Streamflow Summary for Gaging Stations on the Snoqualmie River and Selected Tributaries, 2006

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Cover photo: Snoqualmie River near Monroe, WA.

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Abstract

From June to October 2006, the Washington State Department of Ecology (Ecology) conducted a streamflow assessment on the Snoqualmie River and its major tributaries.

This monitoring was conducted in support of a temperature Total Maximum Daily Load (TMDL) study. The purpose of the TMDL study was to (1) characterize summer stream temperature conditions in the Snoqualmie River basin, and (2) establish the heat loading capacity as well as load and wasteload allocations for heat sources in the watershed. These allocations will be set in order for the Snoqualmie River to meet Washington State water quality standards.

The TMDL study was initiated because of federal Clean Water Act 303(d) listings of three reaches of the Snoqualmie River which are water quality impaired for temperature.

A continuous stage height (water surface elevation) recorder was installed at one site, Snoqualmie River near Monroe, and individual discharge measurements were taken to model a continuous record of discharge.

Discrete stage height readings and discharge measurements were taken at four additional sites: Tolt River near Carnation, Raging River at Fall City, North Fork Snoqualmie River near Ellisville, and Middle Fork Snoqualmie River near Ellisville. Each of these four sites was located downstream of a U.S. Geological Survey (USGS) stream gaging station. A continuous record of discharge for each of these sites was modeled using comparative analysis with the respective USGS data sets.

Potential error of streamflow data collected from the five Ecology monitoring sites ranged from ±8% to ±27%.

Introduction

From June to October 2006, the Environmental Assessment (EA) Program of the Washington State Department of Ecology (Ecology) conducted a streamflow assessment on the Snoqualmie River and its major tributaries.

This monitoring was conducted in support of a temperature Total Maximum Daily Load (TMDL) study developed by the EA Program. The purpose of the TMDL study was to (1) characterize summer stream temperature conditions in the Snoqualmie River basin, and (2) establish heat loading capacity as well as load and wasteload allocations for heat sources in the watershed. These allocations will be set in order for the Snoqualmie River to meet Washington State water quality standards (Kardouni and Cristea, 2006).

The TMDL study was initiated because of federal Clean Water Act 303(d) listings of three reaches of the Snoqualmie River which are water quality impaired for temperature (Kardouni and Cristea, 2006).

Sampling Sites

The Snoqualmie and Skykomish Rivers converge to form the Snohomish River in the city of Monroe. The Snoqualmie River flows north from the confluence of its three forks near the town of North Bend to its confluence with the Skykomish River. The Snoqualmie River basin covers an area of 700 square miles.

The upper watershed, comprised of the three forks, is predominantly private and public timber land. The headwaters of the North and Middle Fork Snoqualmie River are within the Alpine Lakes Wilderness Area. Both forks flow generally west from the Wilderness area to North Bend. The headwaters of the South Fork Snoqualmie River are on Snoqualmie Pass, and the river flows west along the Interstate-90 corridor to North Bend. From North Bend downstream, the land use in the watershed is predominantly residential and agricultural, with forestry uses in the upper watersheds of many of the tributaries.

For this streamflow study, Ecology established a continuous stage height recorder near the mouth of the mainstem Snoqualmie River (Figure 1, Site 1). The intent of this site was to characterize the total contribution of the Snoqualmie River and its tributaries to the Snohomish River.

Discharge rating curves were established and instantaneous stage height readings were taken at four additional sites. Each of the four sites were located downstream of established continuous monitoring sites operated by the United States Geological Survey (USGS). Data from these USGS sites were used to estimates continuous records of discharge at each of the instantaneous sites operated by Ecology:

