WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Flow Summary for Gaging Stations on the Stillaguamish River and Selected Tributaries

May through October 2001

April 2003

Publication No. 03-03-019

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Flow Summary for Gaging Stations on the Stillaguamish River and Selected Tributaries

May through October 2001

by
Chuck Springer

Environmental Assessment Program
Olympia, Washington 98504-7710

April 2003

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Abstract

Between May and October 2001, the Washington State Department of Ecology measured flows and developed continuous stage records at five sites on the Stillaguamish River and selected tributaries. Two of the five stations were located on the South Fork Stillaguamish River, one at the U.S. Forest Service Verlot Campground, and one at Snohomish County's River Meadows Park. One station was located on the North Fork Stillaguamish River, in the Mount Baker/ Snoqualmie National Forest. One station was located near the mouth of Deer Creek, a tributary to the North Fork. One station was located near the mouth of Pilchuck Creek, a tributary to the mainstem Stillaguamish River. A rating curve was also developed at one additional site on the North Fork Stillaguamish River at Oso.

The streamflow monitoring was conducted in support of a temperature total maximum daily load (TMDL) study developed by the Department of Ecology. The purpose of this TMDL was to characterize water temperature and to establish load and wasteload allocations for heat sources in order to meet water quality standards for surface water temperature in the basin.

Continuous stage height recorders and staff gages were installed, and four to six discharge measurements were taken at each site. Discharge rating curves were developed for each site by relating various stage height values to corresponding discharge measurements. Applying these rating curves over the range of stage height enabled a continuous record of discharge to be developed at each station.

Streamflow in the Stillaguamish basin followed a general pattern of dry season decline, with the exception of a several small storm events throughout the study period, and one large storm event in August, which resulted in peak flows for the entire water year.

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Introduction

Between May and October 2001, the Environmental Assessment Program of the Washington State Department of Ecology (Ecology) conducted streamflow gaging on the mainstem, North, and South Forks of the Stillaguamish River, as well as on two major tributaries. The Stillaguamish River basin is located in northwest Washington State. The basin is approximately 680 square miles in area, and includes over 4,618 miles of rivers and streams. Elevations in the basin range from sea level to about 6,844 ft on Whitehorse Mountain.

The gaging was undertaken in support of a temperature total maximum daily load (TMDL) study developed by the Environmental Assessment Program. The purpose of the study was to characterize the water temperature in the basin and establish load and wasteload allocations for the heat sources to meet water quality standards for surface water temperature. The study was initiated because of the 303(d) listings of river segments which are water quality limited for temperature (Pelletier and Bilhimer 2001).

For this study, Ecology established continuous stage height recorders at five locations in the basin; two on the South Fork Stillaguamish River, one on the North Fork Stillaguamish River, One on Deer Creek, a tributary of the North Fork, and one on Pilchuck Creek, a tributary of the mainstem Stillaguamish River.

Sites

On the North Fork Stillaguamish River, the continuous gaging station was located above Crevice Creek in the Mount Baker/Snoqualmie National Forest, at river mile 39.0 (Figure 1, Site 1). On the South Fork, the uppermost continuous gaging station was located across from the Mount Baker/Snoqualmie National Forest Verlot Campground, at river mile 46.5 (Site 2). The lower station on the South Fork was located at Snohomish County's River Meadows Park, approximately 4 miles southwest of Arlington, at river mile 24.4 (Site 3). On Deer Creek, the gaging station was located at a private residence approximately 0.5 miles upstream of the mouth in Oso (Site 4). On Pilchuck Creek, the gaging station was located approximately 0.5 miles above the mouth (Site 5).

In addition to the five continuous gaging stations, one instantaneous gaging station was established on the North Fork Stillaguamish River above Deer Creek in Oso, at river mile 14.5 (Site 6).

At the request of the TMDL study Project Manager, streamflow data from four existing gaging stations were also used for the project; two continuous gaging stations, and two instantaneous gaging stations. The upper instantaneous gaging station is located on the North Fork Stillaguamish River northwest of Darrington, on Swede Heaven Road at river mile 30.0 (Site 7). The lower instantaneous gaging station is located on the mainstem Stillaguamish River near Silvana, at river mile 11.2 (Site 8). The first continuous gaging station was located on Armstrong Creek at the Stillaguamish tribal fish hatchery near Arlington (Site 9). This station was decommissioned before the study period began, however data has been included through March 2001. The other continuous gaging station is located on the East Fork of Nookachamps Creek in the Skagit River basin, approximately 4.5 miles upstream of Barney Lake (not on map). Streamflow data for these additional stations are included in Appendix A.

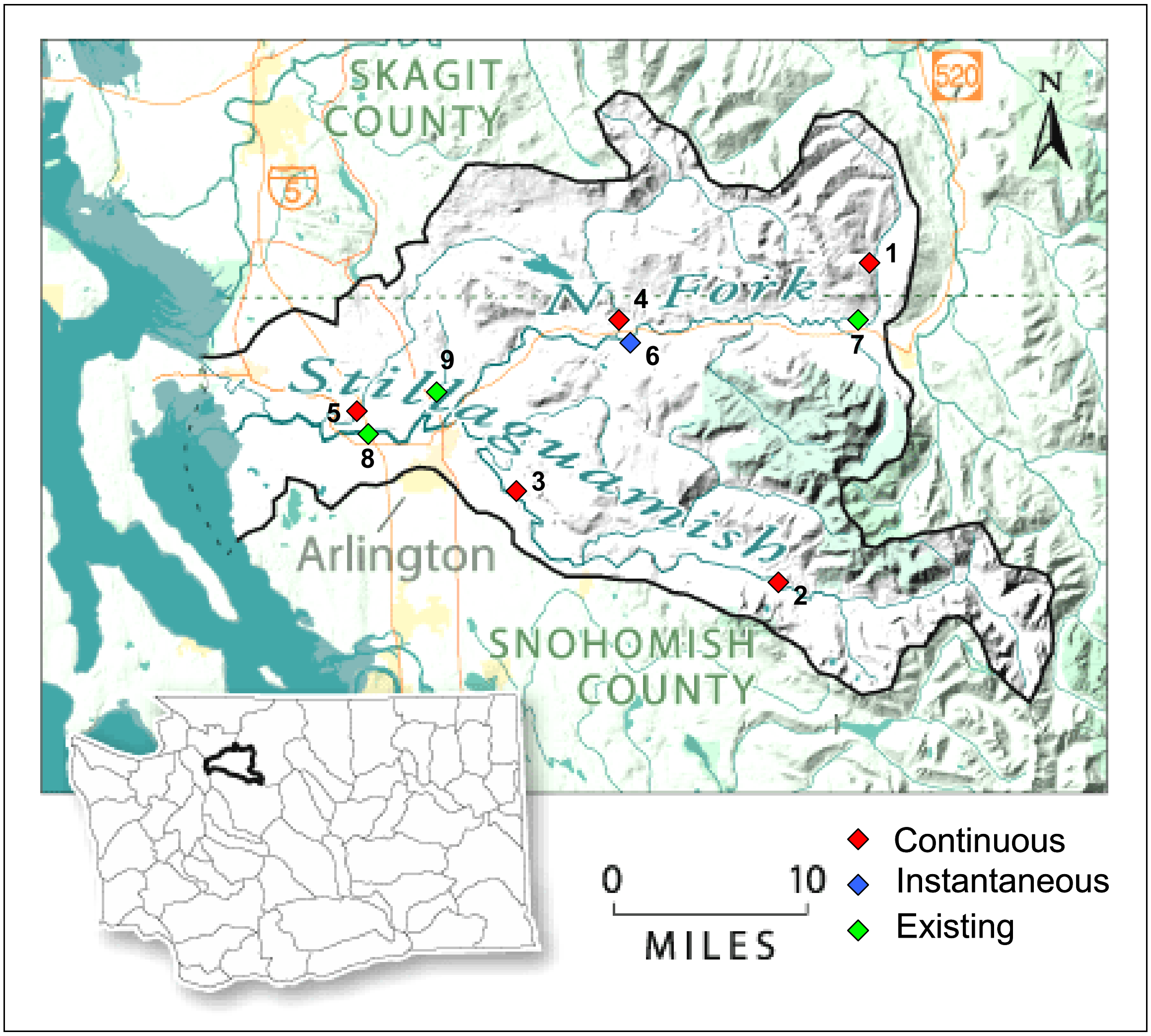

Figure 1: Map of Stillaguamish TMDL study sites.

Methods

Each of the five continuous gaging stations was equipped with a Design Analysis pressure transducer and datalogger that recorded stage height and temperature at 15-minute intervals from June to October 2001. Four to six discharge measurements were taken at each station to establish rating curves used to calculate the average daily discharges. For the instantaneous gaging station at N.F. Stillaguamish River at Oso, four discharge measurements were taken from the 221st Ave. bridge to develop a rating curve for the station. The rating curve was then used to determine discharge associated with stage readings taken by Watershed Ecology Section staff during temperature sampling visits. For the four existing stations, established rating curves were used to give either mean daily discharge records or instantaneous discharge values associated with stage readings taken by Watershed Ecology Section staff.

Discharge measurements were made following the United States Geological Survey (USGS) mid-section method. Ecology has made minor modifications to the USGS method to accommodate its measurement equipment (Hopkins, 1999). The flow measurement cross sections were established by driving re-bar into opposing banks perpendicular to the stream flow. This allowed field staff to return to the same cross-section at different stage heights and added to the reliability of the measured discharge data. In general, the cross-sections were divided into approximately 20 cells so that no more than 5% to 10% of the total discharge passed through any single cell. The width of the individual cells varied in keeping with the 5% to 10% discharge criteria. Velocity measurements were taken at 60% of the stream depth when the total stream depth was less than 1.5 ft and at 20% and 80% of the stream depth when the depth was greater than 1.5 ft (Hopkins, 1999). The instream velocity measurements were taken using a standard USGS top set wading rod fitted for Swoffer type optical sensors and propellers. Stream discharge was calculated in the office using a specialized software program.

Quality Assurance

Discharge Measurements

Because the largest potential source of error involved with a discharge measurement is in the velocity measurement itself, site selection and equipment calibration are of high importance. In this study, the measured cross-sections were rated between good and poor. Based on physical conditions encountered at each site, a good cross-section assumes an error of up to 5% and a poor cross-section assumes an error of up to 8%. Depending on the selected cross-section, a minimum of the assigned error is assumed and carried forward to the final discharge calculation. An additional source of error in velocity measurements is the calibration of the Swoffer instruments. The ideal calibration value of a Swoffer propeller is 186. The Swoffer propellers used during this project were pre- and post-calibrated with values ranging from 185 to 186. A calibration rating of 186 means that for every 186 revolutions of the propeller, 10 ft of water have passed the measurement point. A calibration value of 185 underestimates the discharge measurement by less than 1%. Once a rating curve was established, discharge measurements were tracked by comparing the measured discharge values to the predicted discharge values at the same stage. The combination of propeller variations, poor cross-sections, and low-flow conditions contributed to the measured and predicted discharge differences ranging from 0.1% to over 25%. This range of difference between the measured and the predicted discharge demonstrates the ability of the rating curves to predict stream discharge for each site.

Pressure Transducers and Staff Gages

Based on manufacturer specifications, the theoretical precision of the Design Analysis pressure transducers is less than or equal to 0.02% of the full-scale output. For the transducers used by Ecology, this precision is considered linear from 0 to15 psi or 0 to 34.6 ft (Fletcher, 2000). During the study period, the accuracy of each probe was addressed by using staff gage versus transducer regressions. The r^2 values for the regressions of transducer versus staff gage readings ranged from 0.95 to 1.00.

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Results

This study was designed as a summer low-flow assessment of the Stillaguamish River basin. For some of the selected sites, wide and shallow channel conditions presented unique problems with station placement, and threatened the ability to collect continuous streamflow information from static locations in the streams. In addition, two significant rainfall events occurred during the study period; one during June 11-13, and the other during August 22-24. For many rivers in Western Washington, the August rainfall event resulted in the peak streamflow for the water year. Most of the study sites were not wadable, and thus could not be measured, during high flows. As a result, most of the rating curves do not accurately cover the full range of flows. For any given gaging station, flows encountered that are over two-times the highest measured flow for that station are considered estimates.

Site 1: N.F. Stillaguamish River above Crevice Creek

The average daily discharge for Site 1 ranged from just over 12 cubic feet per second (cfs) during dry periods in August, September and October, to over 300 cfs during an intense storm event in August. Peak flow during the study period was over 550 cfs on August 22 (Figure 2). Daily discharge averages are presented in Appendix B, Table 1. The rating curve encompassed nearly 60% of the range of discharge, with flow measurements ranging from 12 to 315 cfs (Figure 3). However, discharge exceeded the rating curve less than 1% of the time over the duration of the study period (Figure 4). The rating curve, a polynomial regression of discharge versus pressure transducer readings, had an r^2 of 0.99. All six discharge measurements conducted at this station during the study period were within 10% of the flow predicted by the rating curve, and three were within 5% of the flow predicted by the rating curve. The linear regression of staff gage readings against pressure transducer readings was also quite strong, with an r^2 of 1.00 (Figure 5). The overall trend in streamflow at Site 1 reflects a typical dry-period decline in discharge, with the exception of several small storm events occurring at various times throughout the study period, and the water year peak event occurring in late August.

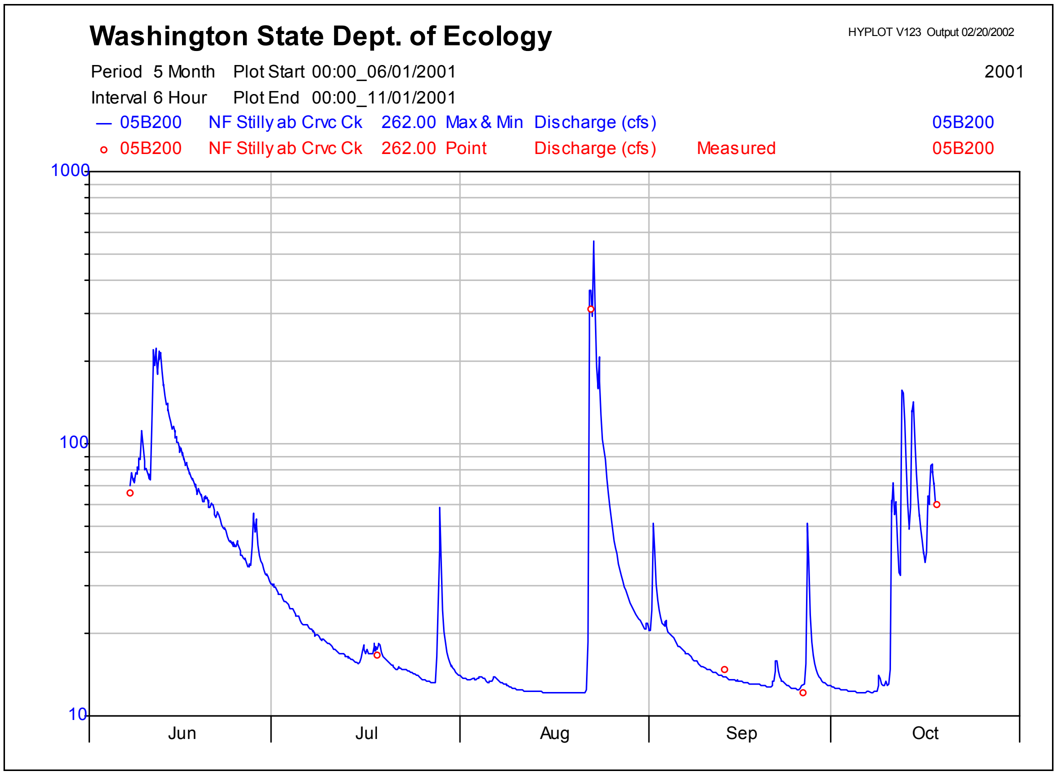

Figure 2: Discharge hydrograph for Site 1.

