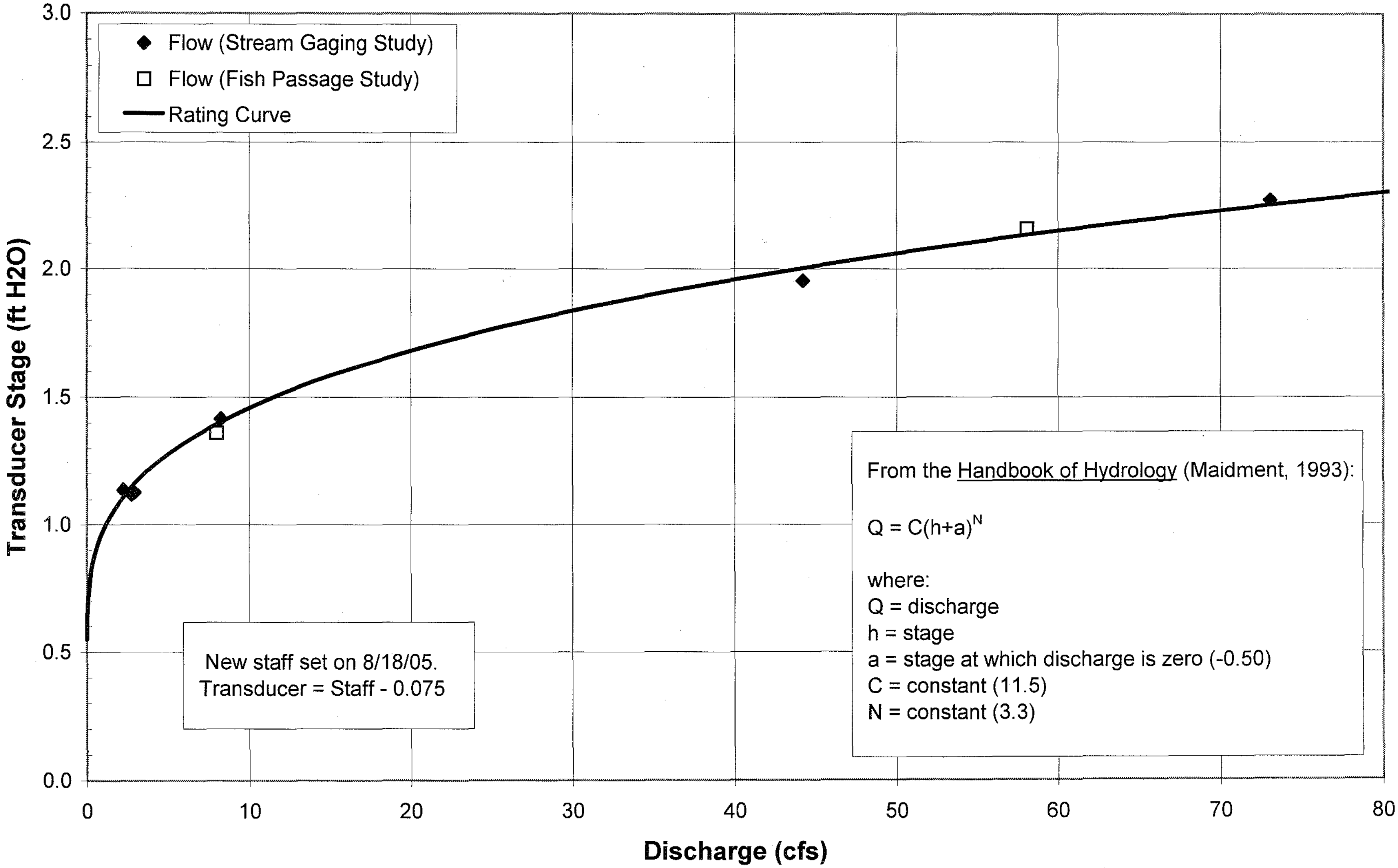


N

Feet
0 250 500

JOHN CREEK STREAM GAGE
AND FISH PASSAGE TRANSECTS
WRIA 16 Instream Flow Studies, Hood Canal, WA

Figure
E-1

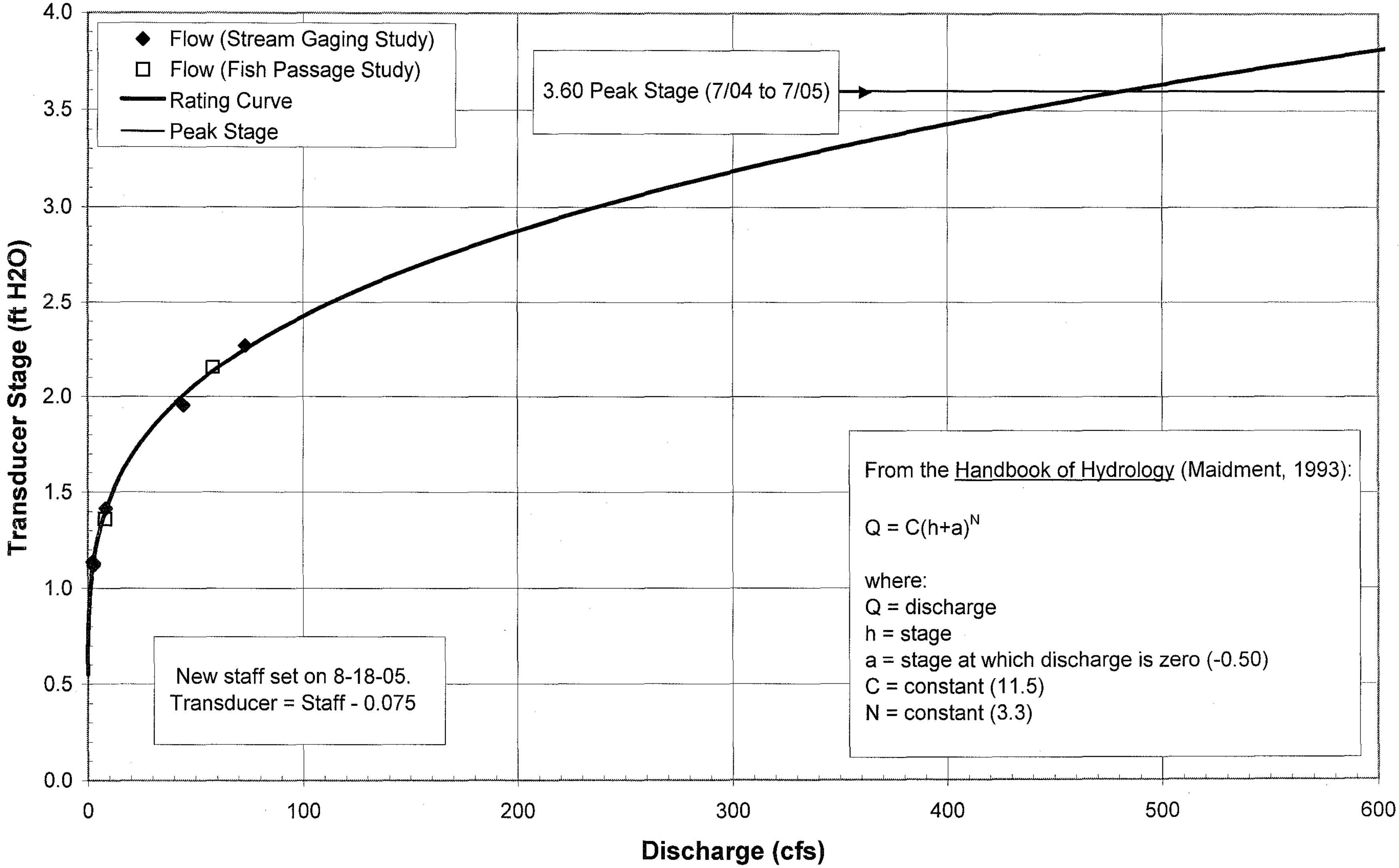


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve - John Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure E-2



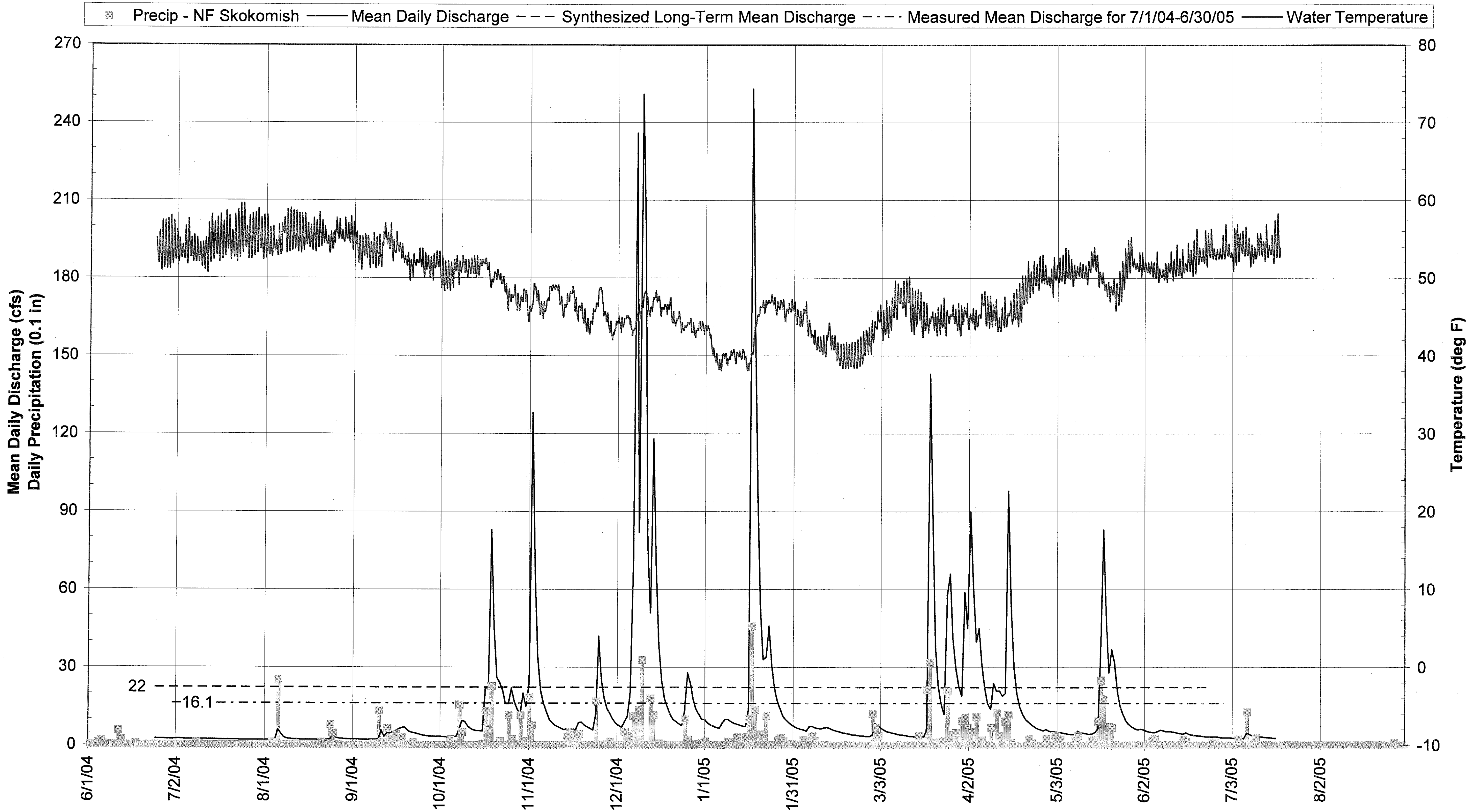
Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve (extrapolated) - John Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure E-3

Precipitation data from NF Skokomish, Staircase Rapids station.
Temperature data were obtained and plotted at 15-minute intervals.
Discharge data were obtained at 15-minute intervals and averaged to mean daily discharge.