- Tolt River near Carnation (Site 2): The Tolt River gage was located 0.6 river miles upstream of the confluence with the Snoqualmie River, near the State Route 203 bridge. The intent of this gage was to characterize the total discharge of the Tolt River. The Tolt River near Carnation USGS gage (USGS No. 12148500) (Site 6) is located 8.1 river miles upstream of Site 2.
- Raging River at Fall City (Site 3): The Raging River gage was located in the town of Fall City 0.5 river miles upstream of the confluence with the mainstem Snoqualmie River, at the Preston-Fall City Road bridge. The intent of this gage was to characterize the total discharge of the Raging River. The Raging River near Fall City USGS gage (USGS No. 12145500) (Site 7) is located 2.3 river miles upstream of Site 3.
- North Fork Snoqualmie River near Ellisville (Site 4): The N.F. Snoqualmie River gage was located 0.3 river miles upstream of the confluence with the Middle Fork Snoqualmie River, at the 428th Ave. bridge. The intent of this gage was to characterize the total discharge of the N.F. Snoqualmie River. The N.F. Snoqualmie River near Snoqualmie Falls USGS gage (USGS No. 12142000) (Site 8) is located 8.9 river miles upstream of Site 4.
- Middle Fork Snoqualmie River near Ellisville (Site 5): The M.F. Snoqualmie River gage was located 0.4 river miles upstream of the confluence with the North Fork Snoqualmie River, at the 428th Ave. bridge. The intent of this gage was to characterize the total discharge of the M.F. Snoqualmie River. The M.F. Snoqualmie River near Tanner USGS gage (USGS No. 12141300) (Site 9) is located 10.3 river miles upstream of Site 5.

Average daily discharges from the USGS gaging stations are presented in Appendix A.