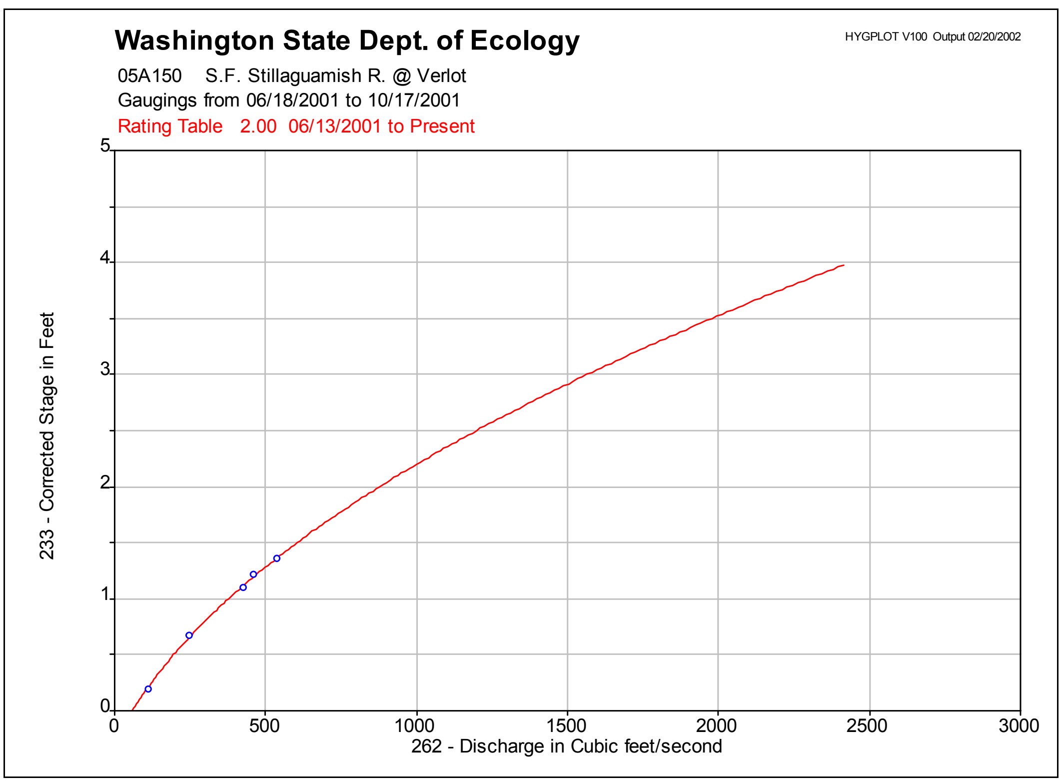

Figure 3: Discharge rating curve for Site 1.

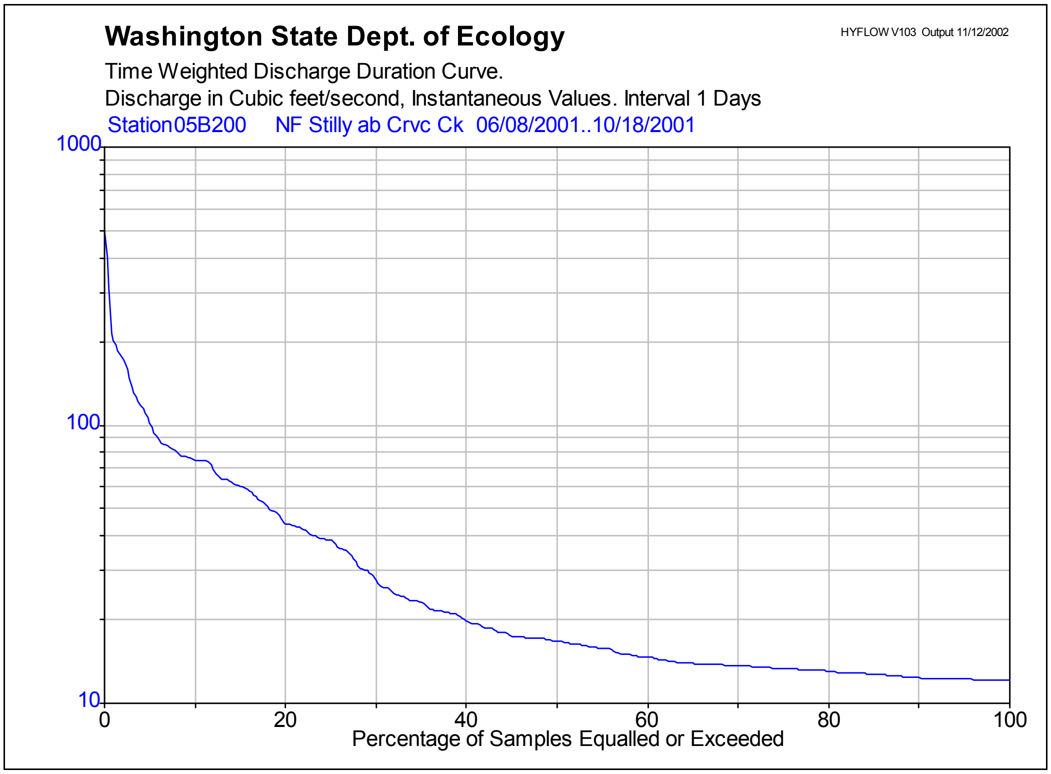

Figure 4: Flow exceedence graph for Site 1.

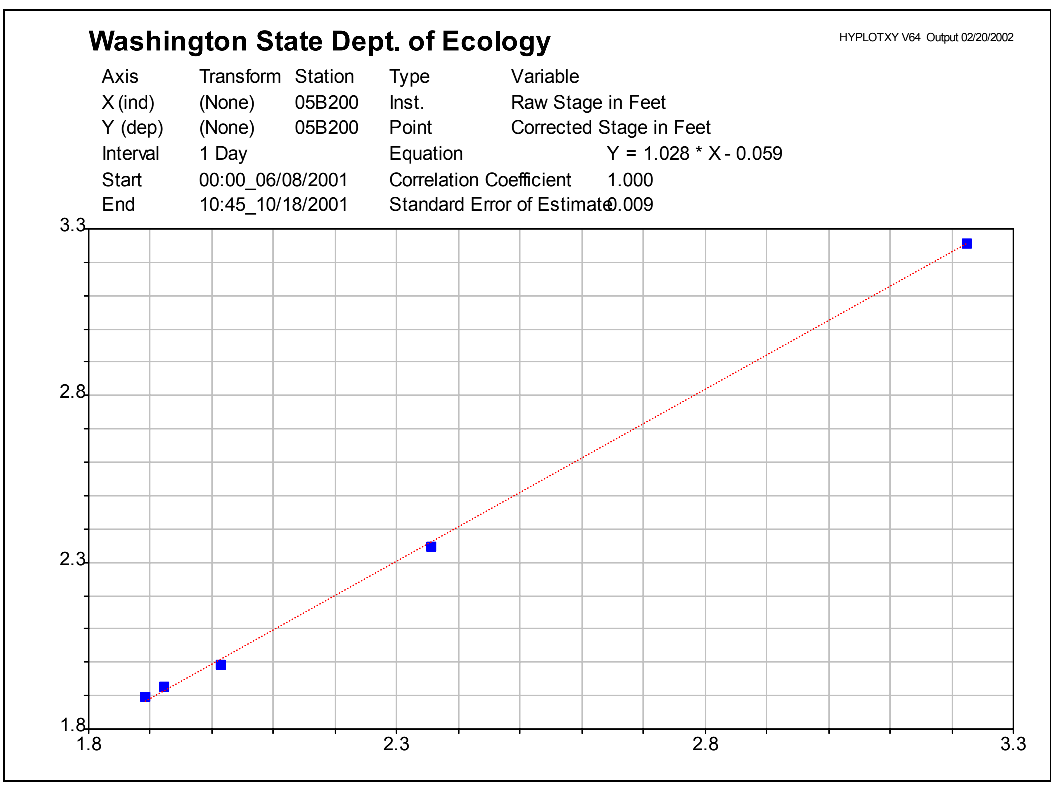

Figure 5: Linear regression of staff gage versus pressure transducer readings for Site 1.

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Site 2: S.F. Stillaguamish River at Verlot

The average daily discharge for Site 2 ranged from 80 cfs during dry periods in August, September and early October, to over 1300 cfs during storm events in mid-October. Peak flow during the study period was nearly 2,200 cfs on August 23 (Figure 6). Daily discharge averages are presented in Appendix B, Table 2. The rating curve encompassed less than 25 percent of the range of flows encountered during the study period, with discharge measurements ranging from 100 cfs to 530 cfs (Figure 7). A substantial portion of the discharge data collected at this site exceeded the rating curve. A discharge of 530 cfs was exceeded more than 15% of the time over the duration of the study period (Figure 8). Channel conditions at this site, combined with the lack of an adequate bridge crossing, resulted in an inability to measure flows greater than 550 cfs. The rating curve, a polynomial regression of discharge versus pressure transducer readings, had an r^2 of 0.99. All five discharge measurements conducted at this station during the study period were within 5% of the flow predicted by the rating curve. The linear regression of staff gage readings versus pressure transducer readings was strong during low-flow conditions, but not so strong during high flow conditions, with an overall r^2 of 0.976 (Figure 9).

The overall trend in streamflow at Site 2 reflects a typical dry-period decline in discharge, with the exception of several small storm events occurring at various times throughout the study period, and the water year peak event occurring in late August. However, during one distinct five-day time period of the study period (August 8-12), a diurnal cycle in stage readings was encountered. This was later determined to be related to an equipment problem, and the original data was corrected. Additional discussion of this problem is included as Appendix C.

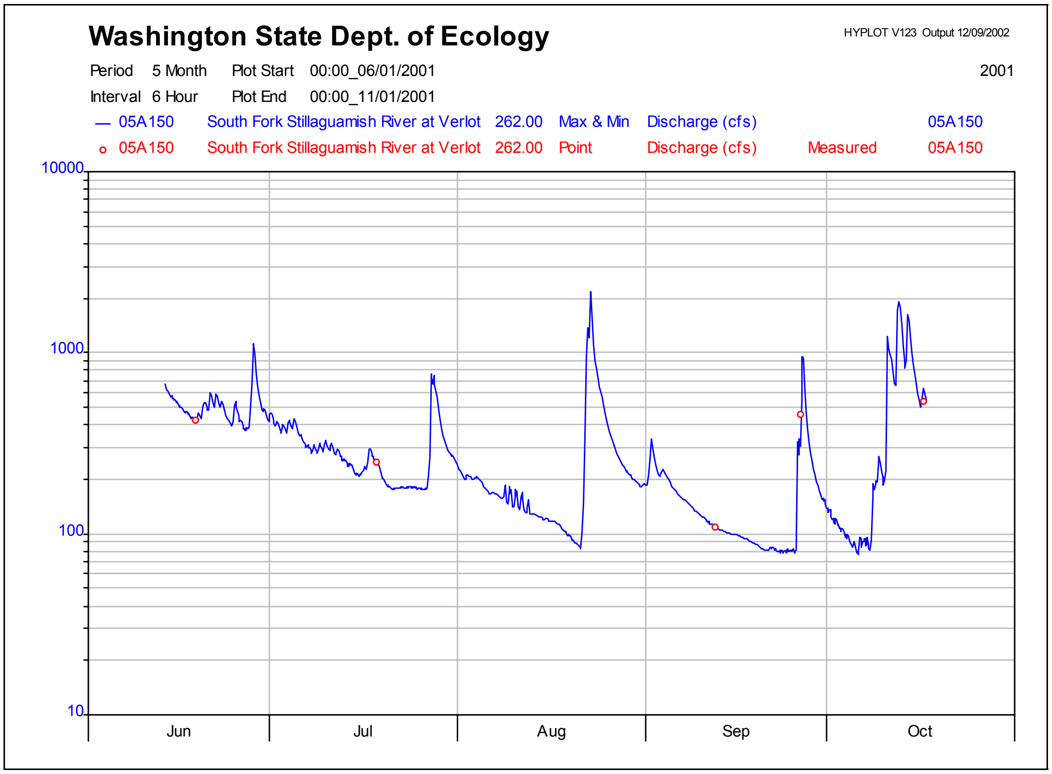

Figure 6: Discharge hydrograph for Site 2.

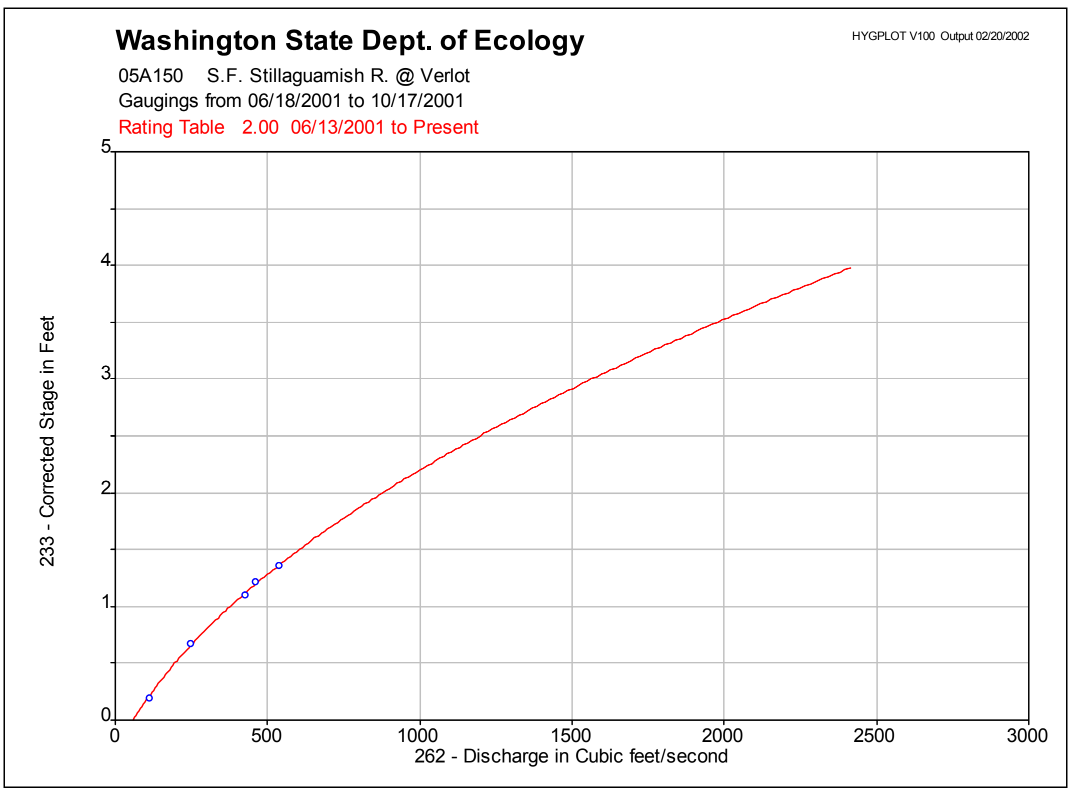

Figure 7: Discharge rating curve for Site 2.