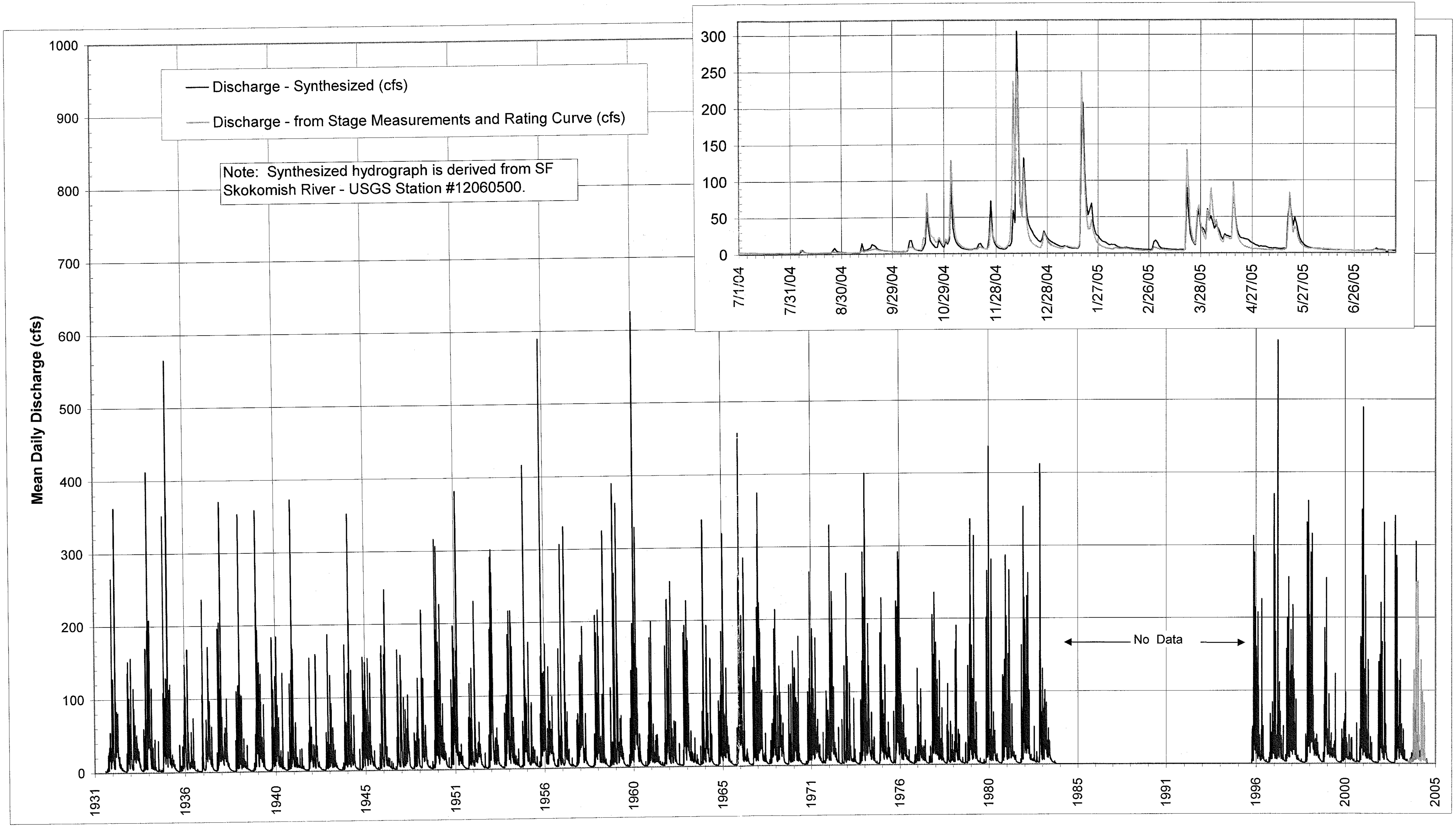


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Mean Daily Discharge.xls

Mean Daily Discharge, Temperature, and Precipitation - John Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure E-4



Aspect consulting
IN-DEPTH PERSPECTIVE

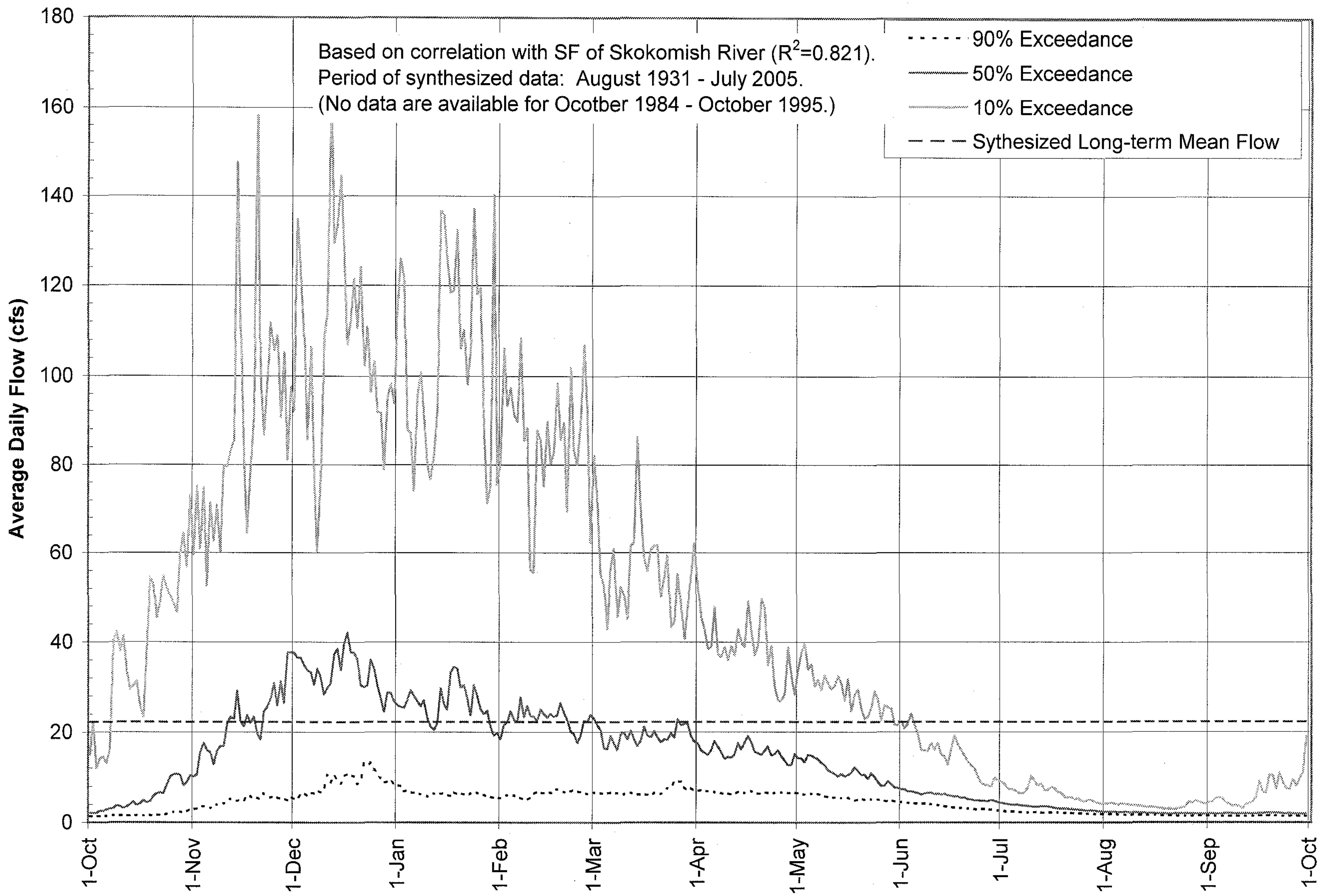
P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Synthesized Hydrograph of John Creek

WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure E-6



Aspect consulting
IN-DEPTH PERSPECTIVE

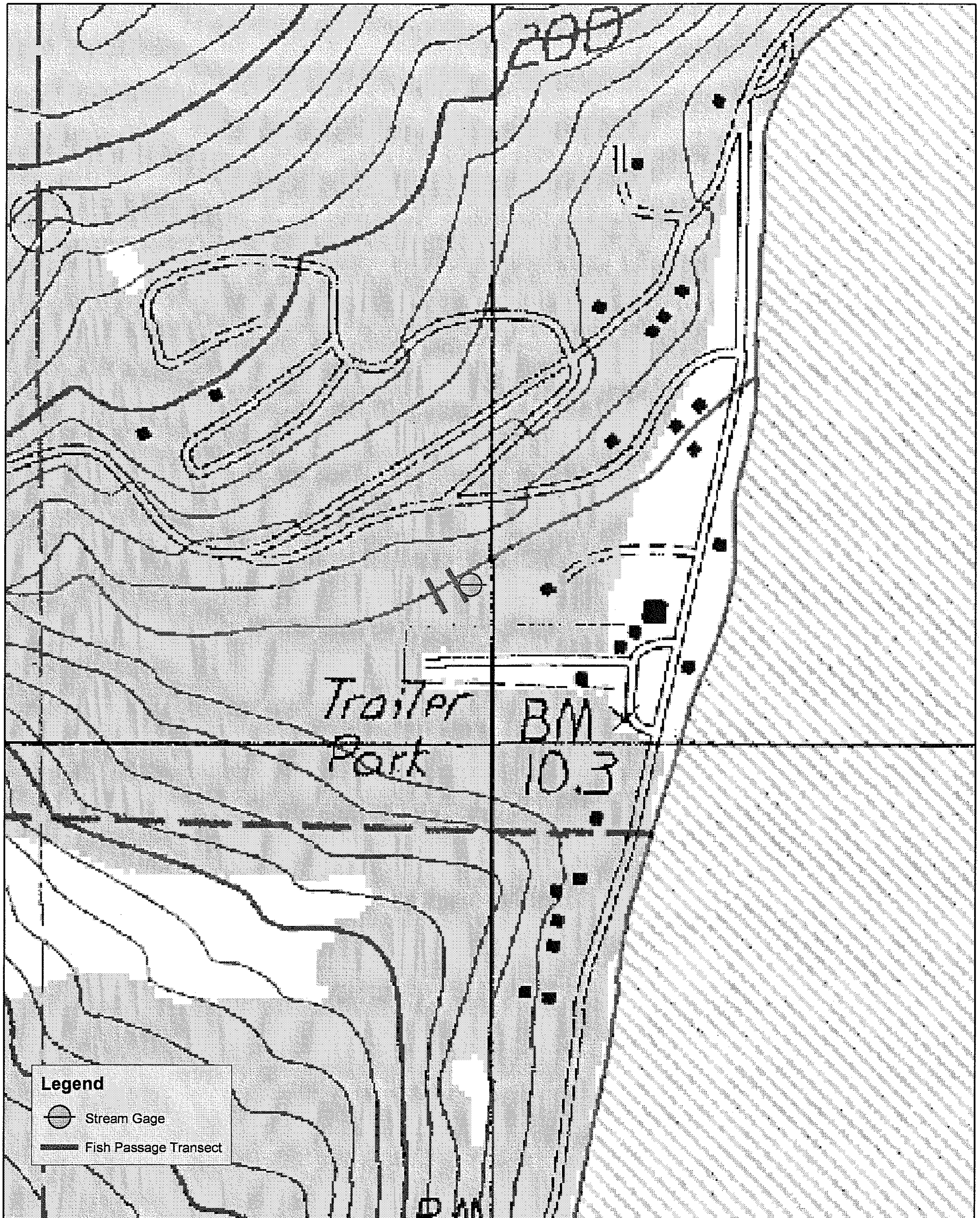
P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Streamflow Exceedance Curves - John Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure E-7