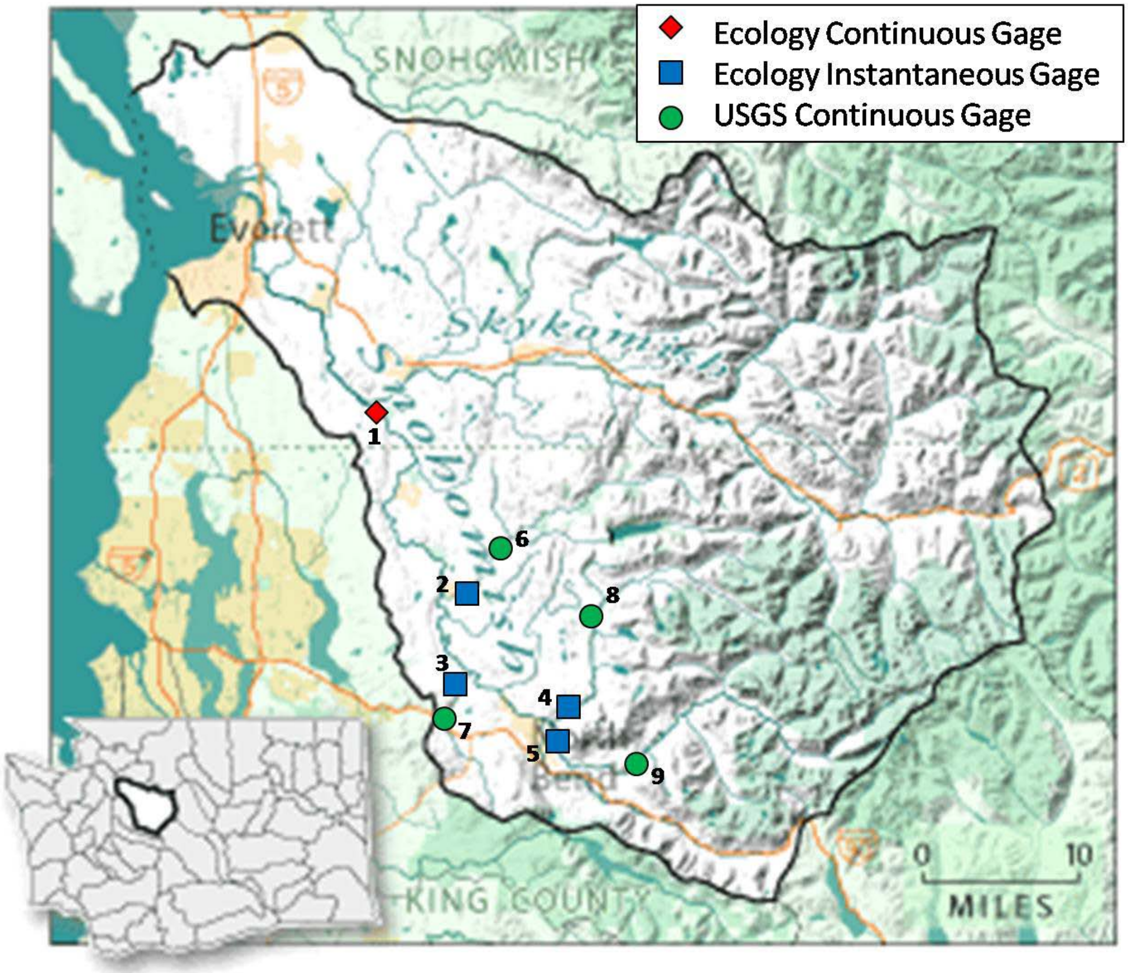

Figure 1: Map of Snoqualmie River basin study sites.

Table 1. Snoqualmie River basin gage sites.

Ecology Site	Gage Name	Ecology Number	RM	Nearby USGS gage used
Site 1	Snoq R near Monroe	07D050	2.7	NA
Site 2	Tolt R near Carnation	07G070	0.6	Site 6, 12148500, RM 8.7
Site 3	Raging R at Fall City	07Q070	0.5	Site 7, 12145500, RM 2.8
Site 4	N.F. Snoq near Ellisville	07N070	0.3	Site 8, 12142000, RM 9.2
Site 5	M.F. Snoq near Ellisville	07D150	0.4	Site 9, 12141300, RM 10.7

Methods

The continuous gaging station (Site 1) was equipped with a pressure transducer and datalogger that recorded water surface elevation (stage height) and water temperature at 15-minute intervals from June to October 2006.

At each of the five sites monitored by Ecology for this study, three to ten discharge measurements were taken to establish a discharge rating curve, which models the relationship between stage and discharge. These rating curves were then used to calculate the average daily discharge for each site.

Discharge Measurements

Discharge measurements at the five sites monitored by Ecology were taken using one of two methods: mechanical current meters or acoustic Doppler current profilers (ADCP).

Discharge measurements that were taken using mechanical current meters were made following the USGS mid-section method (Rantz et al., 1982a, 1982b). Ecology has made minor modifications to the USGS method to accommodate its measurement equipment (Butkus, 2005). The flow measurement cross-sections were established by driving re-bar into opposing banks such that the cross-sections were perpendicular to the streamflow at each site. 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 10% of the total discharge passed through any single cell. The width of the individual cells varied in keeping with the 10% discharge criteria.

Velocity measurements were taken at 60% of the stream depth when the total stream depth was less than 1.5 feet, and at 20% and 80% of the stream depth when the depth was greater than 1.5 feet. 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 using the USGS mid-section method with a specialized discharge calculation software program developed by Ecology (Butkus, 2005).

Many of the discharge measurements taken for this study were made using an ADCP mounted on a durable plastic trimaran vessel. ADCPs use Doppler technology to determine a continuous profile of depth and velocity across the river channel. Four to eight measurements are made by towing or walking the ADCP vessel across the chosen transect, which must be between one and 15 feet deep and have moderate velocities (less than six feet per second). The results of these transects are then averaged (Shedd, Springer, and Clishe, 2008). The continuous profiling capability of ADCPs make them an extremely accurate instrument for measuring discharge, since water column velocities and cross-sectional areas are measured more thoroughly than can be done using mechanical current meters. ADCP measurements were used for this study whenever stream conditions permitted.

Stage Height Records

A submersible pressure transducer was installed to continuously monitor stage height at Site 1. A primary gage index (PGI) was also installed at each of the five sites. The PGI is a readable device, such as a staff gage, wire weight gage, or reference point on an over-passing bridge. The stage heights observed from the PGI are used to develop the rating curve, and to calibrate the datalogger at sites where continuous data are collected. The datalogger at Site 1 was calibrated to the PGI at the time of installation and was subsequently recalibrated as necessary.

Pressure transducers are inherently prone to drift, with the degree varying from instrument to instrument. Drift is essentially a migration of the instrument from its original calibration, and materializes as a difference between observed and logged stage height values. This instrument drift results in erroneous stage height values that, when applied to the discharge rating curve for a station, produce erroneous discharge values. These erroneous stage height values are typically corrected by applying time-weighted adjustments to the continuous data set, which pivot on the stage height values observed on the PGI by field staff.