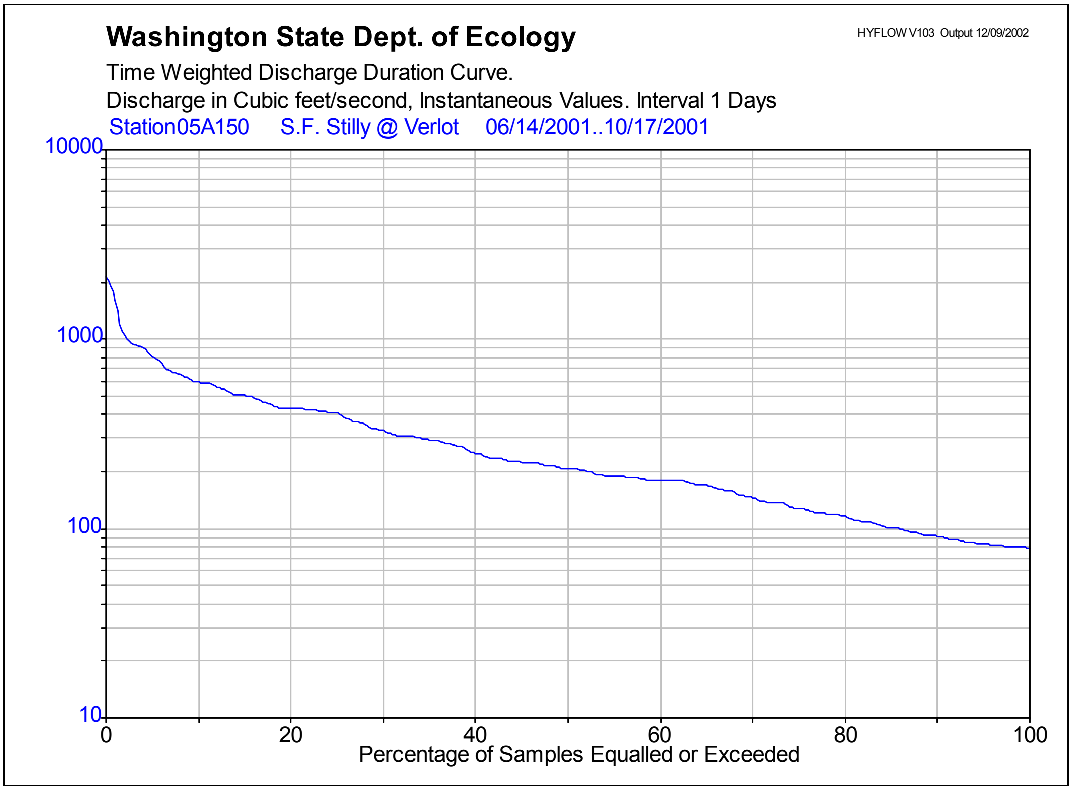

Figure 8: Flow exceedence graph for Site 2.

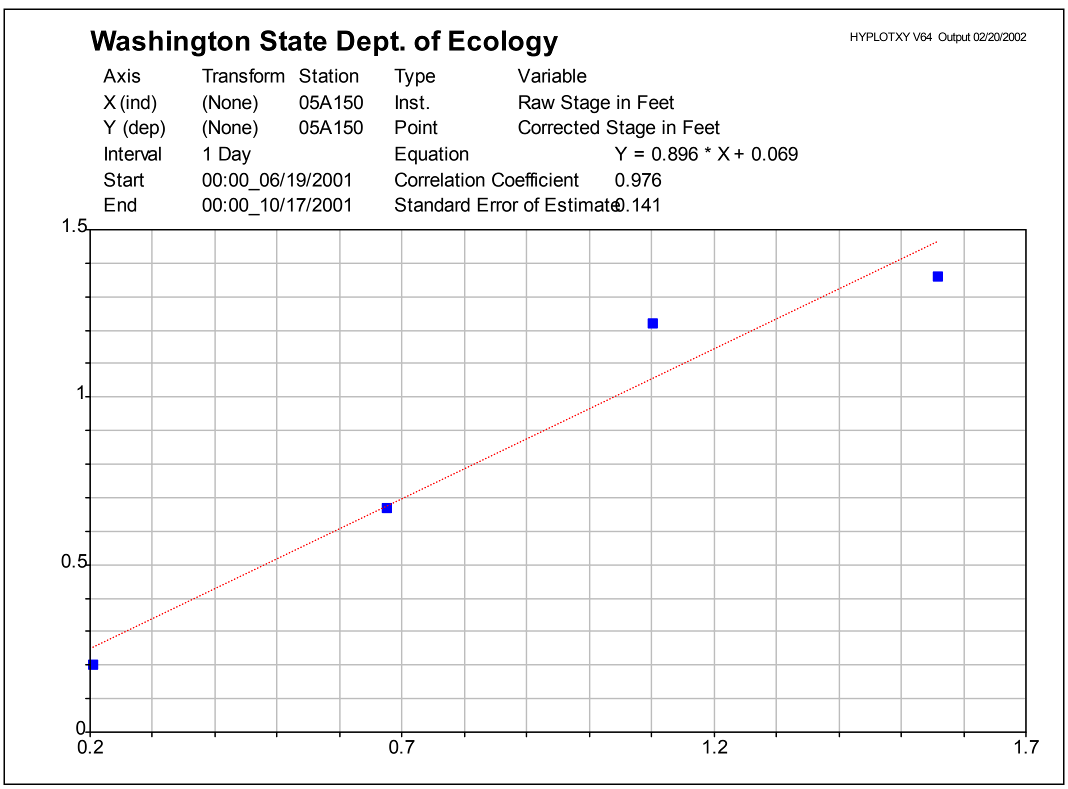

Figure 9: Linear regression of staff gage versus pressure transducer readings for Site 2.

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Site 3: S.F. Stillaguamish River at River Meadows Park

The average daily discharge for Site 3 ranged from around 140 cfs during dry periods in August, September and early October to 4400 cfs during a storm event in late August. Peak flow during the study period was nearly 9,500 cfs on August 23 (Figure 10). Daily discharge averages are presented in Appendix B, Table 3. The rating curve for Site 3 encompassed less than 15 percent of the range of flows encountered during the study period, with flow measurements ranging from 175 cfs to 1400 cfs (Figure 11). Channel conditions at the site, combined with the lack of an adequate bridge crossing, resulted in an inability to measure flows greater than 1,400 cfs. However, discharge exceeded the rating curve less than 10% of the time over the duration of the study period (Figure 12). Within the range of measured flows, the fit of the rating curve was very good. A log-log regression of river stage against discharge had an r^2 value of 0.999 (Figure 13). All five discharge measurements conducted at this station during the study period were within 5% of the flow predicted by the rating curve. The linear regression of staff gage readings versus pressure transducer readings was stronger during low flow conditions than during high flow conditions, with an overall r^2 of 0.991 (Figure 14). The overall trend in streamflow at Site 3 reflects a typical dry-period decline in discharge, with the exception of several small storm events occurring at various times throughout the study period, and the water year peak event occurring in late August.

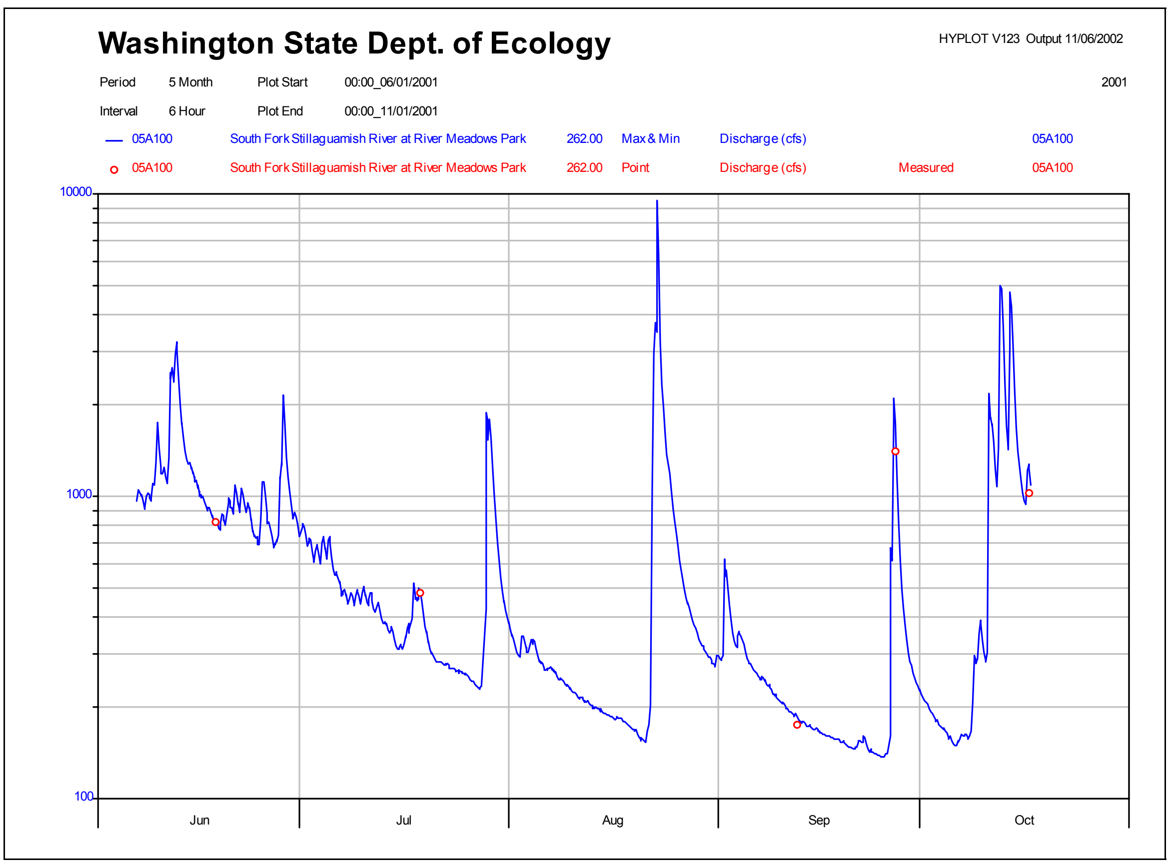

Figure 10: Discharge hydrograph for Site 3.

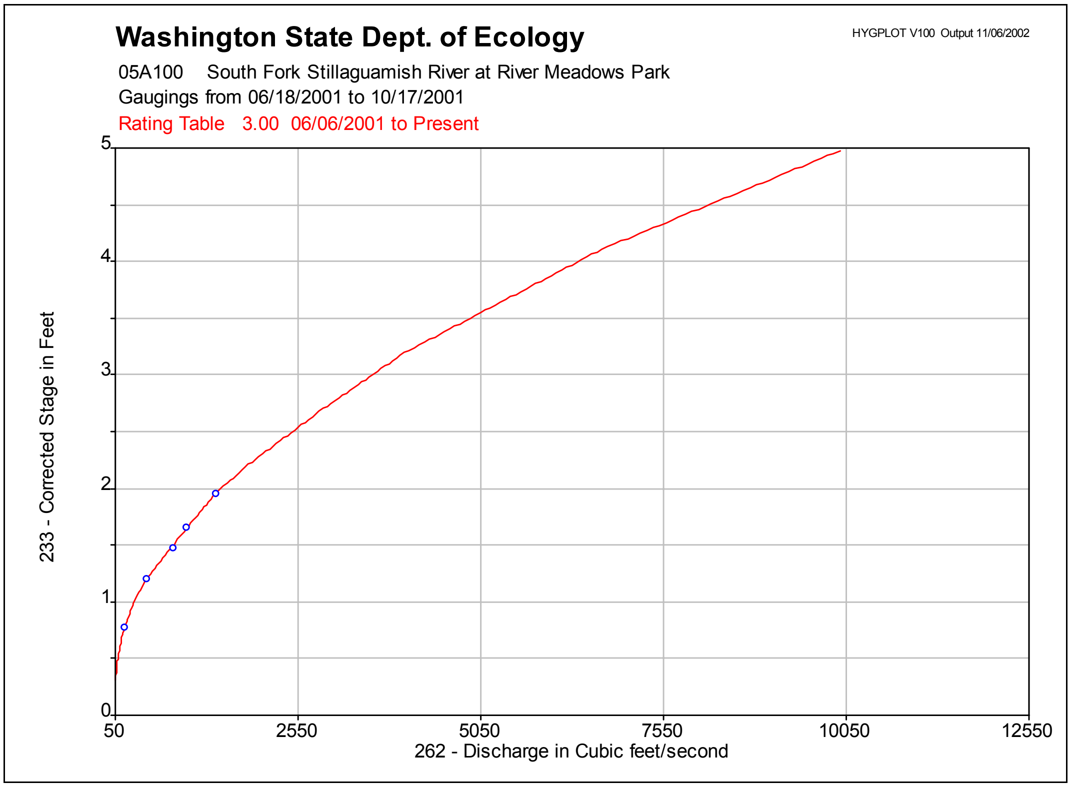

Figure 11: Discharge rating curve for Site 3.