APPENDIX F

Jorsted Creek



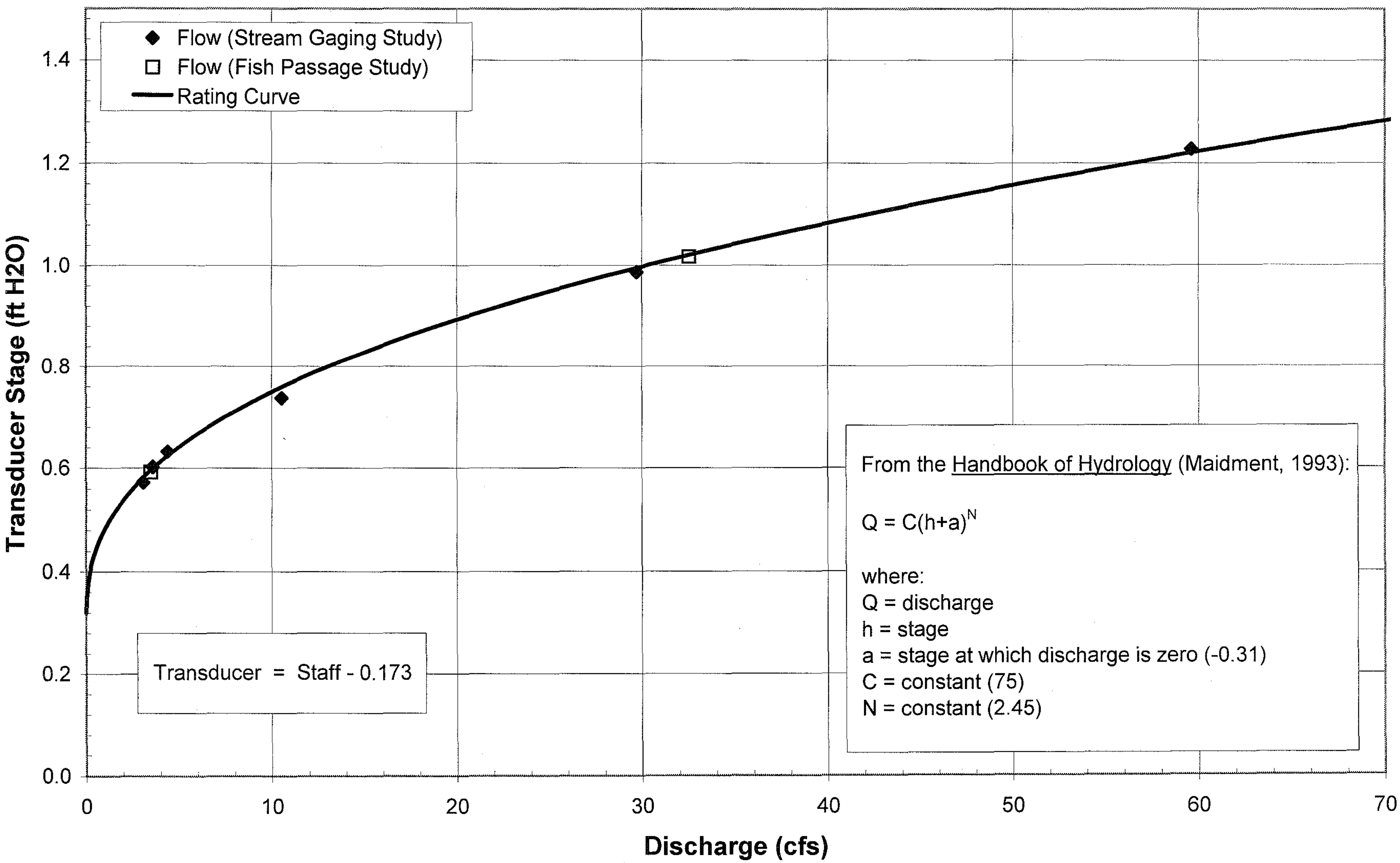
Aspect consulting

N

Feet
0 250 500

JORSTED CREEK STREAM GAGE
AND FISH PASSAGE TRANSECTS
WRIA 16 Instream Flow Studies, Hood Canal, WA

Figure
F-1



Aspect consulting IN-DEPTH PERSPECTIVE

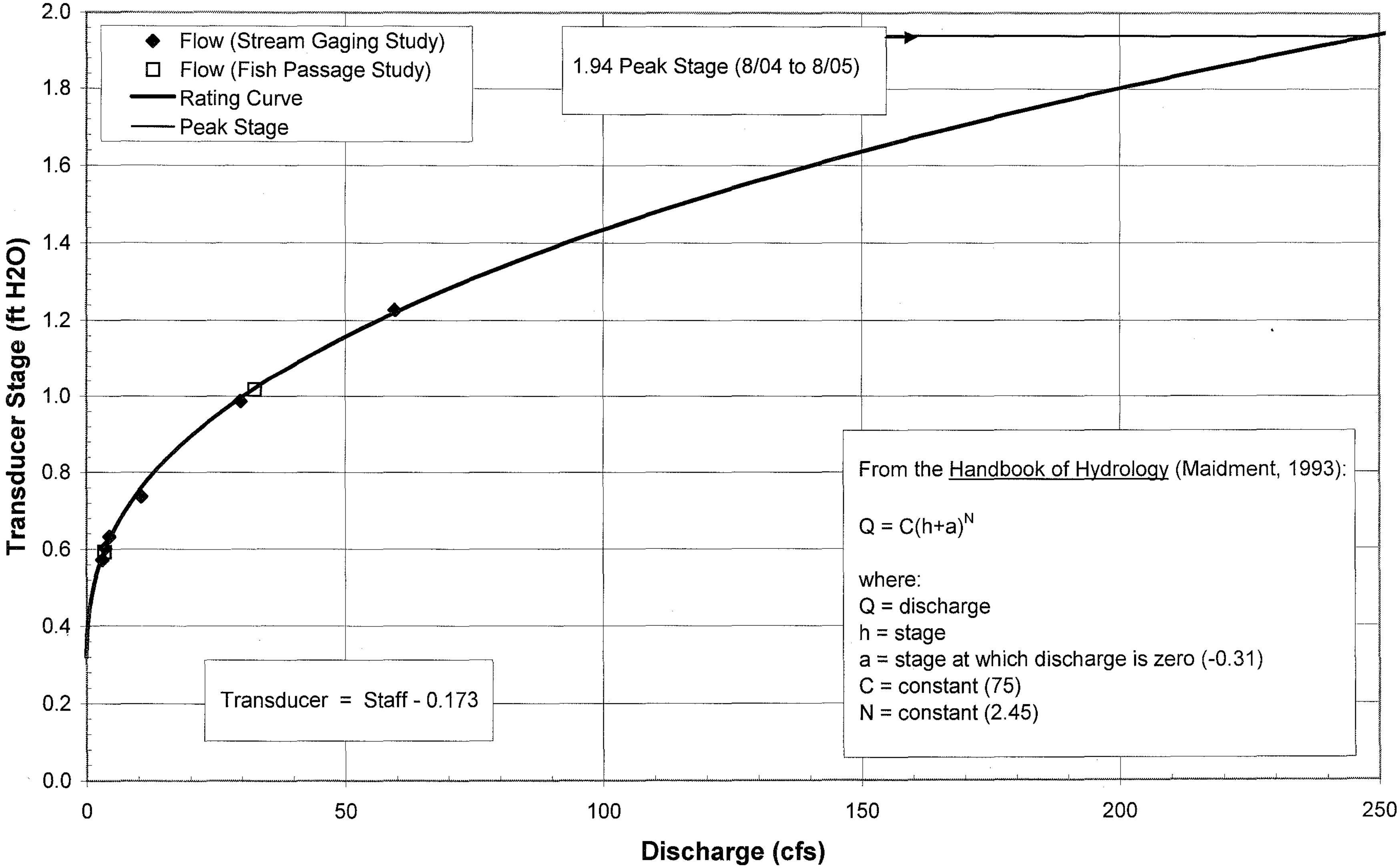
P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve - Jorsted Creek

WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure F-2



Aspect consulting IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

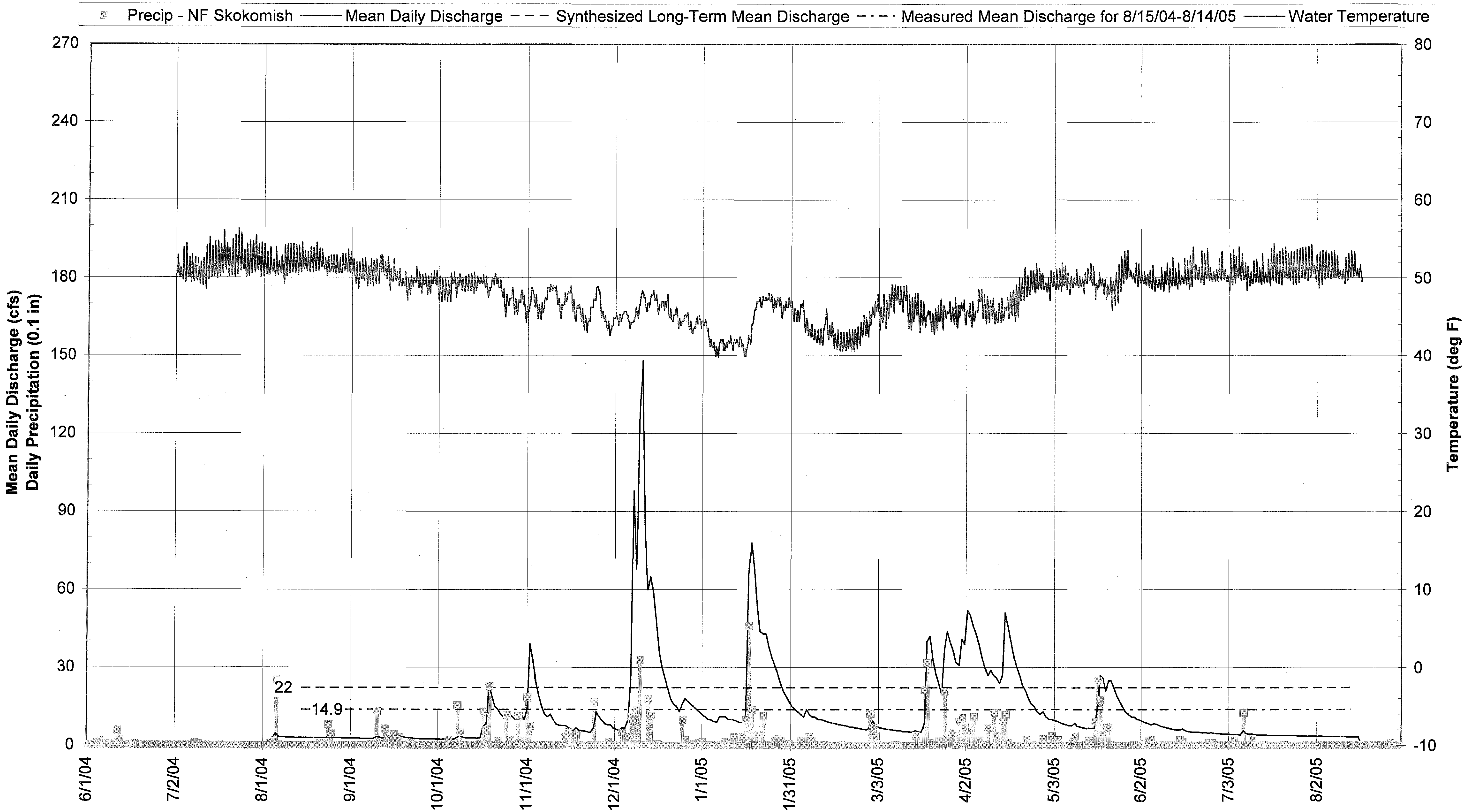
Discharge Rating Curve (extrapolated) - Jorsted Creek

WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure F-3

Precipitation data from NF Skokomish, Staircase Rapids station.
Temperature data were obtained and plotted at 15-minute intervals.
Discharge data were obtained at 15-minute intervals and averaged to mean daily discharge.

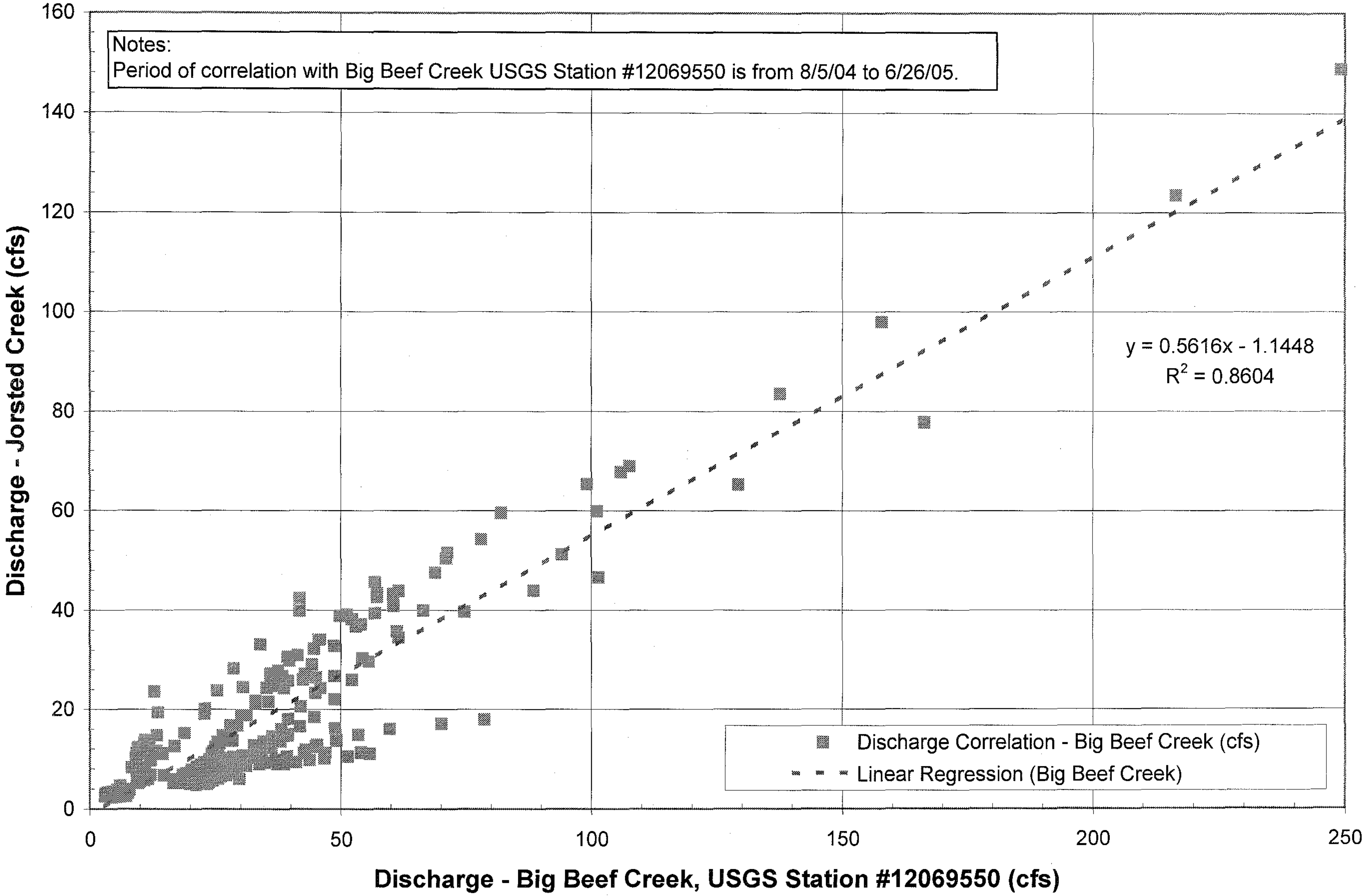


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Mean Daily Discharge.xls

Mean Daily Discharge, Temperature, and Precipitation - Jorsted Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure F-4



Discharge Correlation Between Jorsted Creek and Big Beef Creek

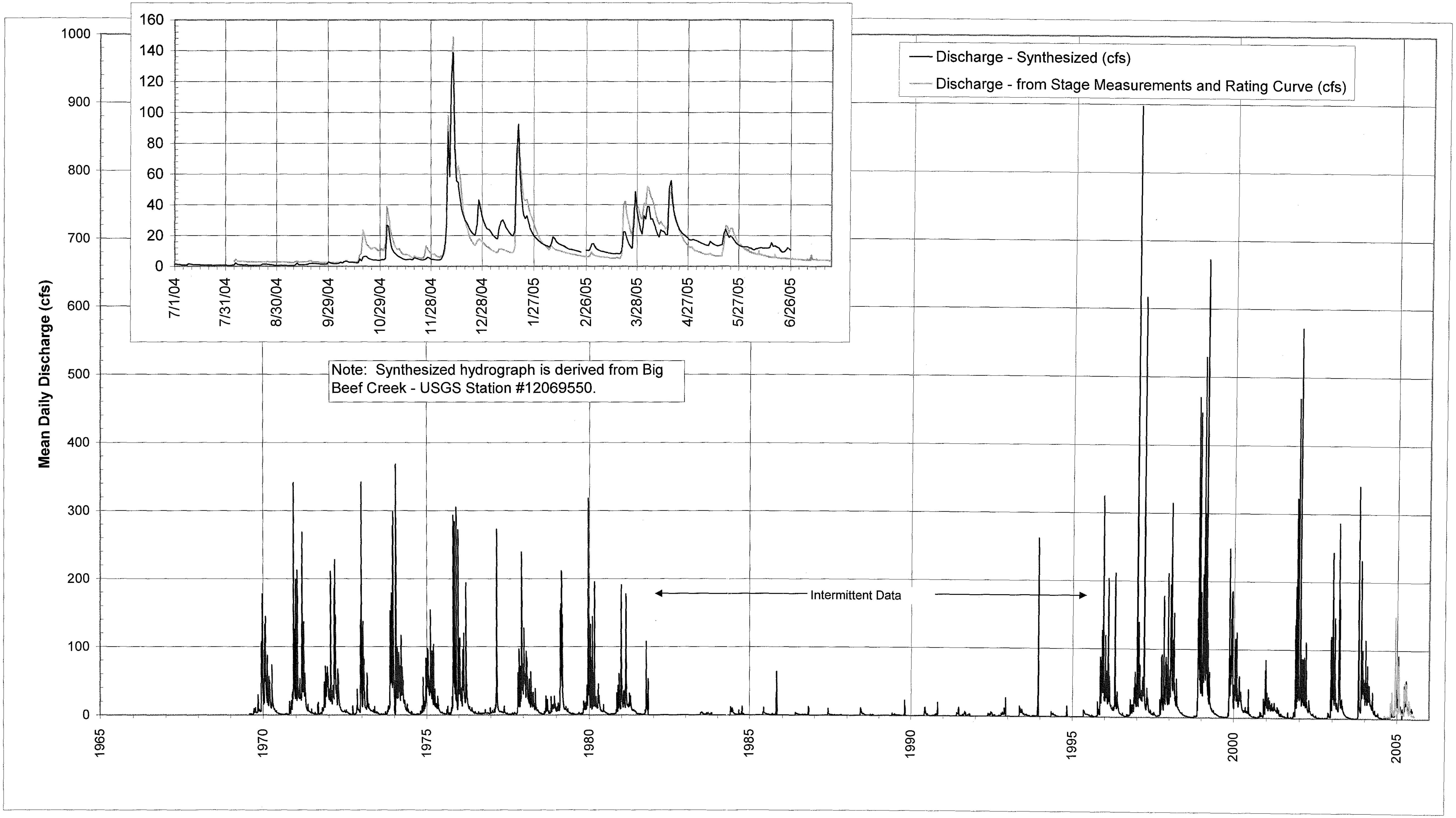
WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Aspect consulting IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Discharge Correlations.xls