The adjusted stage height values are then applied to the discharge rating curve for the site, yielding a more accurate record of discharge. The time-weighted adjustments are based on the assumption that instrument drift occurs gradually and evenly over time, which under conditions such as sedimentation and biofouling is generally true (Freeman et al., 2004).

Error Assessments

Error estimates were calculated for each site for the two primary sources of error: pressure transducer drift and the discharge rating curve. The error estimates were calculated for each site for the June-October 2006 study period.

Error introduced by pressure transducer drift was quantified using the following calculation:

$$\frac{1}{n}\sum_{1}^{n}\left(\frac{\left|Q_{rec}-Q_{obs}\right|}{Q_{obs}}\right)$$

where

Q_{rec} is the corresponding discharge for the recorded stage values.

Q_{obs} is the corresponding discharge for the observed stage height values.

Error in the discharge rating curve is quantified using the following calculation:

$$\frac{1}{n}\sum_{1}^{n}\left(\frac{\left|Q_{pred}-Q_{adj}\right|}{Q_{pred}}\right)$$

where

Q_{pred} is the discharge predicted by the rating curve.

Q_{adj} is the measured discharge plus or minus the maximum potential error, based on the professional quality rating of each discharge measurement.

Error due to pressure transducer drift and error inherent in the discharge rating curve are mutually exclusive sources of error, and are thus treated as additive.

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Quality Assurance

Quality assurance measures were taken during this study to address (1) error inherent in the instream discharge measurements, and (2) error in stage height record produced by the datalogger at Site 1.

Discharge Measurements

Because the largest potential source of error in a discharge measurement is in the velocity measurement, site selection and equipment calibration are of high importance. In this study, the measured cross-sections were qualitatively rated from excellent to poor, based on physical conditions encountered during each measurement.

- An *excellent* cross-section, which lies in a straight channel segment with laminar flow and fairly fine-grained substrate, assumes an error of up to 2%.
- A *good* cross-section, which generally lies in a straight channel segment with predominantly laminar flow and courser-grained substrate, assumes an error of up to 5%.
- A *fair* cross-section, which may contain sections of angular flow, turbulence, or near-bank eddies, assumes an error of up to 8%.
- A *poor* cross-section, which lies in proximity to bends in the stream channel with predominantly turbulent flow and cobble or boulder substrate, assumes an error of over 8%.

Depending on the selected cross-section, a minimum of the assigned error is assumed and carried forward to the final discharge calculation and rating curve development.

An additional source of error in velocity measurements is the calibration of the Swoffer instruments. The ideal calibration setting of a Swoffer propeller is 186, which means that for every 186 revolutions of the propeller, 10 lineal feet of water has passed the measurement point. The Swoffer meters tend to be temperature sensitive, and the calibration setting of a meter can change over the course of a discharge measurement. The calibration settings for Swoffer meters used during this project were checked before and after each discharge measurement, with values ranging from 185 to 187. A calibration value of 185 overestimates the discharge measurement by 0.5%. Similarly, a calibration value of 187 underestimates the discharge measurement by 0.5%.

After a discharge rating curve was established for each site, discharge measurements were tracked by comparing the measured discharge values to the discharge values predicted by the rating curve at the same stage. The combination of propeller variations, turbulent flow conditions at high flows, and high bottom roughness at low flows contributed to the measured and predicted discharge differences for individual flow measurements ranging from 3.9% to 52.8%. This range of differences between measured and predicted discharge demonstrates the ability of the rating curves to predict stream discharge at each site.

Stage Height Records

Based on manufacturer specifications, the theoretical precision of the 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 to 15 pounds per square inch (psi), or 0 to 34.6 feet (Fletcher, 1994).

During the study period, the accuracy of pressure transducer at Site 1 was addressed by using depth to water surface, or "tape down" readings, versus pressure transducer regressions. The correlation coefficient (r) values for the regression of raw pressure transducer readings against the final data set, which had been adjusted to the discrete observed stage height values, had a value of 0.99. This correlation provides an indication of the severity of pressure transducer drift (discussed above in the *Methods* section) at Site 1.