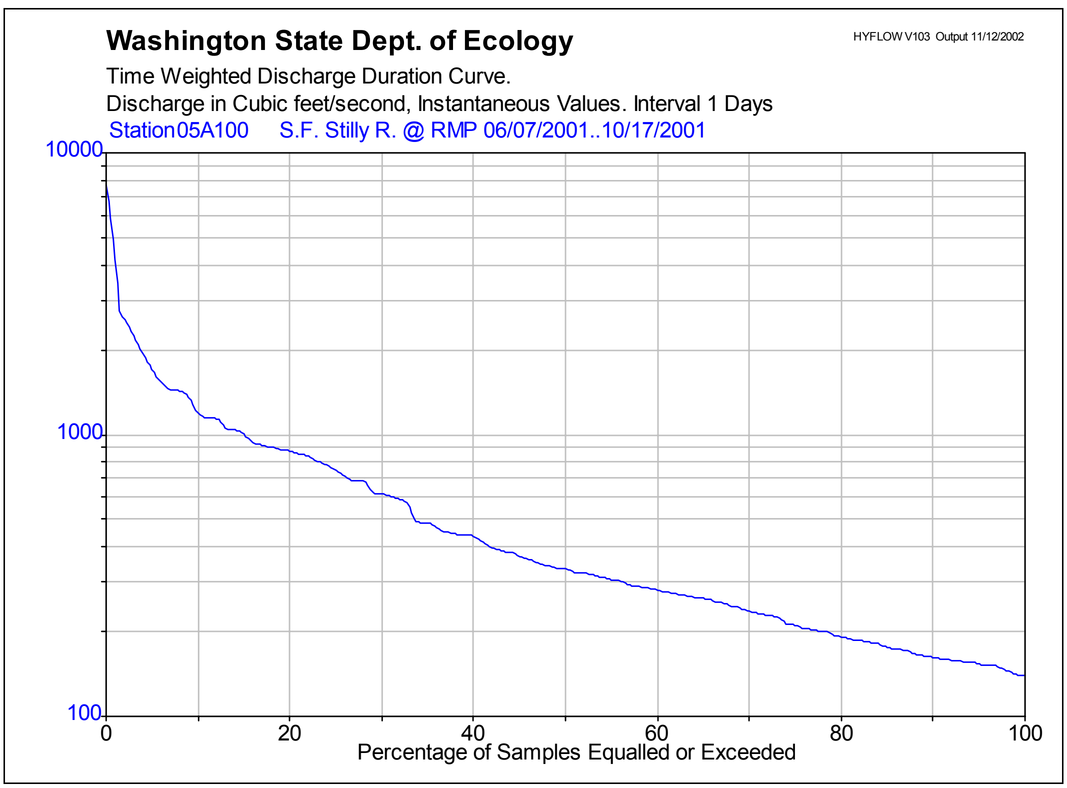

Figure 12: Flow exceedence graph for Site 3.

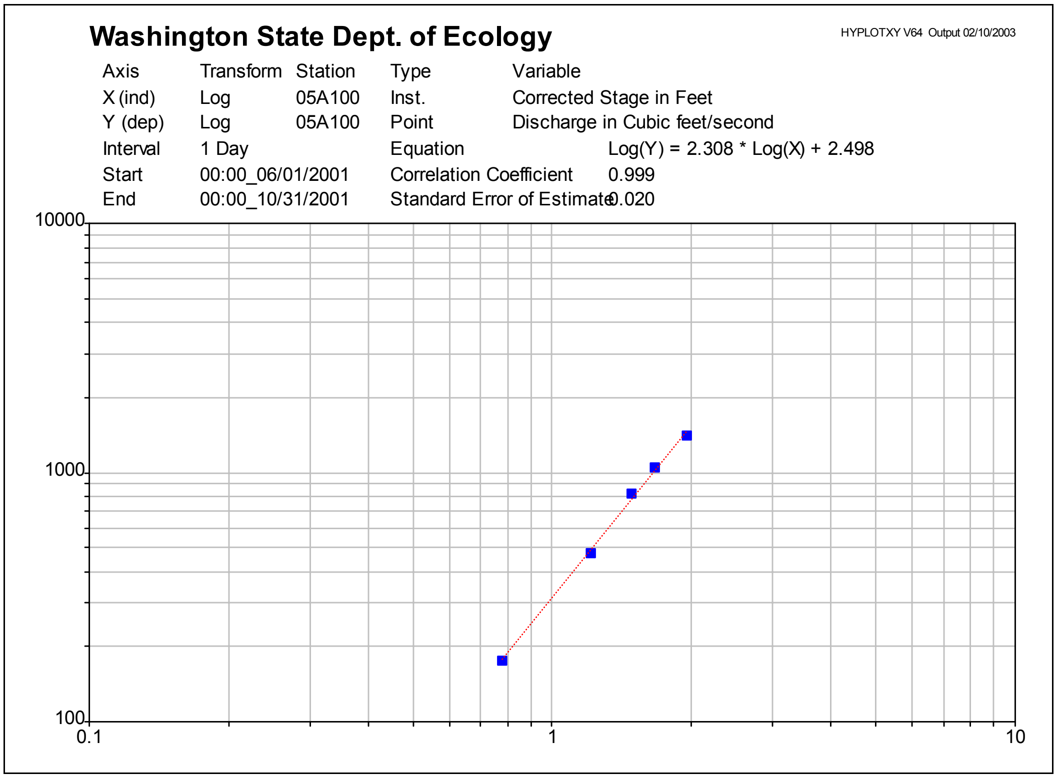

Figure 13: Log-Log regression of stage versus discharge for Site 3.

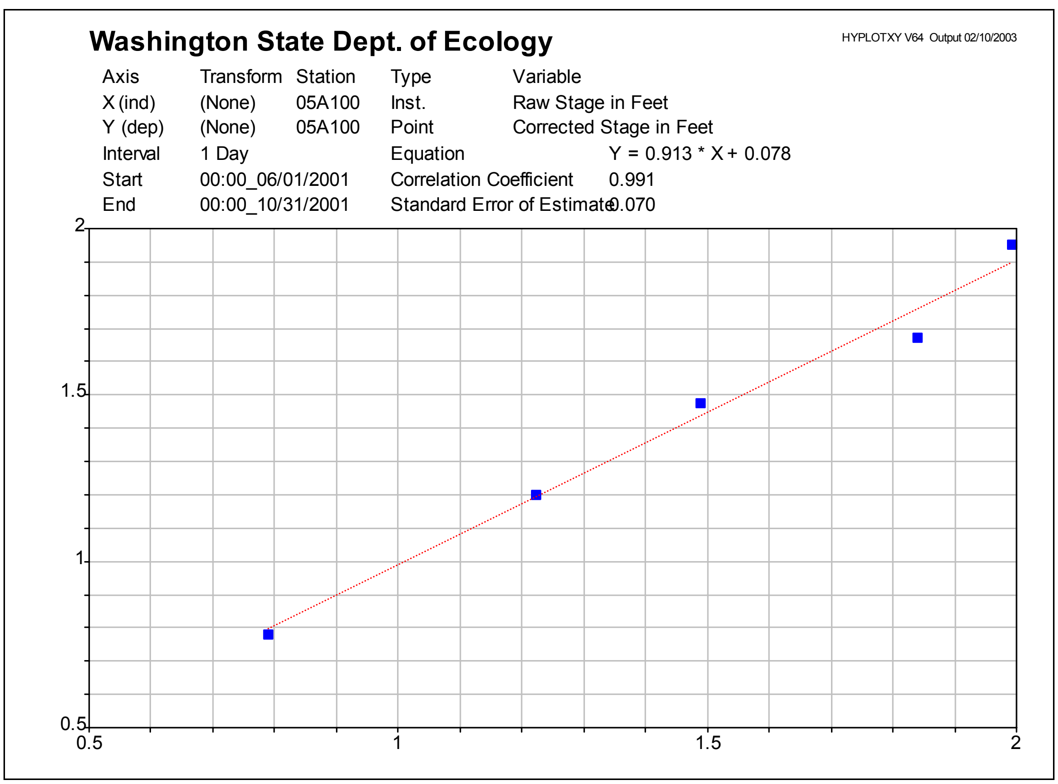

Figure 14: Linear regression of staff gage versus pressure transducer readings for Site 3.

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Site 4: Deer Creek at Oso

The average daily discharge for Site 4 ranged from over 30 cfs in mid-August to 1,240 cfs during a storm event in late-August. Peak flow during the study period was 2,150 cfs on August 22 (Figure 15). Daily discharge averages are presented in Appendix B, Table 4. The rating curve encompassed only 10 percent of the range of flows encountered during the study period, with flow measurements ranging from 40 cfs to 236 cfs (Figure 16). Channel conditions at the site, combined with the lack of an adequate bridge crossing, resulted in an inability to measure flows greater than 240 cfs. Discharge exceeded the rated range of flows during peak flows each month of the study period, with event peaks ranging from 364 cfs in June to 2,150 cfs during the peak event in August. This represents a fairly sizeable portion of the encountered flows, as discharge exceeded the rating curve 10% of the time over the duration of the study period (Figure 17). The rating curve, a polynomial regression of discharge versus pressure transducer readings, had an r^2 of 0.999. All five discharge measurements conducted at this station during the study period were within 5% of the flow predicted by the rating curve. The linear regression of staff gage readings versus pressure transducer readings was strong throughout the range, with an r^2 of 1.00 (Figure 18). The overall trend in streamflow at Site 4 reflects a typical dry-period decline in discharge, with the exception of several small storm events occurring at various times throughout the study period, and the water year peak event occurring in late August.

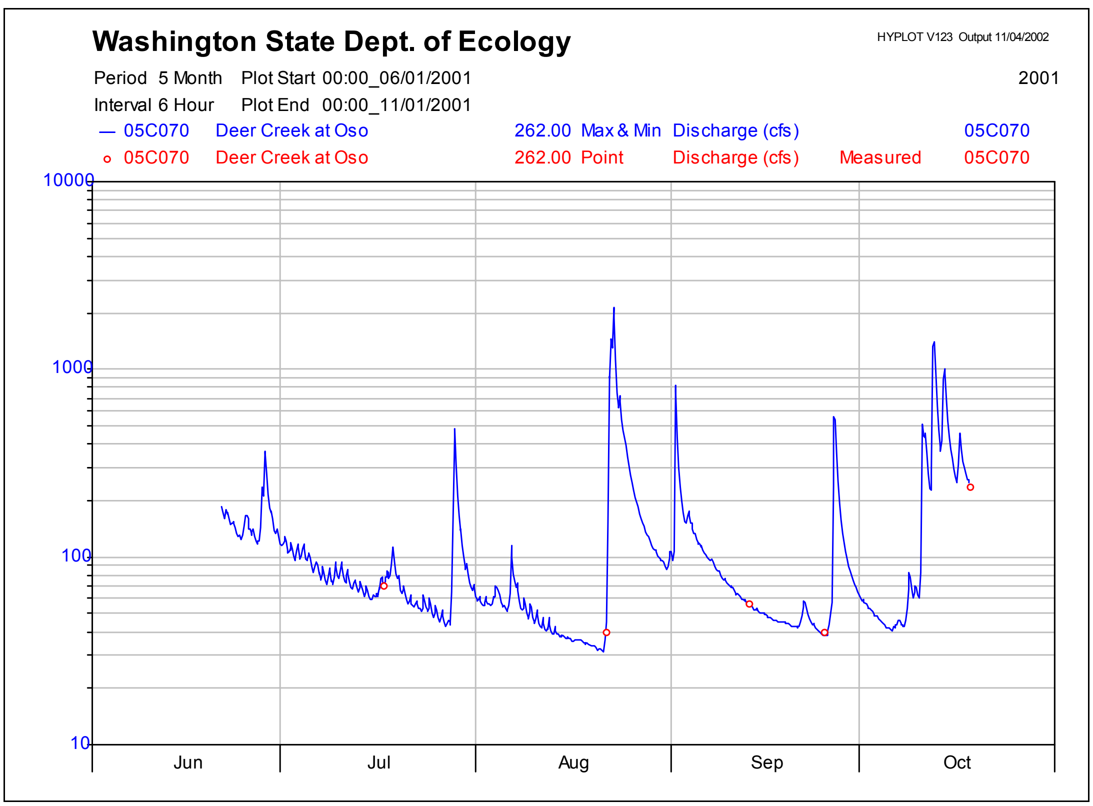

Figure 15: Discharge hydrograph for Site 4.

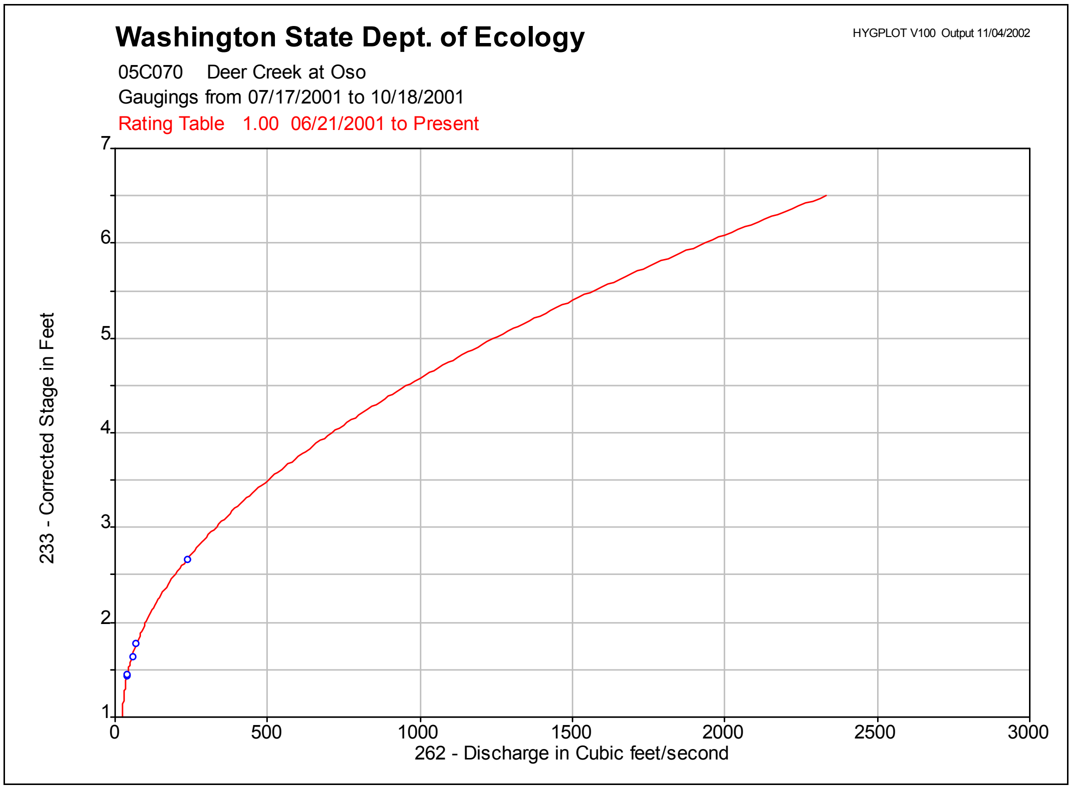

Figure 16: Discharge rating curve for Site 4.