Figure F-5

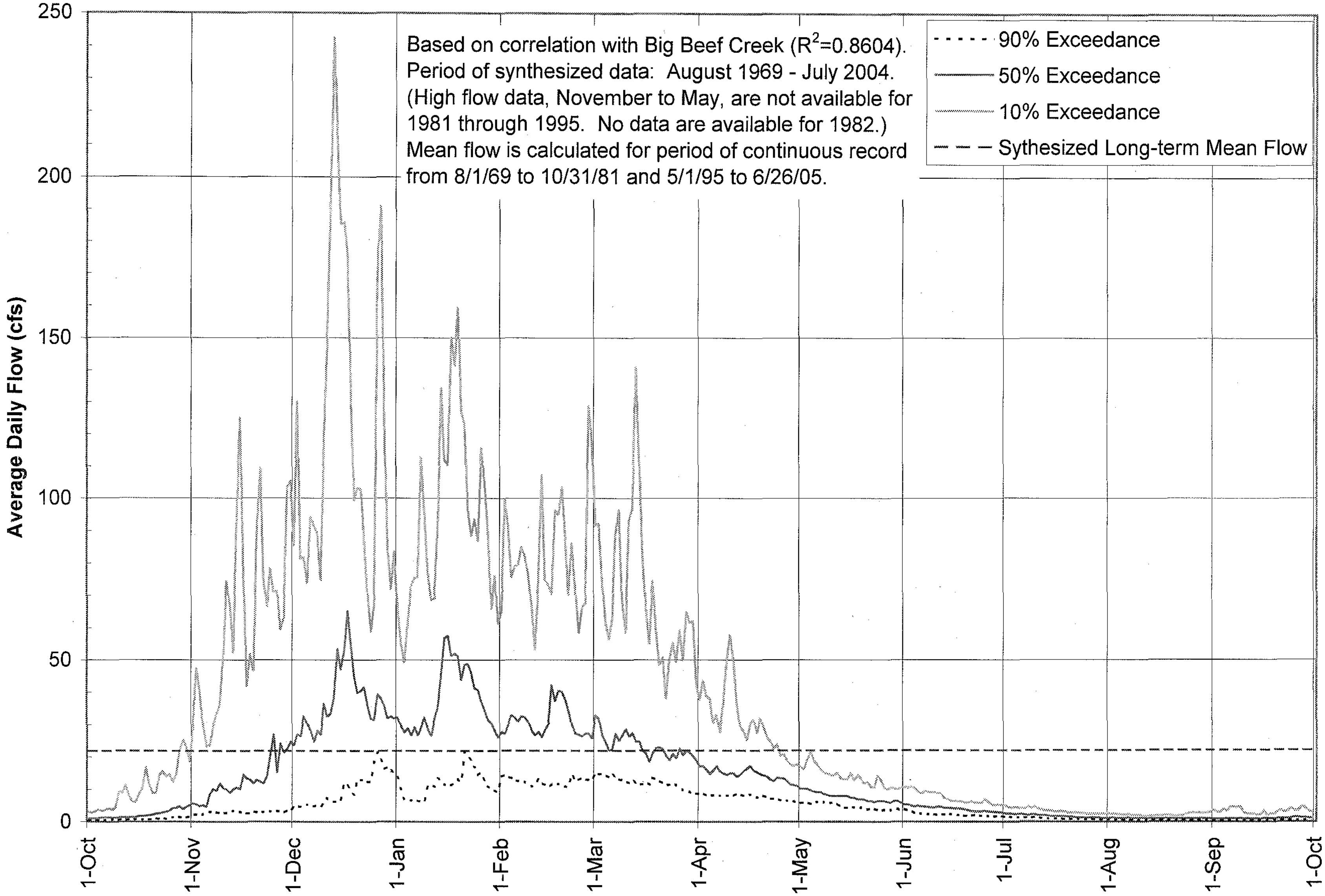


Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

Synthesized Hydrograph of Jorsted Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure F-6



Aspect consulting
IN-DEPTH PERSPECTIVE

Streamflow Exceedance Curves - Jorsted Creek

WRIA16 Instream Flow Studies

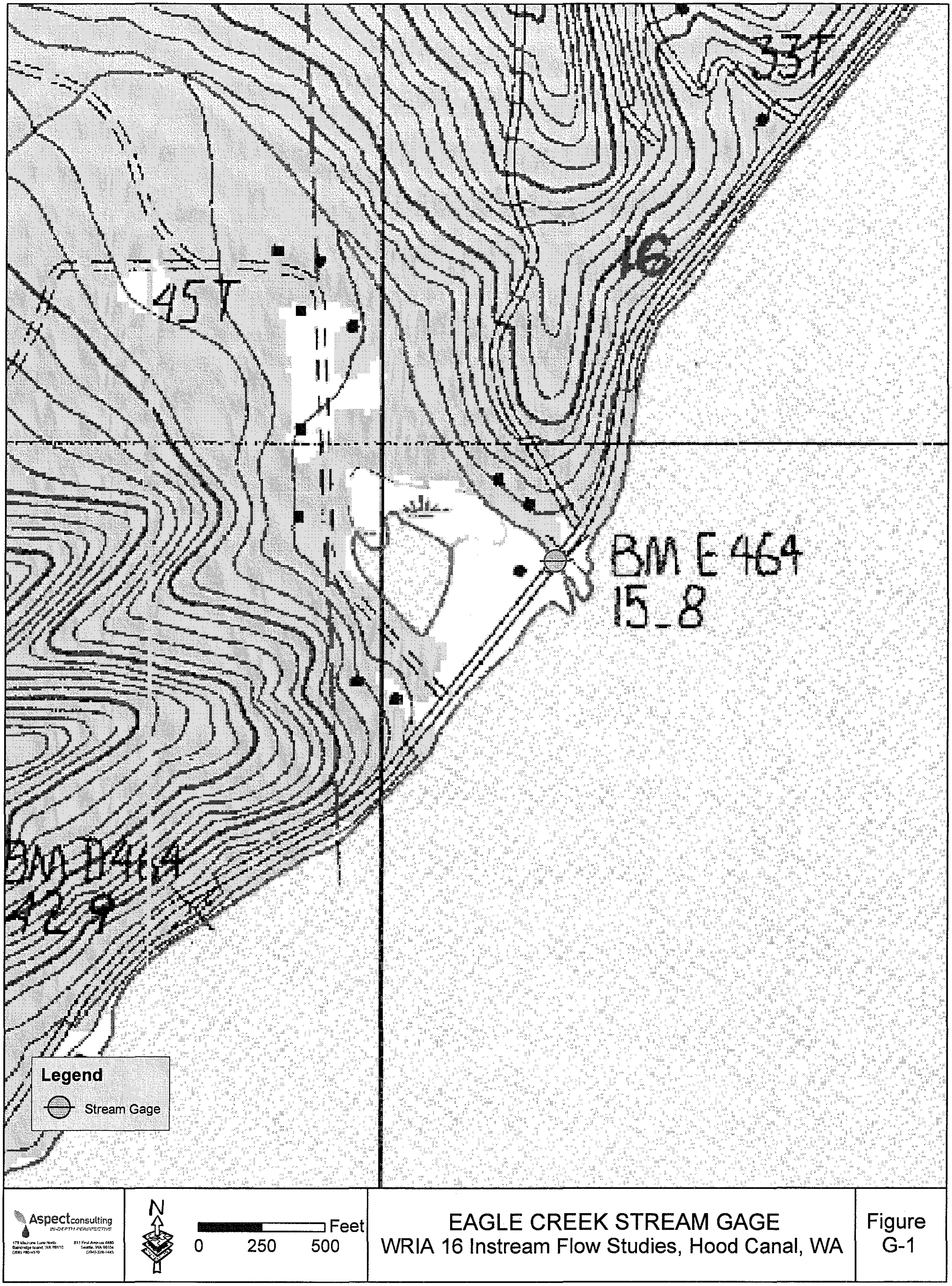
Jefferson and Mason Counties, WA

Figure F-7

P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Synthesized Hydrographs - Final.xls