Results

Results for the five Ecology sites are as follows:

Site 1: Snoqualmie River near Monroe

The average daily discharge for Site 1 ranged from 541 cubic feet per second (cfs) in late September to 7,720 cfs in early June. Peak flow during the study was 8,110 cfs during snowmelt in early June (Figure 2). Daily discharge averages are presented in Appendix B, Table B-1. The measured range of discharge for this site encompassed only 62% of the range of discharge encountered, with flow measurements ranging from 616 to 5,330 cfs (Figure 3). Those flows that exceeded the measured range occurred 20% of the time. 15% of flows were less than the lowest measured flow, and 5% of flows were higher than the highest measured flow (Figure 4). The discharge measurements taken at this station are listed in Appendix C, Table C-1.

Within the measured range of flows, the fit of the rating curve was very good. All four discharge measurements taken at Site 1 were within 5% of the flow predicted by the rating curve.

Time-weighted adjustments were performed on the continuous data to correct for pressure transducer drift. A linear regression of pre- versus post-adjusted continuous discharge data showed a correlation coefficient (r) of 0.99 and a standard error of 218 cfs (13% of the mean flow for the study). This regression indicates moderate pressure transducer drift at this site (Figure 5). Most of the drift occurred during a distinct period from mid-September to mid-October. Stage height data during this period were discarded, and data from USGS station 12149000 Snoqualmie River near Carnation, which is located 20.3 river miles upstream, were used to estimate stage height for Site 1. The discharge rating curve for Site 1 was then applied to these estimated stage height data to produce an estimated continuous discharge record.

Overall, the potential error for discharge data for this site is estimated to be ±14%. Of this, 6% of the error is from the continuous stage data, and 8% is from the rating curve.

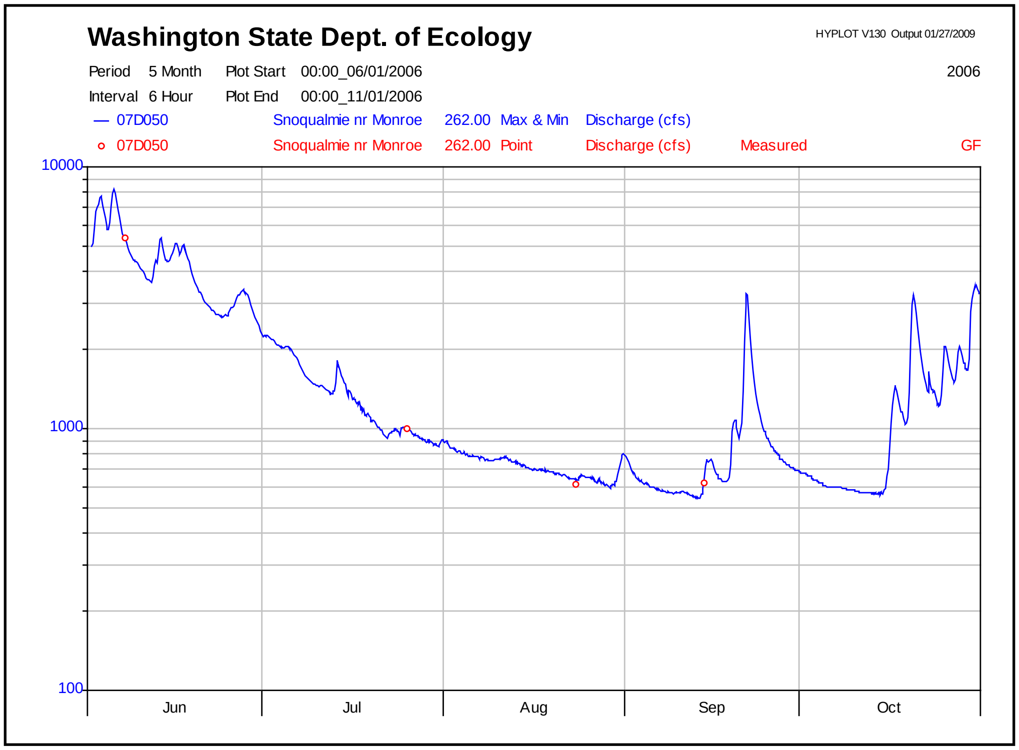

Figure 2: Discharge hydrograph for Site 1.