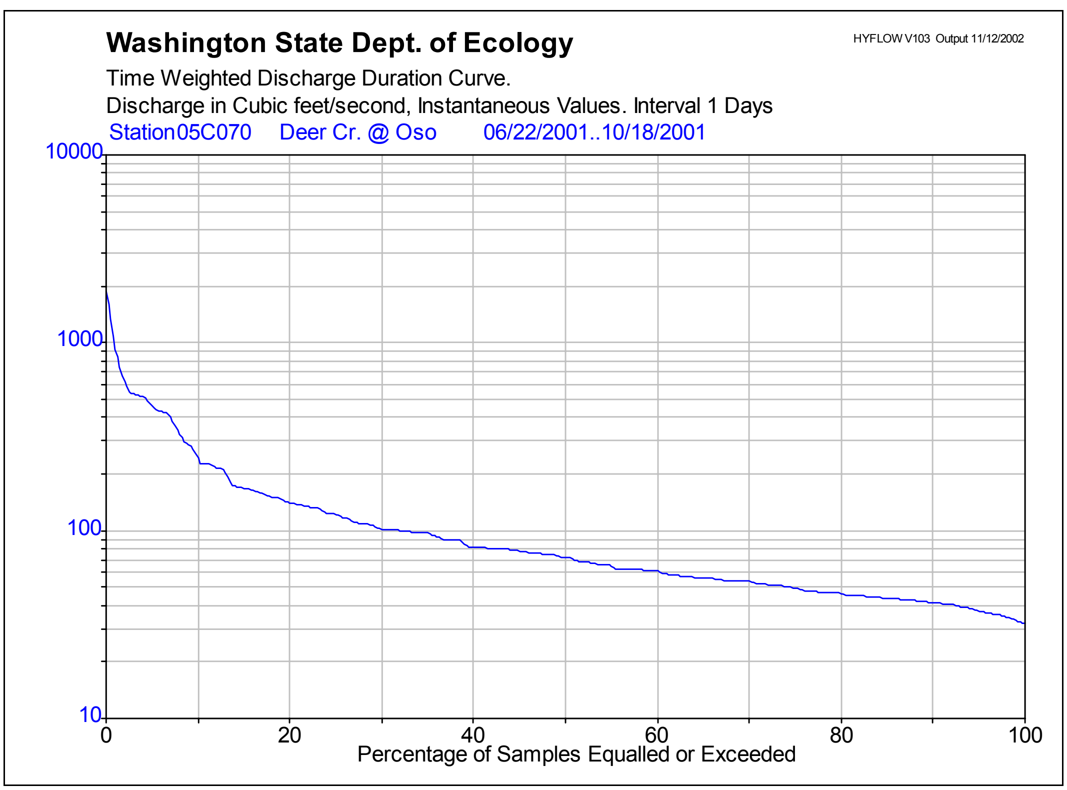

Figure 17: Flow exceedence graph for Site 4.

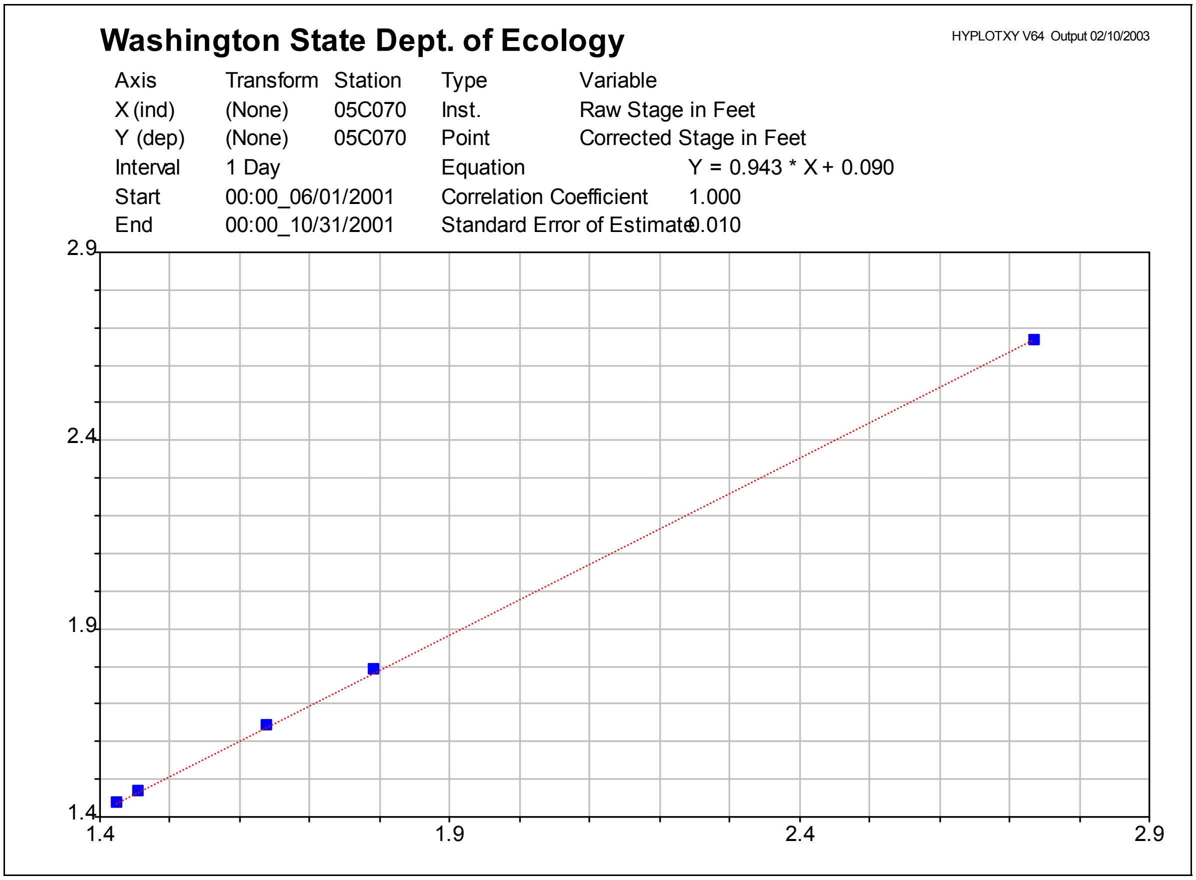

Figure 18: Linear regression of staff gage versus pressure transducer readings for Site 4.

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Site 5: Pilchuck Creek at Bridge 626

High flows from a storm event submerged the datalogger at the Pilchuck Creek station on June 11, 2001, causing it to fail. As a result, data were not collected for a period of 35 days from June 11 through July 17. All analyses for this station are based on data exclusive of this period.

The average daily discharge for Site 5 ranged from 9.5 cfs in mid-August to 1,740 cfs during a storm event in mid-November. Peak flow during the study period was 3,970 cfs on November 14 (Figure 19). Daily discharge averages are presented in Appendix B, Table 5. The rating curve encompassed only 27 percent of the range of flows encountered during the study period, with flow measurements ranging from 12 cfs to 1,080 cfs (Figure 20). However, discharge exceeded the rating curve only 2% of the time during the study period (Figure 21). The rating curve, a polynomial regression of discharge versus pressure transducer readings, had an r^2 of 0.999. Out of seven discharge measurements conducted at this station during the study period, six were within 10% of the flow predicted by the rating curve, and four were with in 5% of the flow predicted by the rating curve. The linear regression of staff gage readings versus pressure transducer readings was strong throughout the range, with an r^2 of 1.00 (Figure 22). The overall trend in streamflow at Site 5 reflects a typical dry-period decline in discharge, with the exception of several small storm events occurring at various times throughout the study period, and the water year peak event occurring in late August. The rise in flows with the onset of fall rains began in early- to mid-October.

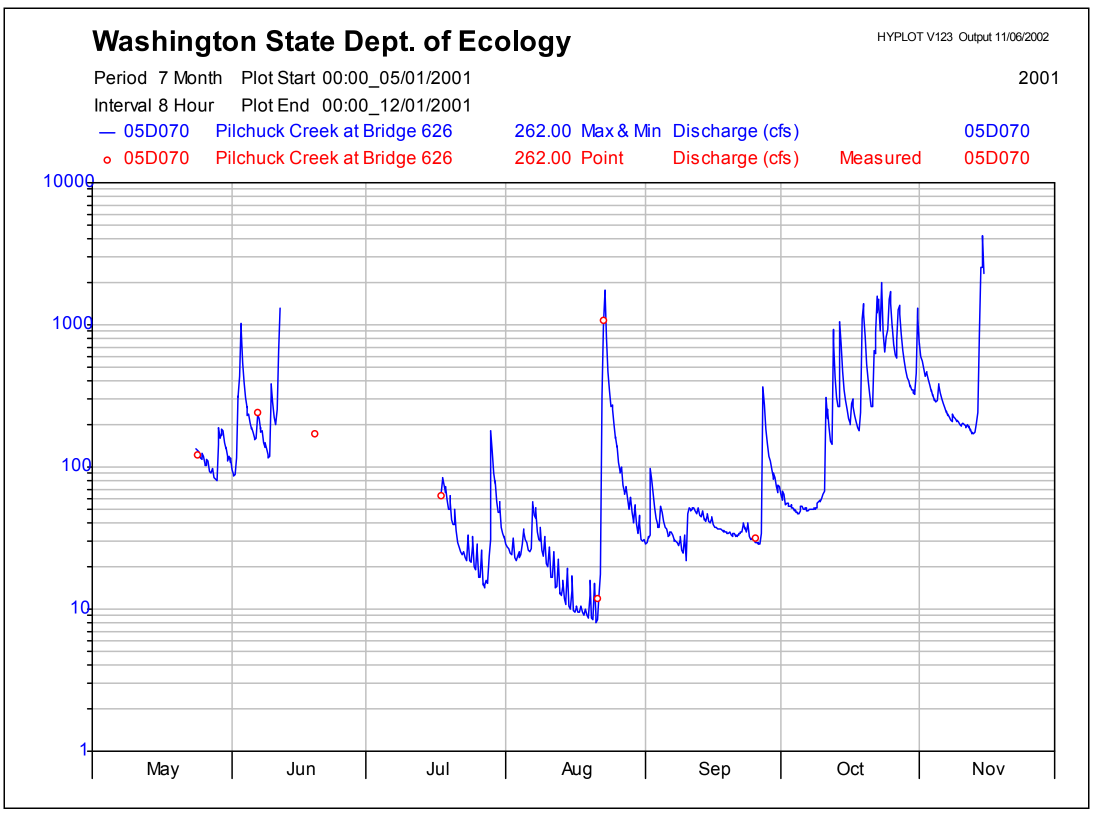

Figure 19: Discharge hydrograph for Site 5.

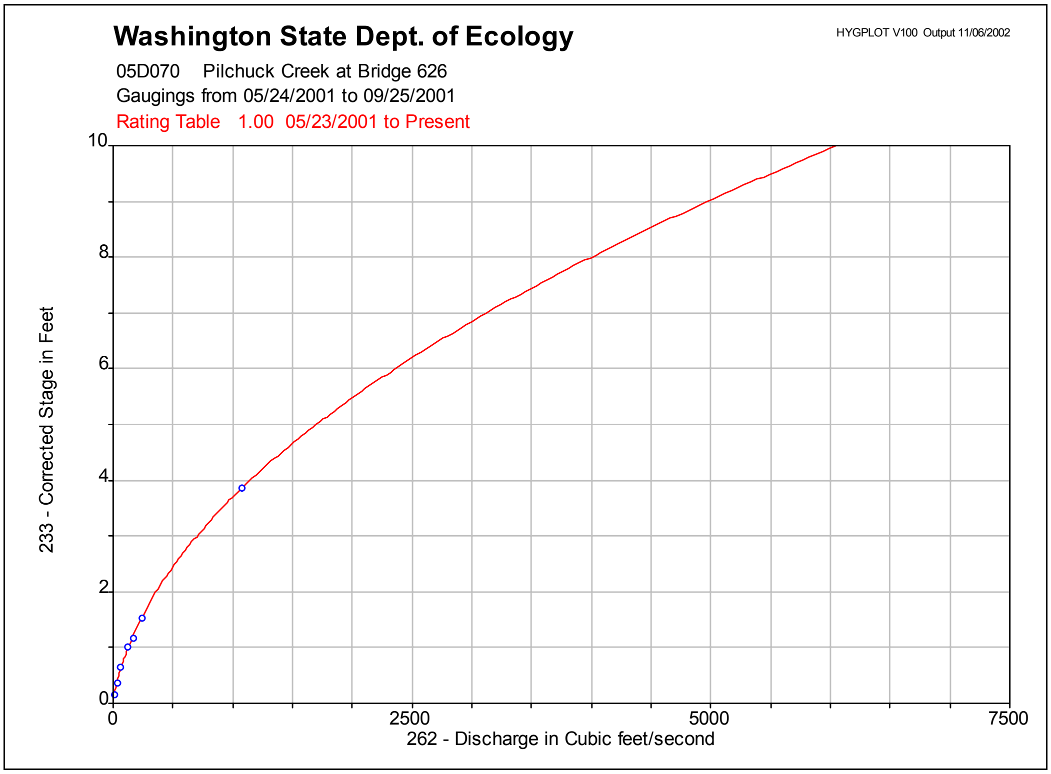

Figure 20: Discharge rating curve for Site 5.

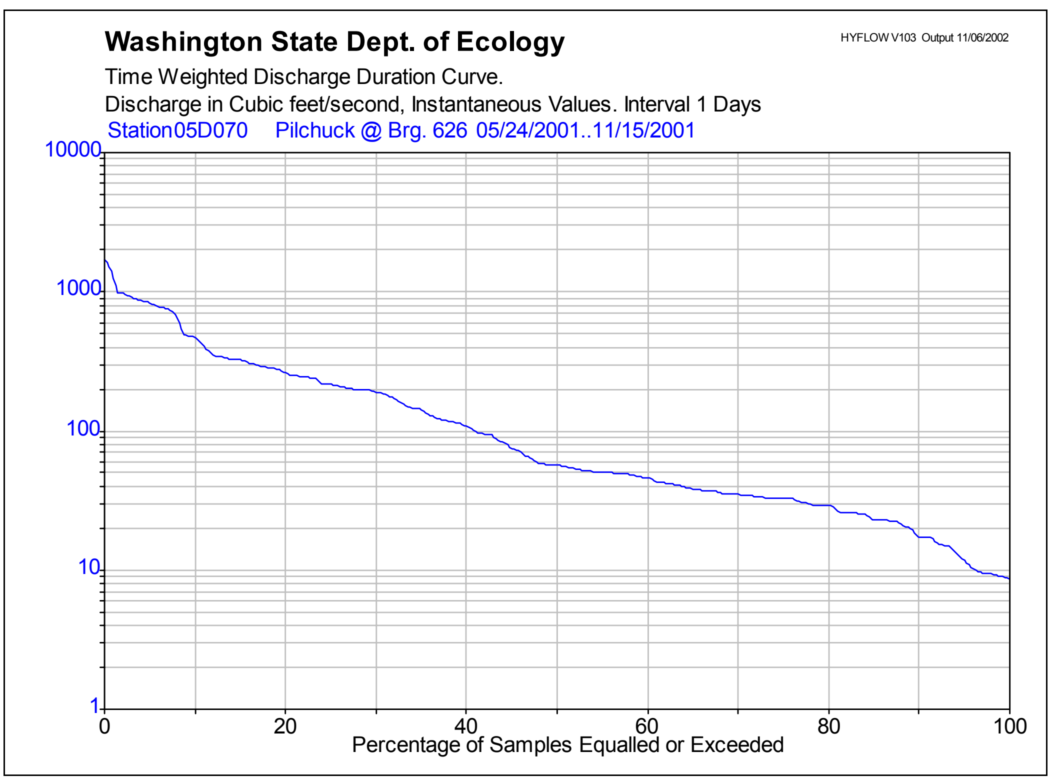

Figure 21: Flow exceedence graph for Site 5.