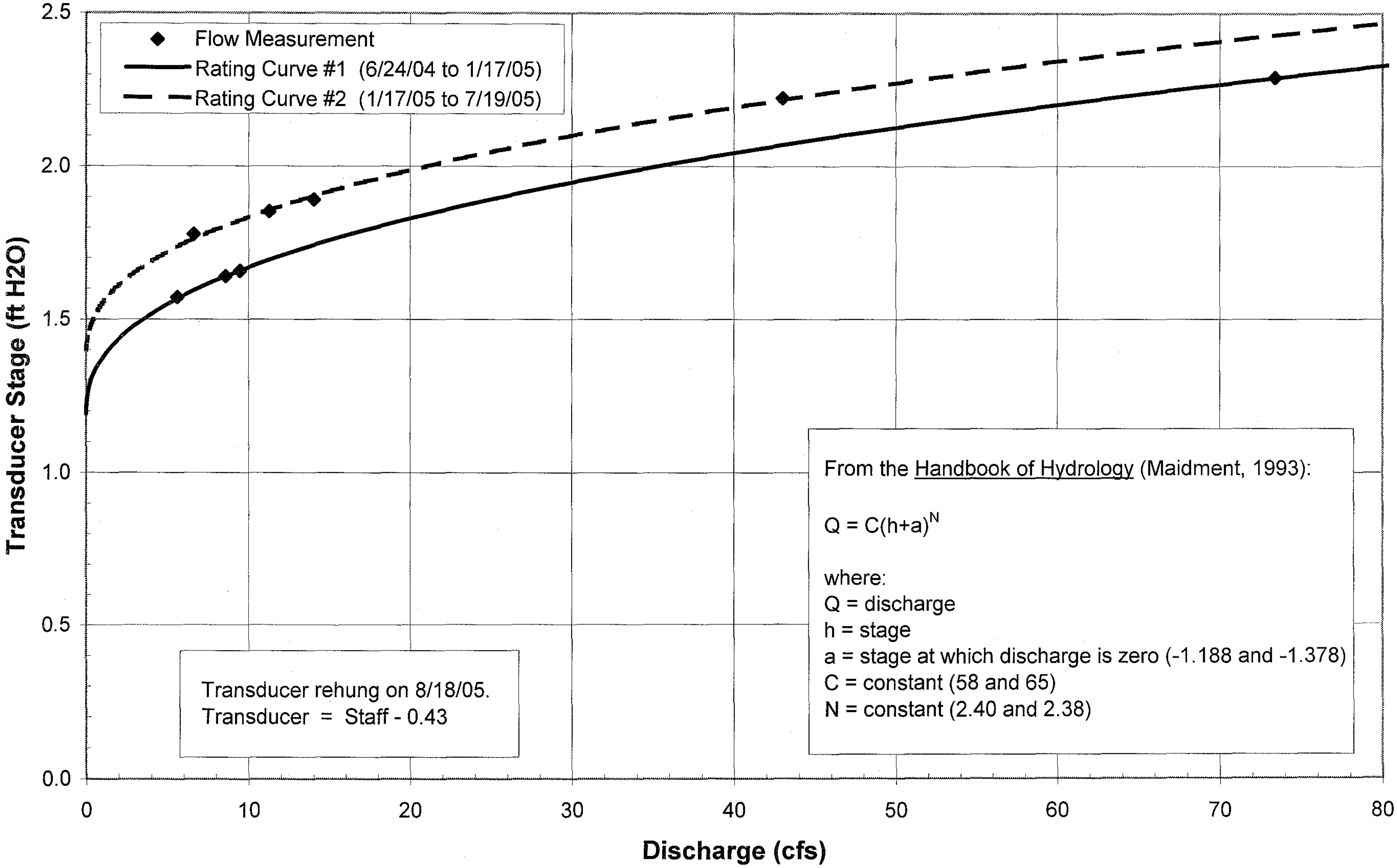
APPENDIX G

Eagle Creek



EAGLE CREEK STREAM GAGE
WRIA 16 Instream Flow Studies, Hood Canal, WA

Figure G-1

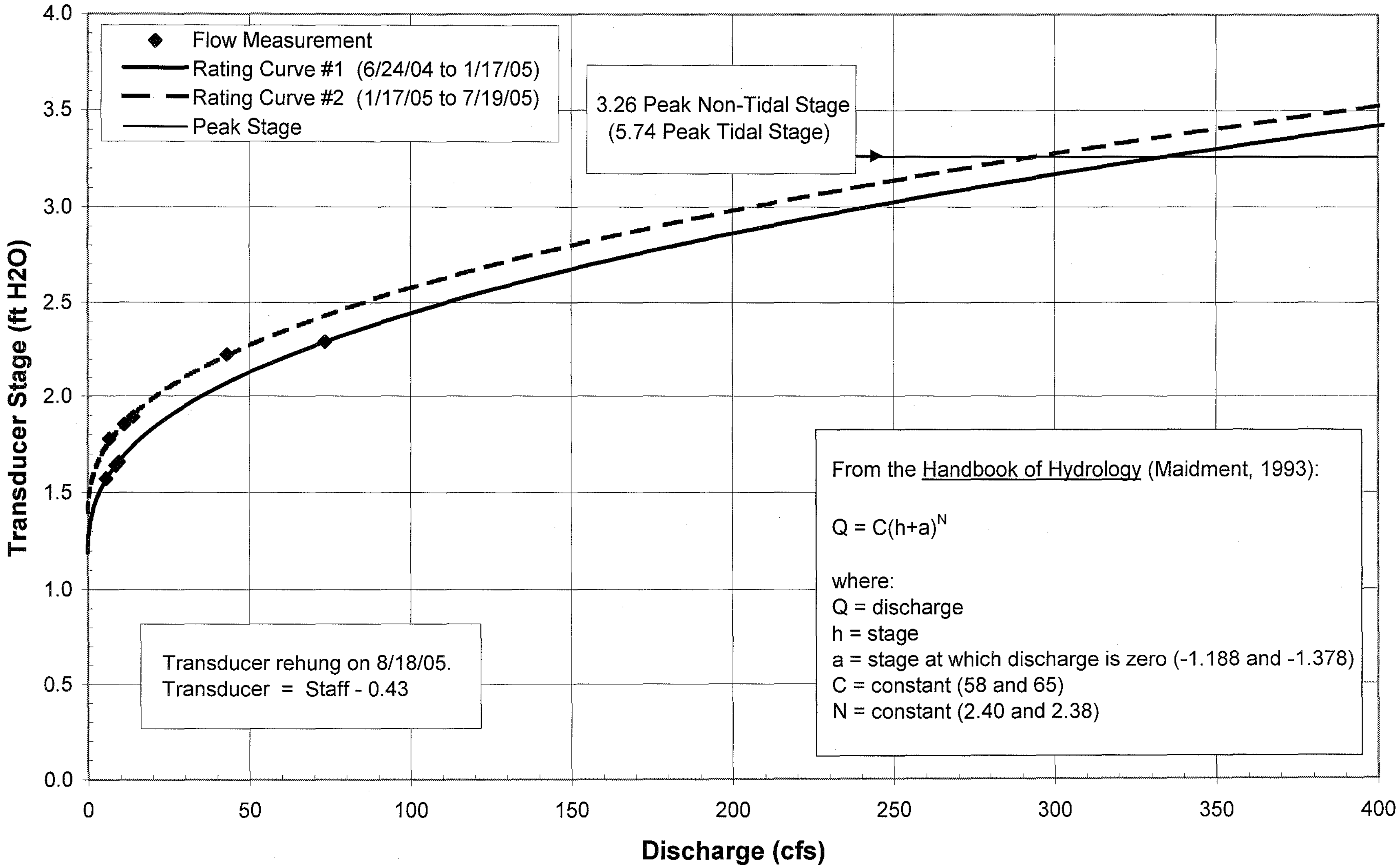


Aspect consulting IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

Discharge Rating Curve - Eagle Creek
WRIA16 Instream Flow Studies
Jefferson and Mason Counties, WA

Figure G-2



Aspect consulting
IN-DEPTH PERSPECTIVE

P:\WRIA 16 Instream Flow\Data\Rating Curves.xls

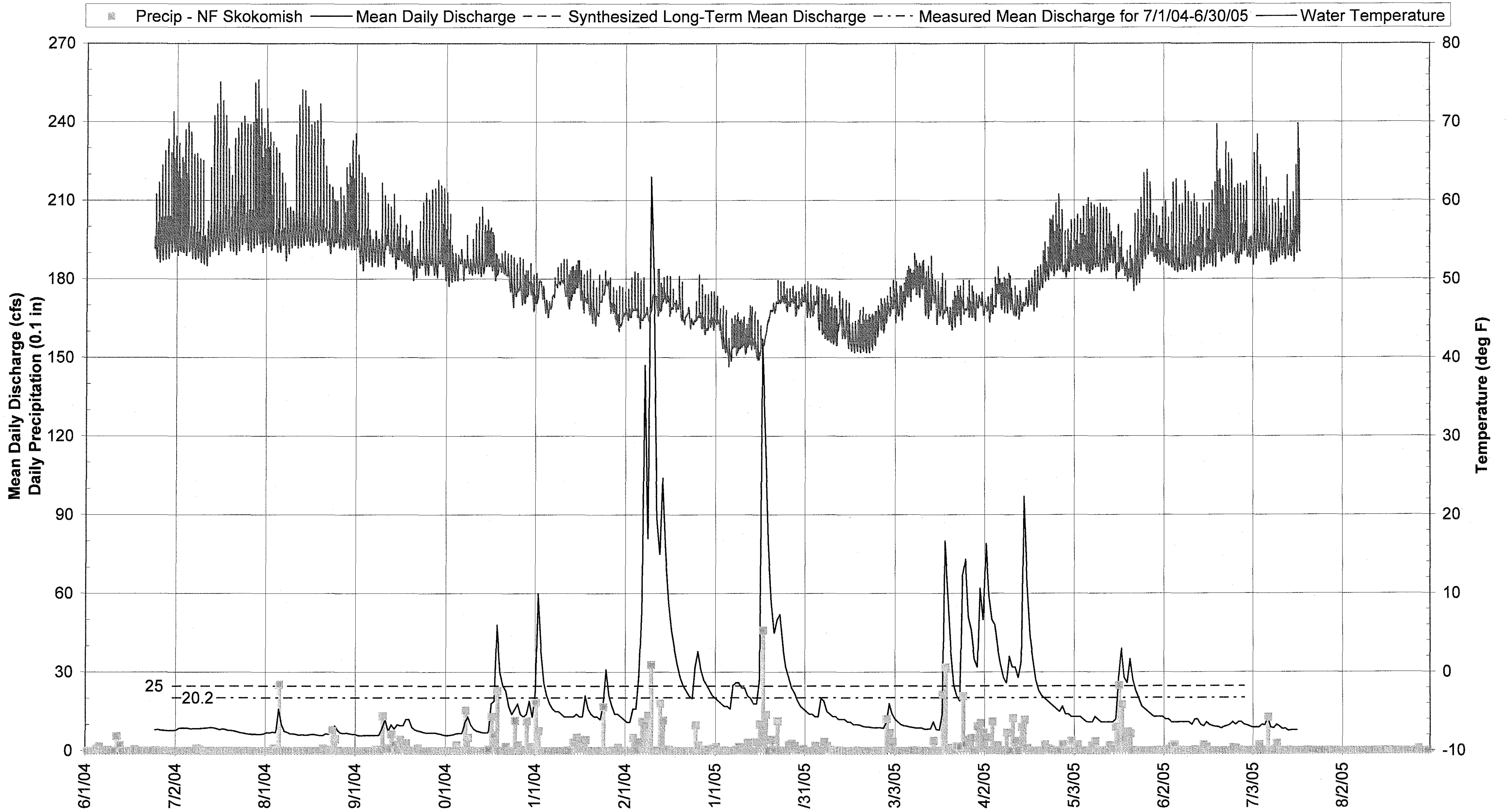
Discharge Rating Curve (extrapolated) - Eagle Creek

WRIA16 Instream Flow Studies

Jefferson and Mason Counties, WA

Figure G-3

Precipitation data from NF Skokomish, Staircase Rapids station.
Temperature data were obtained and plotted at 15-minute intervals.
Discharge data were obtained at 15-minute intervals and averaged to mean daily discharge.



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P:\WRIA 16 Instream Flow\Data\Discharge Measurements\Mean Daily Discharge.xls

Mean Daily Discharge, Temperature, and Precipitation - Eagle Creek
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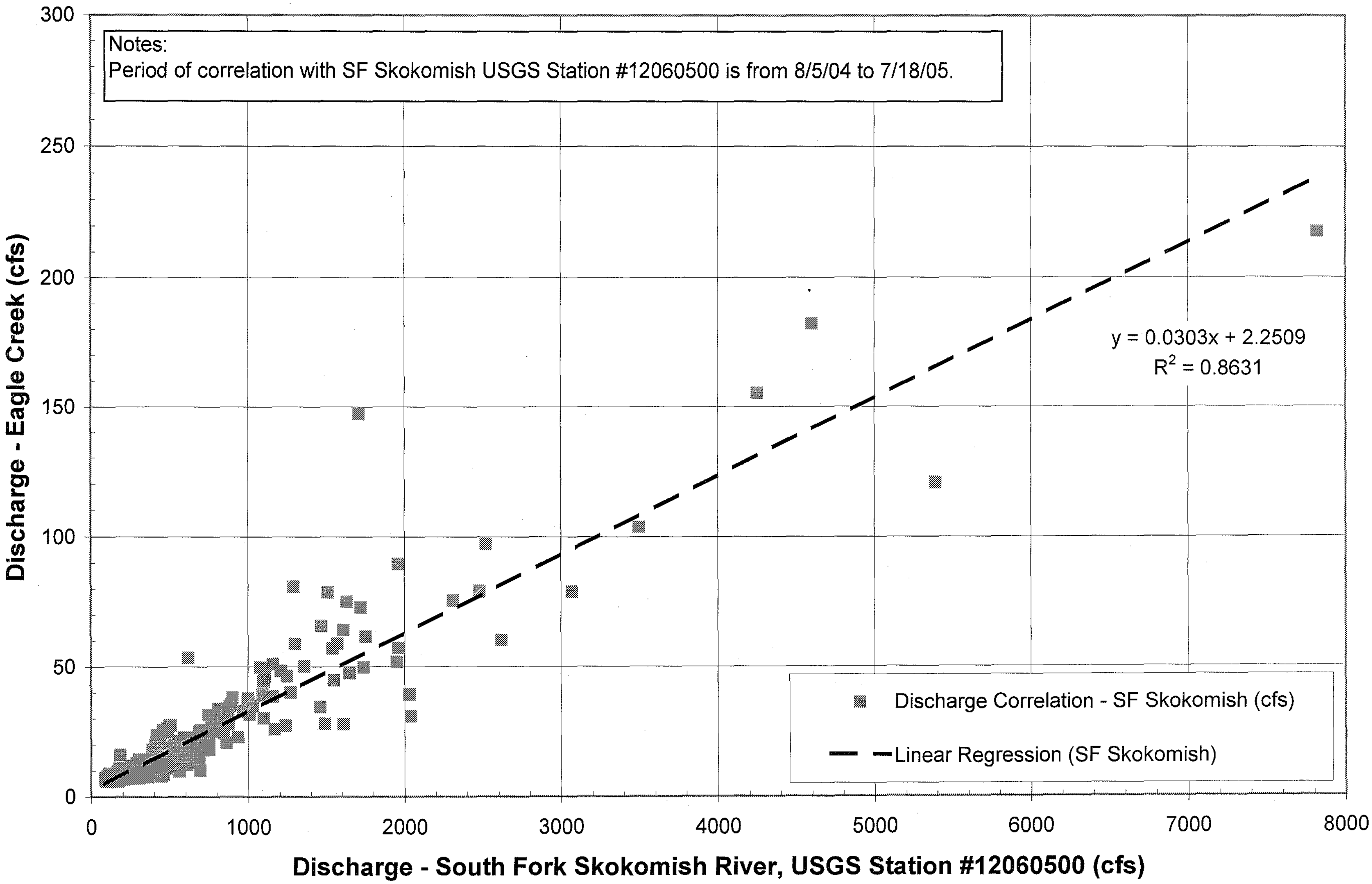
Figure G-4