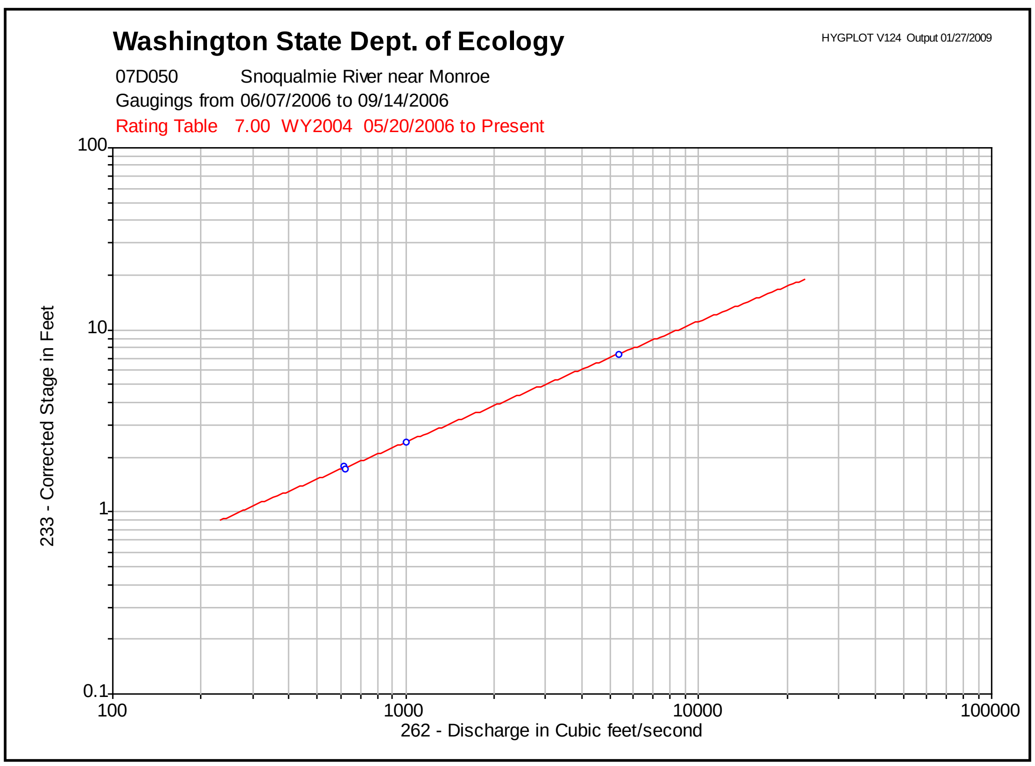

Figure 3: Discharge rating curve for Site 1.