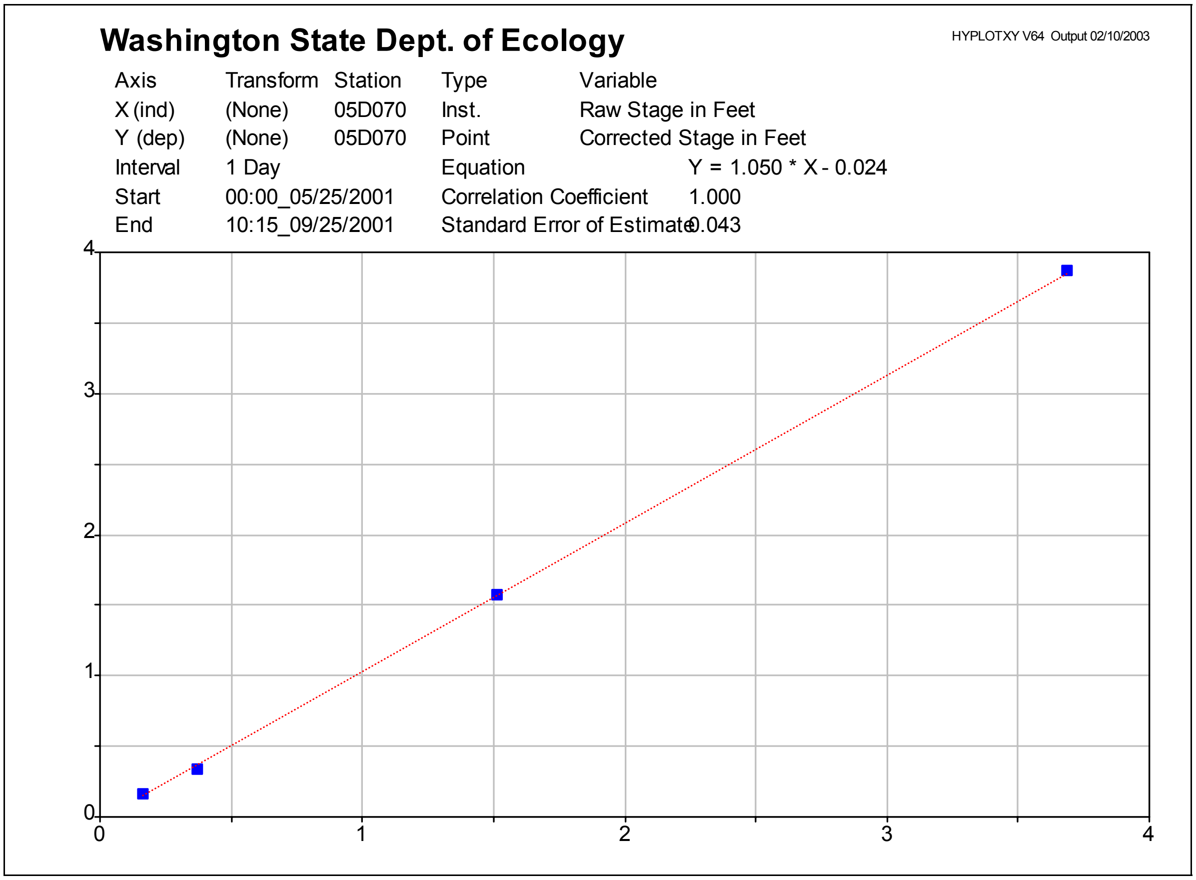

Figure 22: Linear regression of staff gage versus pressure transducer readings for Site 5.

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Site 6: N.F. Stillaguamish River at Oso

Continuous data collection was not conducted at Site 6. Instead, a rating curve was developed, and used to derive flows from stage readings taken during temperature sampling visits by Watershed Ecology Section staff. The stage index for this site was derived from a reference point established on a bridge over the river. River stage readings were taken by measuring from the reference point down to the water surface. Thus, as the river rose, the distance from the reference point to the water surface would decrease, and vice versa. Flows encountered during the study period ranged from just over 100 cfs in mid-September to over 840 cfs in mid-October (Figure 23). The rating curve encompassed nearly 70% of the range of flows encountered during the study period, with flow measurements ranging from 145 cfs to 655 cfs (Figure 24). The linear regression of discharge versus distance to water surface measurements had an r^2 of 0.999. All four discharge measurements conducted at the site during the study period were within 5% of the flow predicted by the rating curve. The overall trend in streamflow at Site 6 seems to be a typical dry-period decline in discharge. The storm events that occurred in each of the months of June through September were not measured, nor was temperature sampling conducted during those periods.

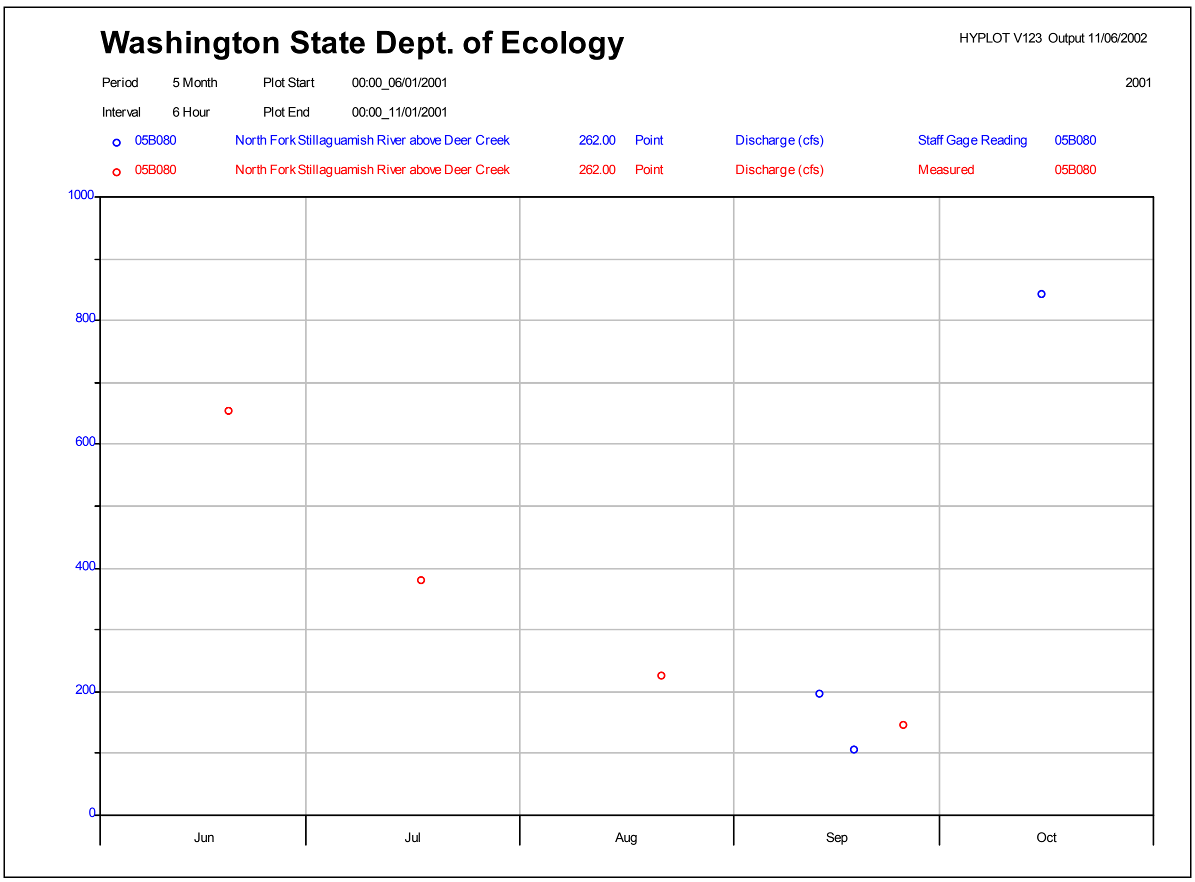

Figure 23: Discrete flow hydrograph for Site 6.

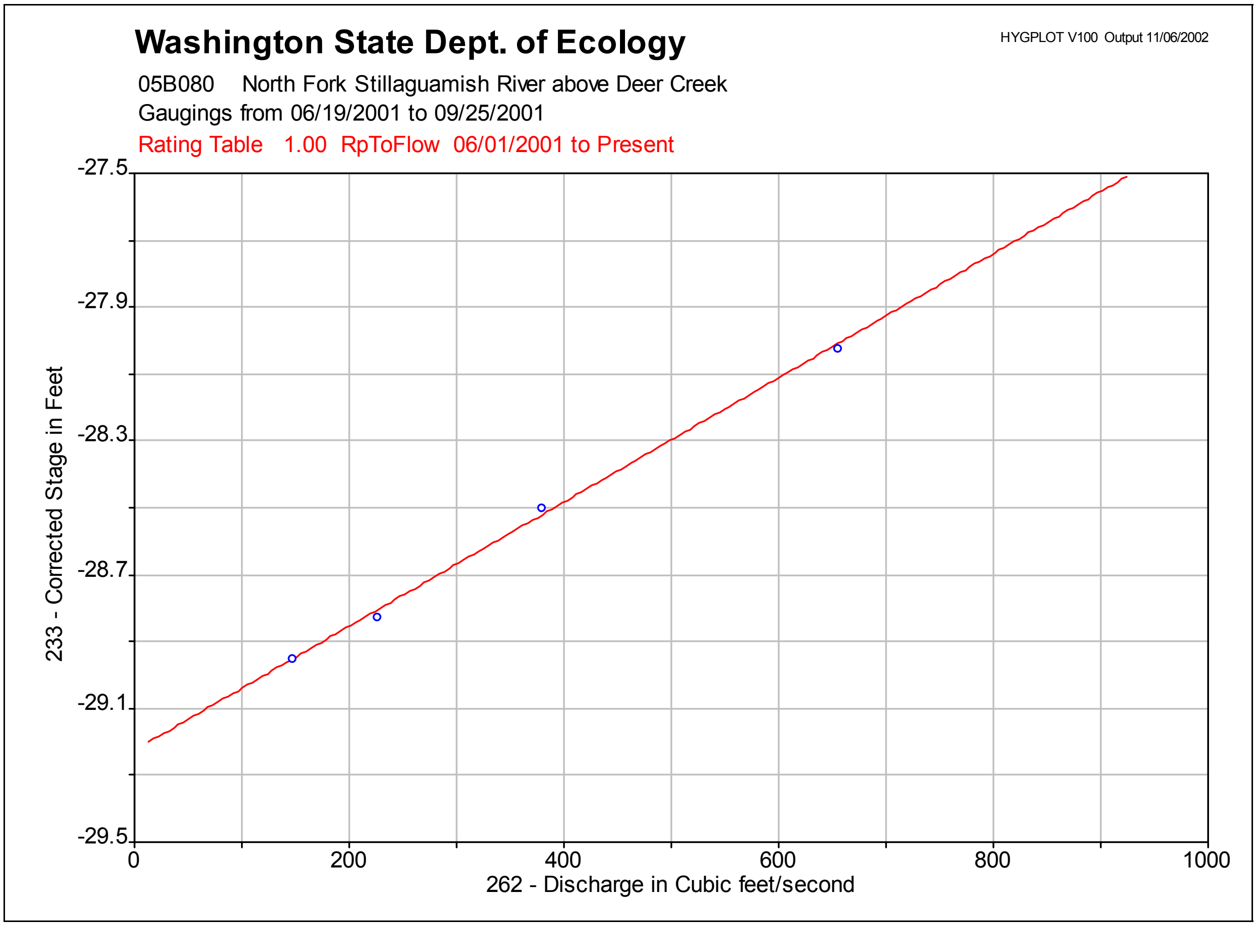

Figure 24: Discharge rating curve for Site 6.

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Hopkins, Brad. 1999. *Determination of Instantaneous Flow Measurements on Rivers and Streams*. Washington State Department of Ecology, Olympia, Washington. Draft Paper. P.6.

Pelletier, Greg and Dustin Bilhimer. July 2001. *Stillaguamish River Temperature Total Maximum Daily Load, Quality Assurance Project Plan*. Washington State Department of Ecology, Olympia, Washington.

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Appendix A

Supplemental Station Data

Table A-1: Discrete discharge values for N.F. Stillaguamish R. near Darrington (Site 7)

DATE	TIME	FLOW (CFS)
05/22/2001	09:40	560
06/19/2001	09:20	219
07/17/2001	09:20	72
07/25/2001	15:30	42
08/21/2001	09:55	40
09/11/2001	17:30	38
09/18/2001	10:00	41
09/20/2001	11:10	34
09/26/2001	07:30	40
10/16/2001	12:00	105
10/23/2001	11:00	1520
11/14/2001	09:35	8900
11/15/2001	10:45	3170

Table A-2: Discrete discharge values for Stillaguamish R. near Silvana (Site 8)

DATE	TIME	FLOW (CFS)
05/22/2001	16:20	3400
05/24/2001	10:00	4060
06/13/2001	11:15	5140
06/19/2001	16:00	2030
07/12/2001	11:20	1170
07/17/2001	10:00	1070
07/17/2001	16:30	1090
07/24/2001	13:15	799
08/07/2001	16:35	75
08/14/2001	16:05	598
08/22/2001	11:50	4280
08/22/2001	12:50	5000
08/31/2001	11:30	887
09/19/2001	10:30	488
09/19/2001	15:22	498
09/26/2001	12:00	1900
10/16/2001	12:15	2270
10/19/2001	12:25	7420
10/23/2001	13:20	17200
11/14/2001	09:30	23500
11/14/2001	11:40	26300
11/15/2001	09:10	19400
11/15/2001	22:00	15700

Table A-3: Armstrong Cr. near Arlington (Site 9) Daily Discharge Averages (cfs).