Discharge Correlation Between Eagle Creek and the South Fork Skokomish River

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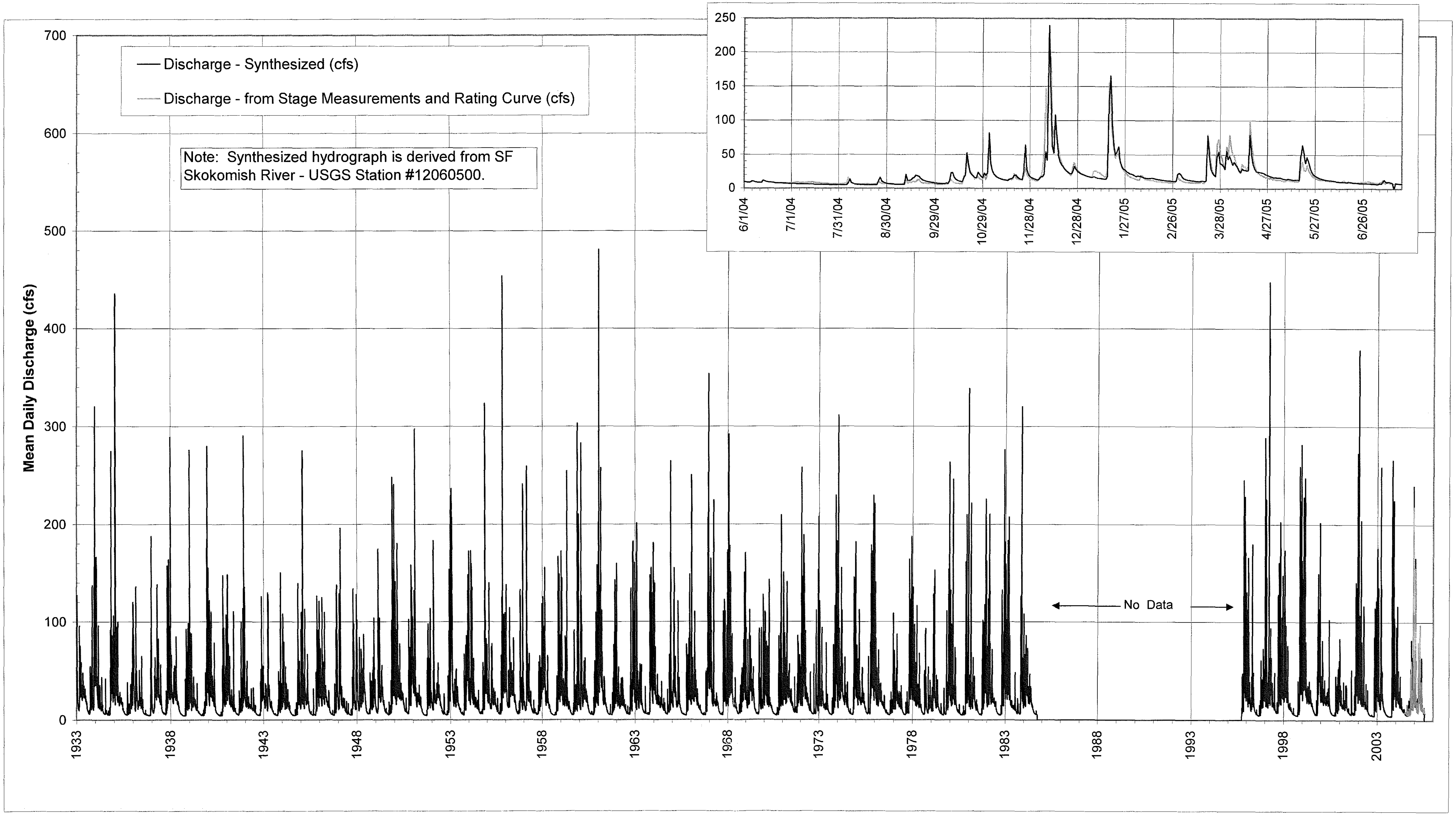
Figure G-5



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Synthesized Hydrograph of Eagle Creek
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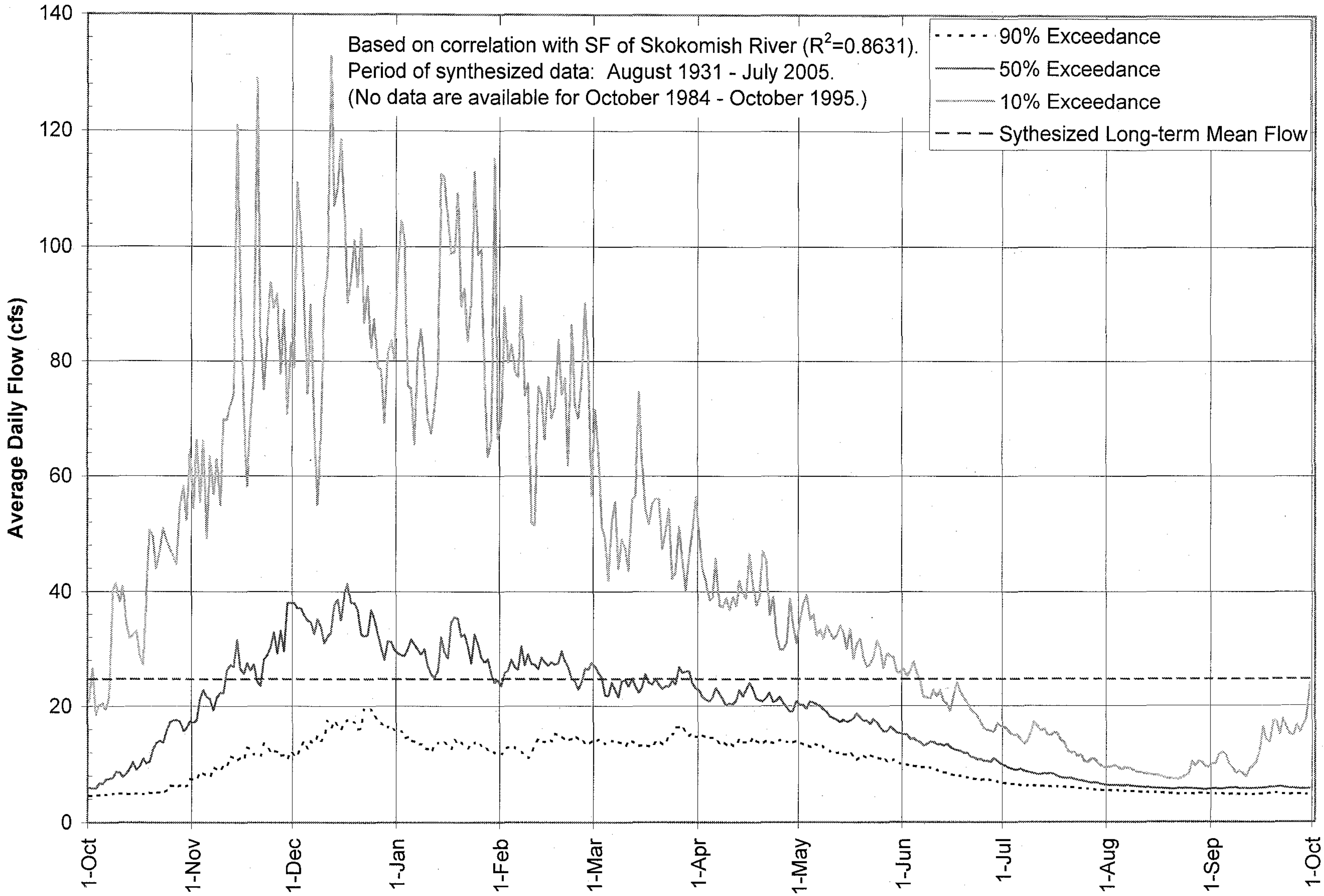
Figure G-6



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Streamflow Exceedance Curves - Eagle Creek

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Figure G-7

G.8 Determination of Discharge for Eagle Creek

Due to access constraints, stage and discharge measurements of Eagle Creek were made at the Highway 101 bridge. The stage monitoring site is located on a bridge piling and is tidally influenced. Discharge measurements were made within 50 feet of the bridge either upstream or downstream depending on conditions. Tidal swings in southern Hood Canal are significant (varying from approximately 8 to 17 feet) and Eagle Creek flow conditions at the bridge vary from free flow to full submergence.

Evaluations of discharge for tidally affected stream reaches generally use two monitoring points (Rantz, et al., 1982). The discharge is the determined as a function of stage at the base gage and fall between gage locations. The dependence on a single monitoring point requires a non-standard analysis of the Eagle Creek data.

In summary, the analysis is divided into high and low flow regimes. The high flow method entails distinguishing between tidally submerged and free-flow (or non-tidally influenced) stage data, then correcting the tidally submerged data based on stages measured before and after this period. Any storage accumulated during tidal inundation is assumed to be released during recession of the tide. In the low flow regime, water is stored and released over a tidal cycle. This method assumes that the inflow during the cycle may be estimated by the minimum observed stage during the cycle. The technique slightly overestimates flow.

G.8.1. Flow Regimes

Review of the stage data for this study suggested that the analysis can be reasonably divided into low and high flow regimes. The flow regimes most appropriate for specific sections of the data were determined by inspection. Stage data were then modified, if necessary, according to the criteria described below and discharges calculated as usual from the rating curve.