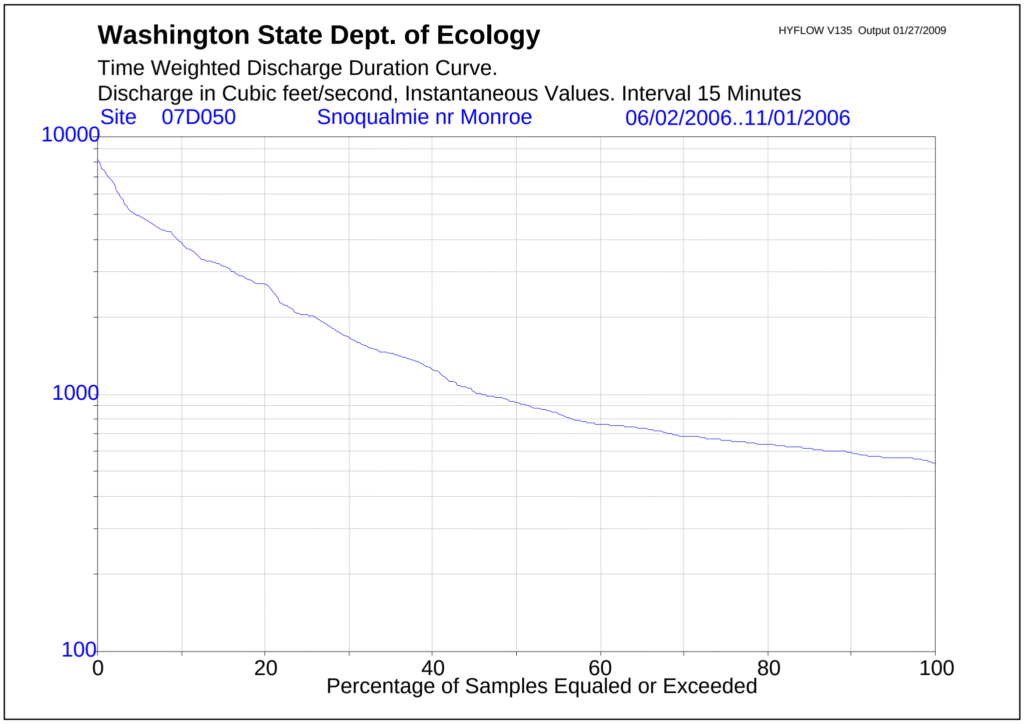

Figure 4. Discharge exceedance graph for Site 1.

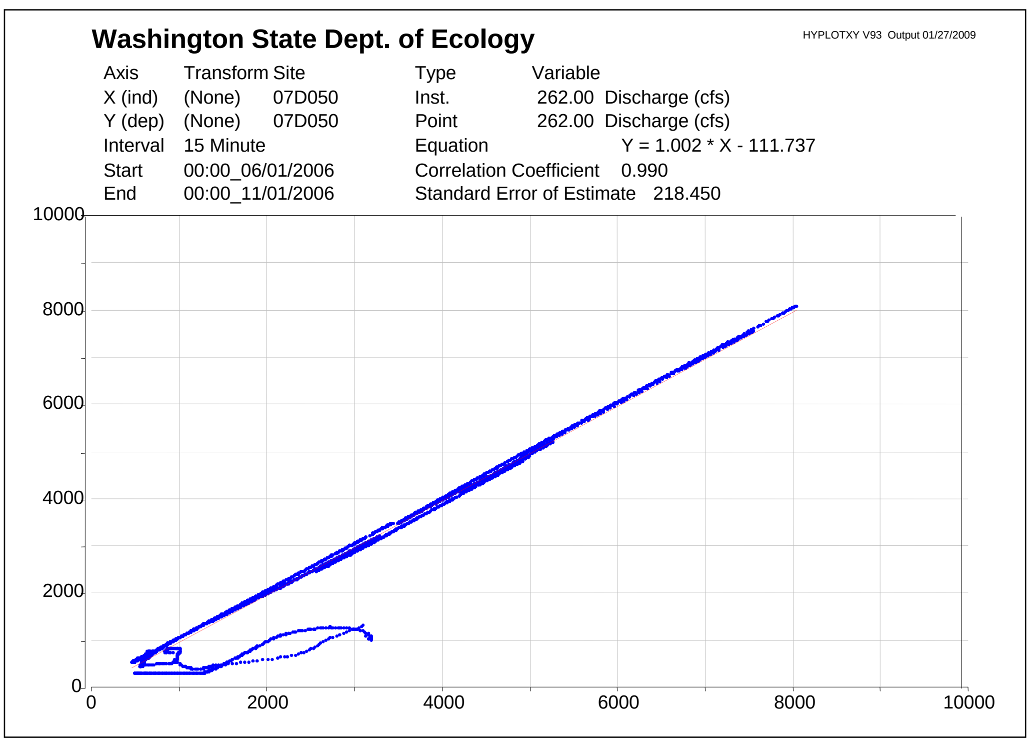

Figure 5: Linear regression of pre- versus post-adjusted discharge data for Site 1. Deviations from the regression line indicate pressure transducer drift.

Site 2: Tolt River near Carnation

Continuous data were not collected at Site 2. Instead, continuous data from a USGS gage located 8.1 river miles upstream (12148500 - Tolt R. near Carnation, Site 6) was used to estimate a continuous record of discharge for Site 2. To do this, a discharge rating curve was developed for Site 2 based on the relationship between stage and discharge at the site. The measured discharges at Site 2 were then regressed against discharges at Site 6 to produce a linear equation ($y = 1.247x - 36.138$, $r^2 = 0.996$) by which Site 6 discharges could be transformed to estimate Site 2 discharges (Figure 6). The resulting continuous discharge record was an excellent match with the discrete discharge measurements that had been taken at Site 2, so no additional adjustments were necessary. The analyses below are based on this estimated continuous discharge record.