Day	Oct	Nov	Dec	Jan	Feb	Mar
1	32.8~	24.1~	23.2~	35.3~	115~	26.9~
2	24.2~	23.3~	22.5~	31.7~	71.3~	43.3~
3	22.4~	22.7~	21.8~	31.5~	53.5~	32.9~
4	21.6~	23.9~	20.0~	45.5~	63.3~	30.1~
5	21.0~	25.7~	19.3~	92.9~	57.5~	28.1~
6	20.8~	24.6~	18.7~	97.2~	48.8~	26.8~
7	19.9~	23.9~	18.0~	58.1~	42.4~	26.2~
8	20.1~	35.9~	18.1~	47.8~	41.8~	31.5~
9	23.3~	36.9~	21.9~	57.5~	44.5~	38.3~
10	28.5~	27.9~	19.6~	43.4~	38.6~	31.3~
11	23.2~	25.3~	18.6~	37.9~	35.0~	30.1~
12	21.4~	24.7~	18.2~	34.6~	32.9~	31.4~
13	21.1~	24.8~	17.3~	37.4~	31.3~	34.6~
14	21.5~	23.5~	17.3~	40.7~	30.3~	33.4~
15	21.0~	22.3~	19.2~	37.4~	34.0~	43.2~
16	22.4~	21.7~	24.4~	33.6~	34.6~	69.2~
17	25.4~	21.7~	44.8~	31.5~	35.8~	53.8~
18	22.7~	21.6~	30.1~	33.9~	33.1~	57.4~
19	23.0~	21.8~	25.6~	38.3~	31.0~	54.3~
20	28.9~	22.7~	23.7~	33.9~	30.2~	[]
21	33.1~	22.0~	23.7~	60.2~	29.5~	[]
22	29.7~	21.3~	24.2~	69.3~	29.8~	[]
23	25.2~	21.8~	32.9~	49.2*	29.0~	[]
24	23.3~	23.7~	73.3~	42.0~	28.9~	[]
25	23.7~	23.3~	52.0~	43.4~	27.7~	[]
26	22.7~	24.3~	40.6~	37.1~	26.5~	[]
27	23.4~	33.8~	37.9~	33.8~	25.9~	[]
28	29.1~	27.5~	33.4~	32.2~	25.5~	[]
29	29.3~	25.4~	31.0~	45.0~		[]
30	25.9~	25.5~	35.2~	52.0~		[]
31	24.1~		36.4~	168~		[]
Mean	24.4~	24.9~	27.8~	49.4*	40.3~	38.0~
Median	23.3~	23.9~	23.7~	40.7*	33.5~	32.9~
Max.Daily Mean	33.1~	36.9~	73.3~	168*	115~	69.2~
Min.Daily Mean	19.9~	21.3~	17.3~	31.5*	25.5~	26.2~
Inst.Max	49.0~	47.5~	90.9~	245*	168~	76.6~
Inst.Min	18.2~	20.0~	16.5~	28.8*	24.9~	24.9~
Missing Days	0	0	0	0	0	12

------------------ Notes -------------------
All recorded data is continuous and reliable
except where the following tags are used...
* ... Reliable Estimate
[ ] Data Not Recorded
~ ... Provisional data

Table A-4: E.F. Nookachamps Cr. @ Beaver Lake Rd. (Site 10) Daily Discharge Averages (cfs).

Day	May	Jun	Jul	Aug	Sep	Oct	Nov
1	168~	28.6~	24.2~	7.72~	19.4~	3.05~	90.9~
2	124~	105~	21.5~	6.60~	20.7~	2.34~	73.6~
3	89.6~	66.8~	19.2~	7.12~	12.7~	1.96~	54.1~
4	86.1~	37.5~	17.2~	14.3~	12.0~	1.66~	48.8~
5	105~	29.8~	15.6~	8.34~	9.39~	1.75~	64.3~
6	70.2~	46.5~	14.7~	21.1~	8.94~	2.26~	46.0~
7	59.4~	34.0~	13.4~	13.7~	7.84~	1.40~	36.0~
8	53.8~	26.4~	12.1~	7.81~	6.31~	2.02~	29.8~
9	46.5~	37.4~	10.9~	4.79~	4.36~	5.47~	25.8~
10	42.7~	36.0~	9.79~	2.77~	3.04~	26.4~	23.3~
11	45.3~	276~	8.45~	2.11~	2.54~	53.0~	21.6~
12	48.9~	571~	7.50~	1.77~	2.29~	73.0~	20.7~
13	48.7~	188~	7.34~	1.44~	2.08~	52.7~	26.9~
14	174~	108~	6.96~	1.43~	1.90~	122~	235~
15	215~	78.6~	6.95~	2.00~	1.77~	43.5~	198~
16	196~	62.9~	9.43~	2.56~	1.63~	43.0~	105~
17	120~	53.2~	20.0~	2.21~	1.68~	43.8~	69.4~
18	82.0~	46.0~	17.4~	3.50~	1.80~	43.0~	50.4~
19	68.0~	41.1~	11.7~	4.29~	1.78~	177~	45.6~
20	55.4~	36.7~	9.03~	4.75~	1.63~	75.1~	57.1~
21	49.4~	33.3~	7.46~	3.51~	2.50~	79.9~	50.1~
22	51.0~	31.1~	6.97~	176~	4.39~	282~	90.4~
23	46.1~	29.5~	6.02~	95.3~	2.28~	155~	194~
24	37.3~	27.8~	4.69~	44.5~	1.69~	118~	81.4~
25	32.9~	31.4~	3.36~	27.3~	1.49~	264~	56.6~
26	29.2~	27.2~	2.59~	18.6~	26.8~	142~	47.1~
27	25.9~	31.5~	2.30~	13.3~	37.7~	261~	42.9~
28	27.8~	49.8~	36.0~	10.7~	14.8~	105~	71.4~
29	31.5~	35.8~	24.5~	8.80~	7.95~	64.8~	202~
30	25.5~	28.2~	14.3~	7.10~	4.61~	54.6~	149~
31	22.2~		9.77~	8.84~		132~	
Mean	73.5~	74.5~	12.3~	17.2~	7.60~	78.5~	76.9~
Median	51.0~	37.1~	9.79~	7.12~	3.70~	53.0~	55.3~
Max.Daily Mean	215~	571~	36.0~	176~	37.7~	282~	235~
Min.Daily Mean	22.2~	26.4~	2.30~	1.43~	1.49~	1.40~	20.7~
Inst.Max	509~	1030~	66.4~	315~	100~	433~	451~
Inst.Min	20.9~	20.8~	1.85~	1.28~	1.40~	1.27~	19.5~
Missing Days	0	0	0	0	0	0	0

------------------ Notes -------------------
All recorded data is continuous and reliable
except where the following tags are used...
~ ... Provisional data

Appendix B

Average Daily Discharge Tables

Table B-1: N.F. Stillaguamish R. above Crevice Cr. (Site 1) Daily Discharge Averages (cfs).

Day	Jun	Jul	Aug	Sep	Oct
1	[]	29.8	13.8	30.9	12.7
2	[]	27.5	13.7	28.1	12.6
3	[]	25.8	13.7	22.0	12.4
4	[]	24.5	13.9	20.1	12.3
5	[]	22.9	13.4	18.5	12.2
6	[]	21.6	13.7	17.5	12.2
7	[]	20.7	13.5	16.9	12.3
8	76.2	19.7	13.0	16.1	12.8
9	94.6	19.1	12.7	15.4	13.1
10	78.5	18.4	12.5	14.9	19.6
11	165	17.6	12.4	14.5	58.8
12	201	17.0	12.3	14.1	77.1
13	154	16.5	12.3	13.9	69.1
14	121	16.0	12.2	13.6	110
15	101	16.0	12.2	13.5	56.6
16	88.4	17.3	12.2	13.3	42.1
17	78.3	17.2	12.1	13.2	73.8
18	69.9	17.9	12.1	13.1	[]
19	64.4	16.3	12.1	13.0	[]
20	61.2	15.5	12.1	12.8	[]
21	57.2	14.9	12.6	13.9	[]
22	52.5	14.9	306A	14.2	[]
23	47.3	14.6	254A	13.1	[]
24	43.2	14.2	110	12.7	[]
25	41.5	13.8	60.0	12.6	[]
26	37.4	13.5	41.8	15.0	[]
27	40.2	13.3	32.8	28.1	[]
28	46.9	29.2	27.9	14.9	[]
29	35.9	19.1	24.7	13.5	[]
30	32.0	15.4	22.4	13.0	[]
31		14.3	21.3		[]
Mean	77.7	18.5	37.7A	16.2	36.4
Median	64.4	17.2	13.5A	14.2	13.1
Max.Daily Mean	201	29.8	306A	30.9	110
Min.Daily Mean	32.0	13.3	12.1A	12.6	12.2
Inst.Max	225	58.0	552A	51.2	158
Inst.Min	30.4	13.2	12.1A	12.5	12.2
Missing Days	7	0	0	0	14

------------------ Notes -------------------
All recorded data is continuous and reliable
except where the following tags are used...
A ... Above Rating, reliable extrapolation
[ ] Data Not Recorded

Table B-2: S.F. Stillaguamish R. at Verlot (Site 2) Daily Discharge Averages (cfs).

Day	Jun	Jul	Aug	Sep	Oct
1	[]	704A	223	231	130
2	[]	638A	207	270	115
3	[]	613A	202	216	104
4	[]	622A	199	210	94.2
5	[]	584A	180	179	85.8
6	[]	497	168	163	84.8
7	[]	445	165	154	89.2
8	[]	428	162	143	142
9	[]	420	159	132	225
10	[]	415	152	123	277J
11	[]	389	146	116	988J
12	[]	350	138	109	1070J
13	[]	310	128	105	1180J
14	617A	281	124	102	1340J
15	593A	247	120	99.7	766A
16	583A	249	118	97.4	556A
17	586A	281	114	94.1	[]
18	589A	257*	106	90.0	[]
19	652A	214*	96.8	86.8	[]
20	763A	194*	88.4	82.4	[]
21	845A	192*	130	82.8	[]
22	877A	197*	1230J	81.3	[]
23	846A	202*	1260J	80.1	[]
24	791A	207*	653A	80.2	[]
25	867A	212*	430	80.5	[]
26	754A	212*	328	423A	[]
27	800A	211*	270	522A	[]
28	1290J	473*	235	255	[]
29	876A	591*	211	185	[]
30	753A	348*	193	152	[]
31		265*	186		[]
Mean	770J	363*	262J	158A	453J
Median	763J	310*	168J	119A	184J
Max.Daily Mean	1290J	704*	1260J	522A	1340J
Min.Daily Mean	583J	192*	88.4J	80.1A	84.8J
Inst.Max	1610J	804*	2170J	949A	1920J
Inst.Min	573J	190*	83.4J	79.0A	76.8J
Missing Days	13	0	0	0	15

------------------ Notes -------------------

All recorded data is continuous and reliable except where the following tags are used...

* ... Reliable Estimate
A ... Above Rating, reliable extrapolation
J ... Estimated Data
[ ] Data Not Recorded

Table B-3: S.F. Stillaguamish R. at River Meadows Park (Site 3) Daily Discharge Averages (cfs).

Day	Jun	Jul	Aug	Sep	Oct
1	[]	762	348	339	217
2	[]	684	309	494	195
3	[]	646	321	343	180
4	[]	677	329	338	170
5	[]	665	290	285	158
6	[]	538	270	262	152
7	993	475	268	249	162
8	985	462	251	236	192
9	1340A	466	237	220	316
10	1240	473	226	207	314
11	1710A	455	216	195	1610A
12	2770J	424	210	188	1800J
13	1810A	380	201	180	2670J
14	1290	355	196	174	3110J
15	1120	320	190	170	1510A
16	987	329	185	164	1010
17	899	421	184	160	[]
18	822	468	178	157	[]
19	825	381	169	154	[]
20	920	306	159	149	[]
21	987	285	168	150	[]
22	973	279	2570J	155	[]
23	881	271	4400J	145B	[]
24	727	264	1420A	140B	[]
25	951	258	836	138B	[]
26	780	245	573	422A	[]
27	759	234	446	1250A	[]
28	1590A	944A	378	439	[]
29	1060	1280A	330	290	[]
30	833	627	296	243	[]
31		425	284		[]
Mean	1130J	477A	531J	268A	860J
Median	986J	425A	270J	201A	265J
Max.Daily Mean	2770J	1280A	4400J	1250A	3110J
Min.Daily Mean	727J	234A	159J	138A	152J
Inst.Max	3220J	1880A	9510J	2110A	5010J
Inst.Min	675J	231A	153J	138A	149J
Missing Days	6	0	0	0	15

------------------ Notes -------------------
All recorded data is continuous and reliable
except where the following tags are used...
A ... Above Rating, reliable extrapolation
B ... Below rating, reliable extrapolation
J ... Estimated Data
[ ] Data Not Recorded

Table B-4: Deer Cr. at Oso (Site 4) Daily Discharge Averages (cfs).

Day	Jun	Jul	Aug	Sep	Oct	Day
1	[]	119	58.8	274J	59.1	1
2	[]	109	56.7	255A	53.4	2
3	[]	105	57.8	161	49.0	3
4	[]	106	64.5	143	45.2	4
5	[]	98.3	54.3	117	42.1	5
6	[]	86.9	75.9	103	42.0	6
7	[]	80.6	69.9	95.5	44.3	7
8	[]	77.1	54.6	85.0	56.8	8
9	[]	79.8	50.0	76.1	66.8	9
10	[]	83.0	47.0	69.1	111J	10
11	[]	78.0	43.4	63.5	407J	11
12	[]	71.4	41.8	59.3	664J	12
13	[]	68.0	39.8	55.5	534J	13
14	[]	64.6	38.1	52.7	764J	14
15	[]	61.0	36.9	50.3	387J	15
16	[]	65.6	35.9	48.0	305A	16
17	[]	76.8	35.9	46.1	339A	17
18	[]	92.3	34.8	45.1	[]	18
19	[]	78.7	33.8	44.6	[]	19
20	[]	64.2	32.3	42.8	[]	20
21	[]	57.2	43.8	46.0	[]	21
22	166	55.2	1240J	53.0	[]	22
23	147	54.7	942J	44.0	[]	23
24	128	53.8	477J	40.4	[]	24
25	153	50.2	278A	38.5	[]	25
26	133	47.3	197	172J	[]	26
27	139	44.1	153	287J	[]	27
28	265A	216A	126	121	[]	28
29	172	143	108	84.8	[]	29
30	134	86.5	95.7	68.5	[]	30
31		67.5	93.1		[]	31
Mean	160A	81.9A	152J	94.7J	234J	
Median	147A	77.1A	56.7J	66.0J	66.8J	
Max.Daily Mean	265A	216A	1240J	287J	764J	
Min.Daily Mean	128A	44.1A	32.3J	38.5J	42.0J	
Inst.Max	364A	480A	2150J	821J	1400J	
Inst.Min	117A	42.5A	31.5J	38.0J	40.6J	
Missing Days	21	0	0	0	14	

------------------ Notes -------------------
All recorded data is continuous and reliable
except where the following tags are used...
A ... Above Rating, reliable extrapolation
J ... Estimated Data
[ ] Data Not Recorded

Table B-5: Pilchuck Cr. at Bridge 626 (Site 5) Daily Discharge Averages (cfs).