High Flow Regime

The high flow regime is typical of dynamic conditions and higher stages which occurred particularly during the wetter winter months. At high or rapidly changing stages, stream stage appears unaffected by low tides (less than approximately 4 feet). Stage data for mid-range tides (about 4 to 9 feet) sometimes exhibit a weak sensitivity to tidal level. Between a 9-foot rising tide and 10-foot falling tide, the stream becomes completely submerged as evidenced by a large rise in the stage data. This regime is particularly identified by a relatively smooth stage curve, interrupted by spikes during inundation.

Low Flow Regime

The low flow regime is characterized by relatively steady flow, typically encountered during periods of dry weather. During low stages, completely free flow conditions are observed for tide levels less than 4 feet. For the mid-range tides, the stage data indicate that the hydraulic control is affected by the tide, but to a much lesser extent than above the 9 foot threshold. At high tides, the stream becomes fully submerged as described for the high stage regime. The low flow regime is identified by a falling stage after tidal inundation (in the absence of precipitation) and a relative rising tide just prior to inundation.

G.8.1.1 Data Analysis – High Flow Regime

Analysis of the high/dynamic stage regime is the more straightforward and is based on two assumptions.

- The stage-discharge relationship can be applied to all stage data except for the period of tidal inundation indicated by a sharp spike in the stage data.
- Net average stream flow is unchanged during the period of tidal submergence.

The first assumption appears valid where data on both sides of a tidal spike can be joined with a smooth curve. For example, after a sufficient rainfall event, declining stage data fall on a smooth curve for a number of tidal cycles. The second assumption is true where neither storage effects (indicated by a relative decline in stage following submergence) nor changes in hydraulic control (indicated by a relative rise in stage prior to submergence) are observed.

Stage data for the high flow regime is modified by replacing the tidal spike with a straight line interpolated between data points before and after the spike. As noted above, a small sensitivity to mid-range tidal fluctuation was sometimes observed. No adjustments were made due to the relative weakness of that effect.

G.8.1.2 Data Analysis – Low Flow Regime

For the low stage regime, three assumptions were made:

- The stream discharge (Q_{in}) is constant over the averaging period.
- Flow into bank storage occurs during the periods of inundation.
- The volume stored during inundations equals the volume released during the rest of the tidal cycle.

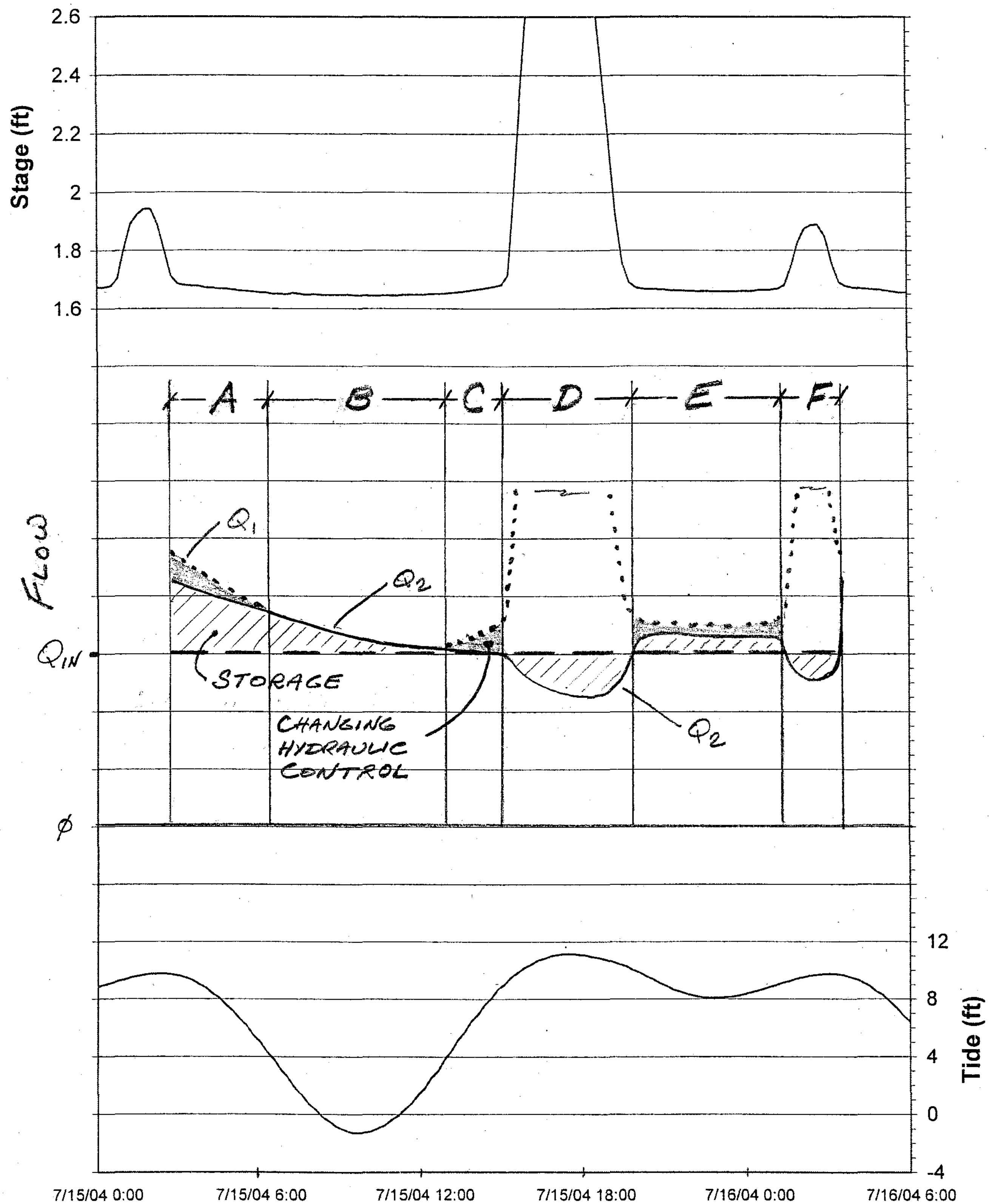
Figure G-8 presents an example of the tidally influenced data during the low stage regime. The figure interprets the flow data as consisting of through flow (the portion of Q_{in} unaffected by storage), storage flow (positive and negative), and artificially high flow that is due to a changing hydraulic control during mid-range tides. The dashed horizontal line (Q_{in}) is the constant discharge into the gaging location. The dotted line (Q_1) is flow calculated directly from the raw stage data. The solid line (Q_2) is actual time dependent flow through the station that has been adjusted for tidal inundations and variable hydraulic control.

In region B, the tide is less than 4 feet and a free flow condition exists. The hydraulic control is unaffected by the tide and the rating curve is directly applicable.

In regions A, C, and E, mid-range tides (4 to 9 feet) change the hydraulic control, the rating curve shifts upward, and Q_1 overstates the actual flow. The upswing in region C is a primary identifier of a changing control. Areas that are artifacts of the changing control are indicated by shading. Actual observed flows are taken from extrapolation of the stage curve in region B into regions A and C. The water volume represented by the area under the curve for regions A, B, and C, and similarly for region E, is composed of normal streamflow (constant Q_{in}) plus flow from storage (hatched area).

In regions D and F, tidal inundations result in a portion of stream flow being pushed into storage. The cross-hatched areas represent flow into storage. Outflow during inundation is Q_{in} less flow into bank storage. The later is equal to the volume of water released from bank storage in regions A, B, C, and E.

In order to calculate mean daily flows, the flow Q_{in} was estimated and applied to the entire tidal period. Q_{in} would be ideally estimated as the extrapolation of the Q_2 curve to the onset of tidal inundation (the start of region D). In order to simplify data processing, the minimum observed stage (typically at the end of period B) in a tidal cycle was used to calculate discharge for the tidal cycle. This technique will slightly overestimate discharge.



Eagle Creek Discharge
for Low Flow Regime
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Figure G-8

APPENDIX H

Summary Statistics for Individual Study Area Transects

Appendix H-1 - Minimum Passage Flows for Individual Transects and Transect Averages using Both Thompson's and Observation Based Criteria, John Creek
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

John Creek.

	Cross Section XS-1			Cross Section XS-2			Transect Average			XS-1	XS-2	
	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Chinook Salmon (0.8ft)	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Chinook Salmon (0.8ft)	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Chinook Salmon (0.8ft)	Observa-tion Based Criteria (0.31ft)	Observa-tion Based Criteria (0.31ft)	Transect Average
Flow (cfs)	12.5	25.0	50.0	17.5	60.0	160.0	15.0	42.5	105.0	7	8	7.5
Wetted Width (ft)	29.0	32.0	46.0	44.6	50.5	56.0				27	42.6	
Passable Width (ft)	9.1	9.1	13.1	12.5	15.1	21.0				7.05	7	
Contiguous Width (ft)	6.1	6.1	10.1	6.0	6.0	7.0				6.05	6	
% Passable	31.2	28.3	28.4	27.9	29.9	37.4				26.1	16.4	
% Contiguous	20.9	18.9	21.8	13.5	11.9	12.5				22.4	14.1	

Appendix H-2 - Minimum Passage Flows for Individual Transects and Transect Averages using Both Thompson's and Observation Based Criteria, Fulton Creek
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

	Cross Section XS-2		Cross Section XS-3		Transect Averages		XS-1	XS-2	
	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Observa-tion Based Criteria (0.31ft)	Observa-tion Based Criteria (0.31ft)	Transect Average
Flow (cfs)	10.0	30.0	20.0	50.0	15.0	40.0	7.5	12.5	10
Wetted Width (ft)	30.3	34.3	40.9	45.9			30.3	35.6	
Passable Width (ft)	10.9	10.9	11.7	15.9			14.5	11.7	
Contiguous Width (ft)	6.4	6.4	6.4	6.4			6.4	6.4	
% Passable	35.9	31.7	28.6	34.6			47.8	32.9	
% Contiguous	21.0	18.5	15.5	13.8			21.0	17.9	

Appendix H-3 - Minimum Passage Flows for Individual Transects and Transect Averages using Both Thompson's and Observation Based Criteria, Jorsted Creek
WRIA 16 Instream Flow Studies
Jefferson and Mason Counties, WA

	Cross Section XS-2		Cross Section XS-3		Transect Averages		XS-2	XS-3	
	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Cutthroat Trout (0.4ft)	Chum Coho Pink Salmon Steelhead Trout (0.6ft)	Observa-tion Based Criteria (0.31ft)	Observa-tion Based Criteria (0.31ft)	Transect Average
Flow (cfs)	5.5	20.0	10.0	32.5	7.8	26.3	4.5	6.5	5.5
Wetted Width (ft)	31.3	41.2	23.2	36.6			31.3	17.7	
Passable Width (ft)	8.7	11.7	8.0	10.0			16.2	8.0	
Contiguous Width (ft)	4.2	4.2	8.0	10.0			10.2	8.0	
% Passable	27.8	28.4	34.6	27.3			51.8	45.3	
% Contiguous	13.4	10.2	34.6	27.3			32.6	45.3	