Day	May	Jun	Jul	Aug	Sep	Oct	Nov
1	[]	92.3	[]	26.9	30.8	60.2	592
2	[]	412	[]	25.6	70.8	54.6	452
3	[]	522	[]	22.9	42.2	52.2	363
4	[]	253	[]	28.2	46.0	48.6	298
5	[]	182	[]	30.1	37.1	50.1	338
6	[]	192	[]	32.0	33.6	50.5	269
7	[]	181	[]	46.2	30.7	50.0	229
8	[]	137	[]	32.2	28.8	50.7	223
9	[]	200	[]	25.2	26.3	55.8	209
10	[]	228	[]	21.1	42.6	62.1	199
11	[]	[]	[]	18.0	50.2	224	195
12	[]	[]	[]	16.1	48.2	324	180
13	[]	[]	[]	13.0	45.4	399	192
14	[]	[]	[]	13.0	42.9	666	1740J
15	[]	[]	[]	11.6	40.8	331	[]
16	[]	[]	[]	9.75	37.6	221	[]
17	[]	[]	[]	9.87	36.5	252	[]
18	[]	[]	71.9	9.48	35.3	192	[]
19	[]	[]	51.7	10.4	34.1	1010A	[]
20	[]	[]	40.4	10.2	33.3	493	[]
21	[]	[]	29.0	11.2	33.1	329	[]
22	[]	[]	24.5	660A	36.5	1150A	[]
23	[]	[]	24.3	729A	35.7	1310A	[]
24	128	[]	22.8	267	31.2	762	[]
25	115	[]	20.4	151	29.5	1370A	[]
26	103	[]	17.9	93.9	37.9	700	[]
27	92.1	[]	15.0	67.7	235	1120A	[]
28	85.6	[]	63.9	54.2	116	622	[]
29	175	[]	86.3	44.9	84.2	416	[]
30	146	[]	48.7	36.1	69.1	347	[]
31	110		33.0	30.0		778A	
Mean	119	240	39.3	82.5A	50.1	437A	391J
Median	112	196	31.0	26.9A	37.4	329A	249J
Max.Daily Mean	175	522	86.3	729A	235	1370A	1740J
Min.Daily Mean	85.6	92.3	15.0	9.48A	26.3	48.6A	180J
Inst.Max	189	1030	181	1780A	363	1970A	3970J
Inst.Min	80.9	85.4	14.2	8.00A	21.6	46.5A	170J
Missing Days	23	20	17	0	0	0	16

------------------ Notes -------------------
All recorded data is continuous and reliable
except where the following tags are used...
A ... Above Rating, reliable extrapolation
J ... Estimated Data
[ ] Data Not Recorded

Appendix C

Discussion of Diurnal Stage Pattern at Site 2: S.F. Stillaguamish River at Verlot

During one distinct five-day time period of the study period (August 8-12), a diurnal cycle in stage readings was encountered at Site 2: S.F. Stillaguamish R. at Verlot. During these days, river stage reached a minimum around 6:00 a.m. and peaked around 6:00 p.m. This cycle was closely correlated with the diurnal water temperature cycle (Figure C-1), with r^2 values for individual days ranging from 0.68 to 0.84 (Figure C-2). The diurnal fluctuations in discharge ranged from 35 to 40 cfs.

To further analyze this pattern, data for this station were compared with a downstream station; S.F. Stillaguamish R. at River Meadows Park (Site 3). During most of the study period, streamflow data collected from Site 3 closely follows that collected from Site 2, with a time-of-travel delay of approximately 8 hours during low-flow conditions. Data for the two sites were compared during two periods of apparent diurnal cycles: July 5-11, 2001 and August 8-12, 2001. During the first period (July 5-11), the rise and fall cycles in stage at Site 2 are followed by a corresponding rise and fall in stage at Site 3 (Figure C-3). However, during the second period (August 8-12), there is no corresponding cyclical rise and fall in stage at Site 3 following the diurnal rise and fall cycles in stage at Site 2 (Figure C-4). This leads the author to believe that the apparent diurnal cycle at Site 2 during August 8-12 was actually sensor error, most likely caused by the formation of an air pocket near the diaphragm of the pressure transducer. Such a scenario would result in a temperature-related diurnal cycle in pressure readings caused by thermal expansion and contraction of the air pocket. The heavy bedload present in the water column may have facilitated the dissipation of the air pocket after a short period of time, thus resuming a normal pattern in river stage.

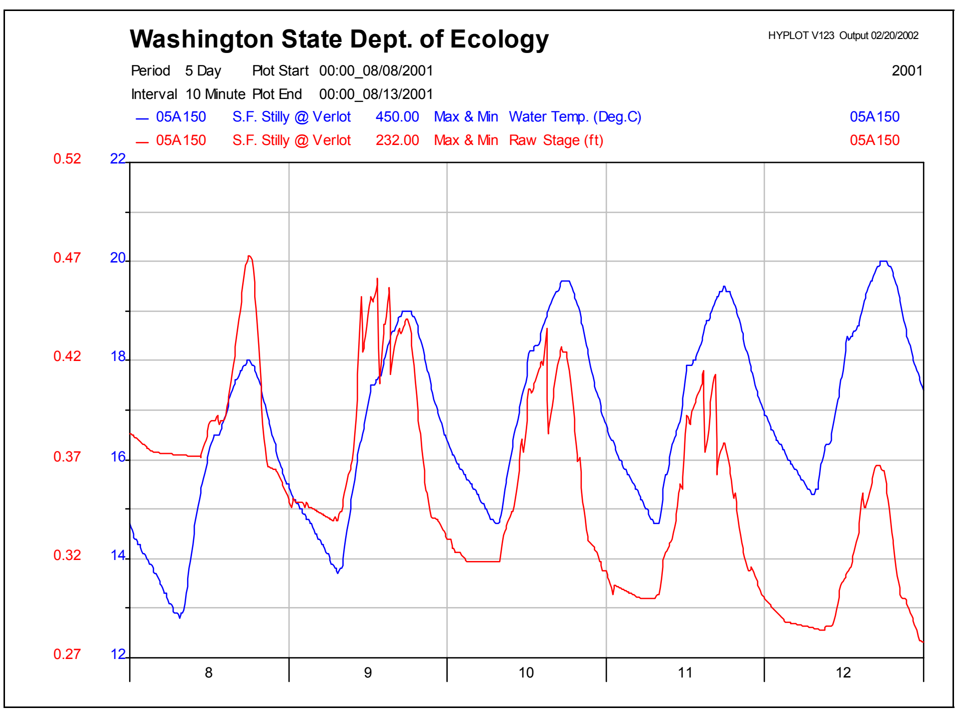

Figure C-1: Diurnal water stage and temperature cycles during August 8-12, 2001.

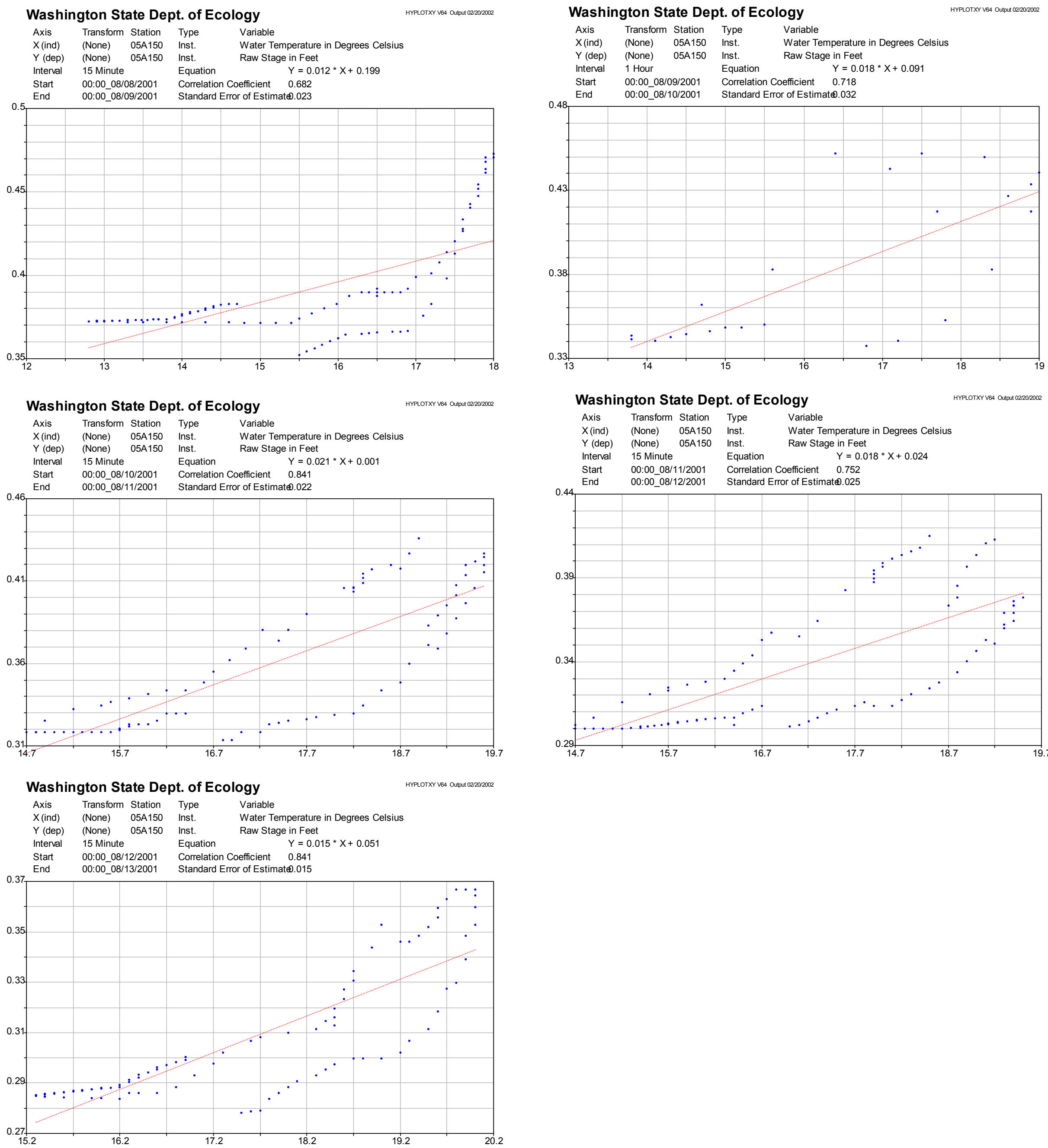

Figure C-2: Water stage versus temperature regressions for Site 2 - August 8-12, 2001.

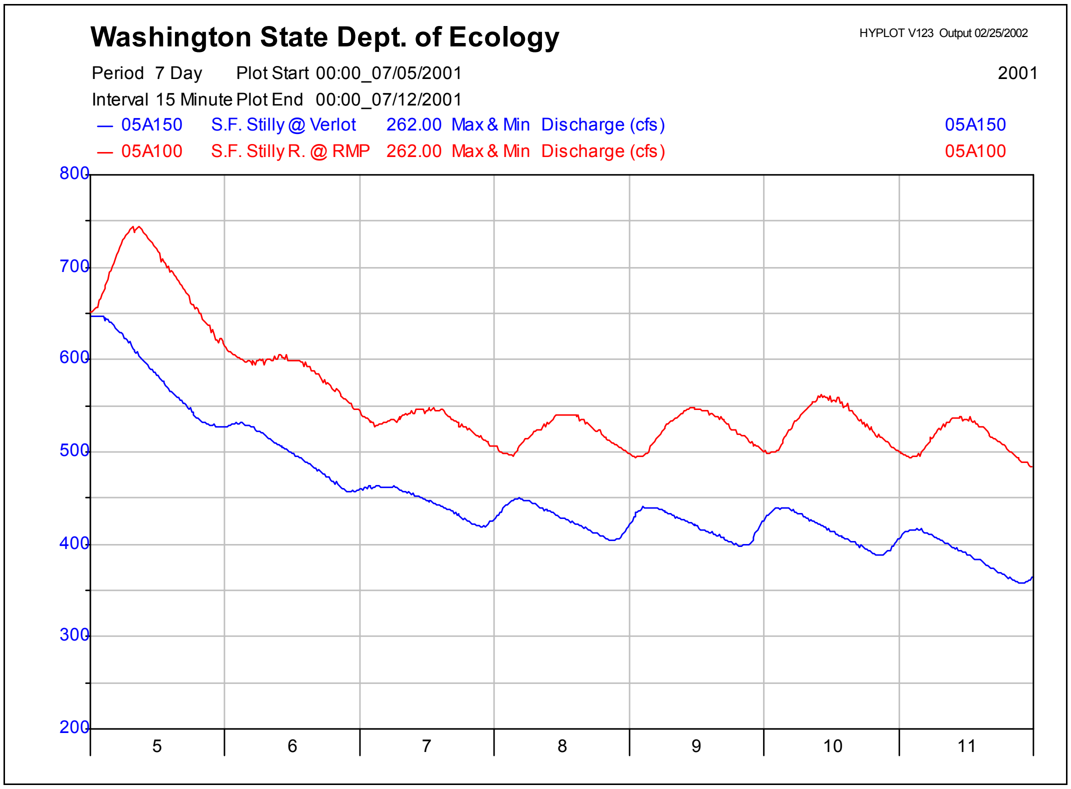

Figure C-3: Comparison of Sites 2 and 3 during seven days in July, 2001.

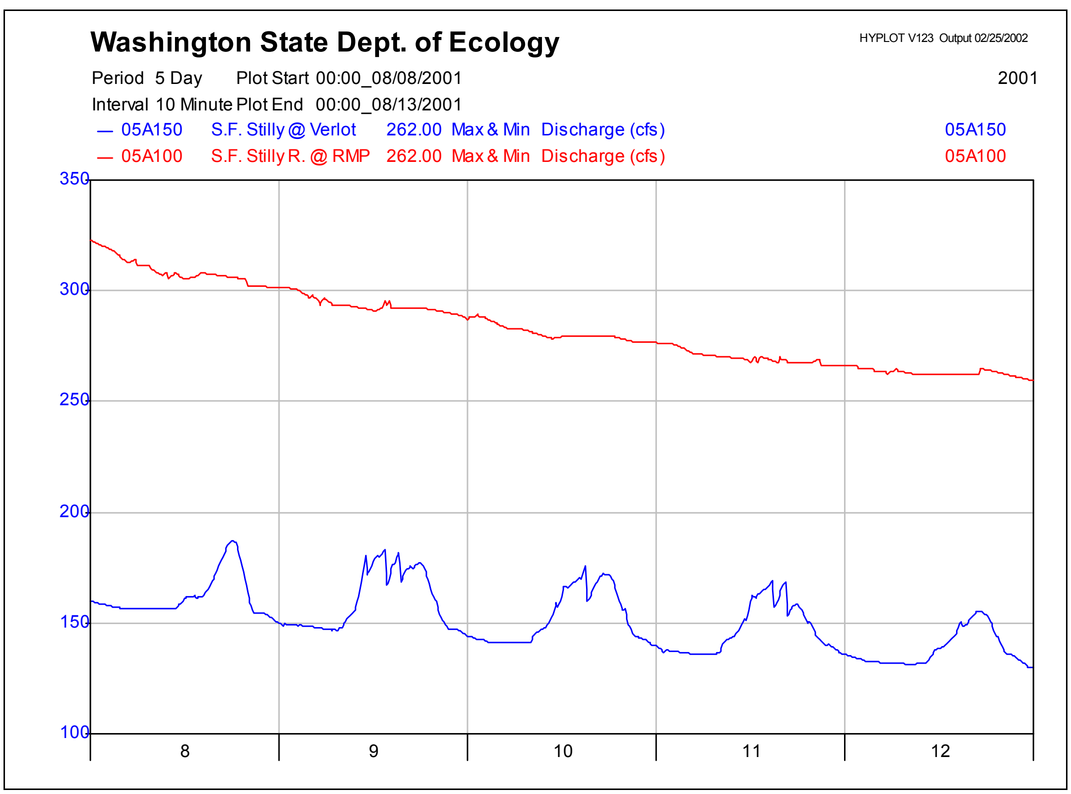

Figure C-4: Comparison of Sites 2 and 3 during five days in August, 2001.