The average daily discharge for Site 2 ranged from 97.1 cfs in mid-September to 990 cfs in late September. Peak flow during the study was 1,460 cfs during a storm event in late September (Figure 7). Daily discharge averages are presented in Appendix B, Table B-2. The measured range of discharge for this site encompassed only 6% of the range of discharge encountered, with flow measurements ranging from 108 to 190 cfs (Figure 8). Those flows that exceeded the measured range occurred 55% of the time. 5% of flows were less than the lowest measured flow, and 50% of flows were higher than the highest measured flow (Figure 9). Due to safety considerations, this station was only measurable under very low flow conditions. The discharge measurements taken at this station are listed in Appendix C, Table C-2.

Within the measured range of flows, the fit of the rating curve was excellent. All three discharge measurements taken at Site 2 were within 1% of the flow predicted by the rating curve.

Overall, the potential error for discharge data for this site is estimated to be ±16%. Of this, 10% of the error is from the continuous stage data, and 6% is from the rating curve.

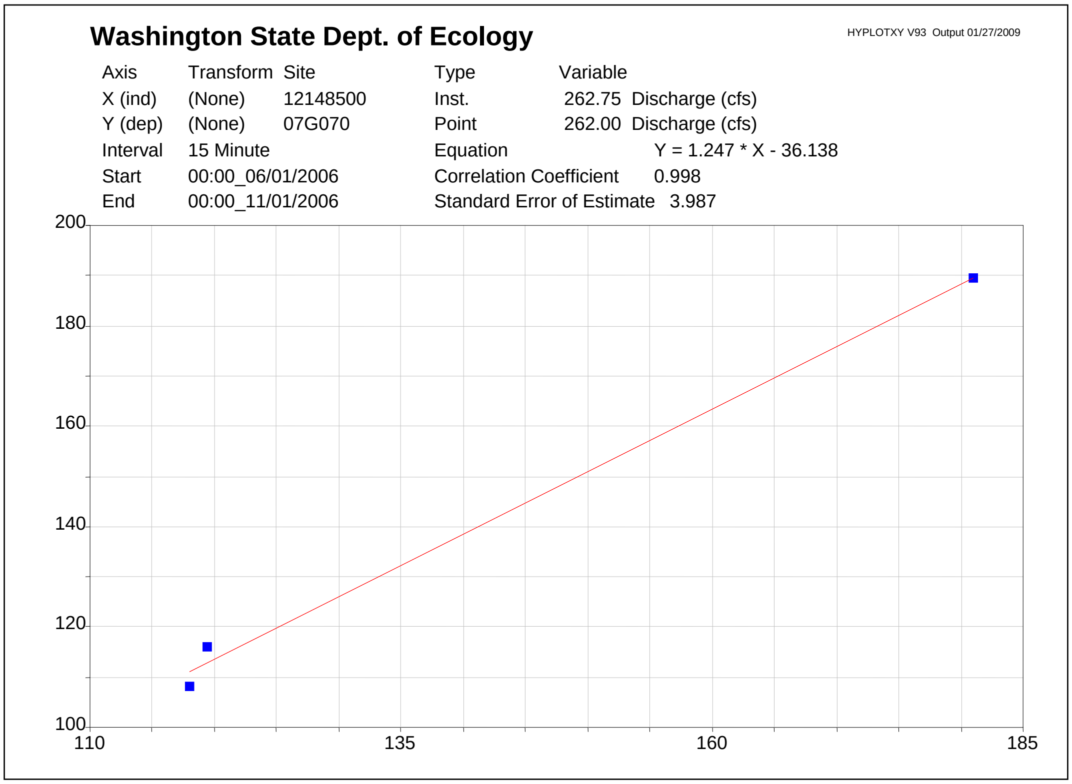

Figure 6: Linear regression of discharges for Site 2 versus Site 6.

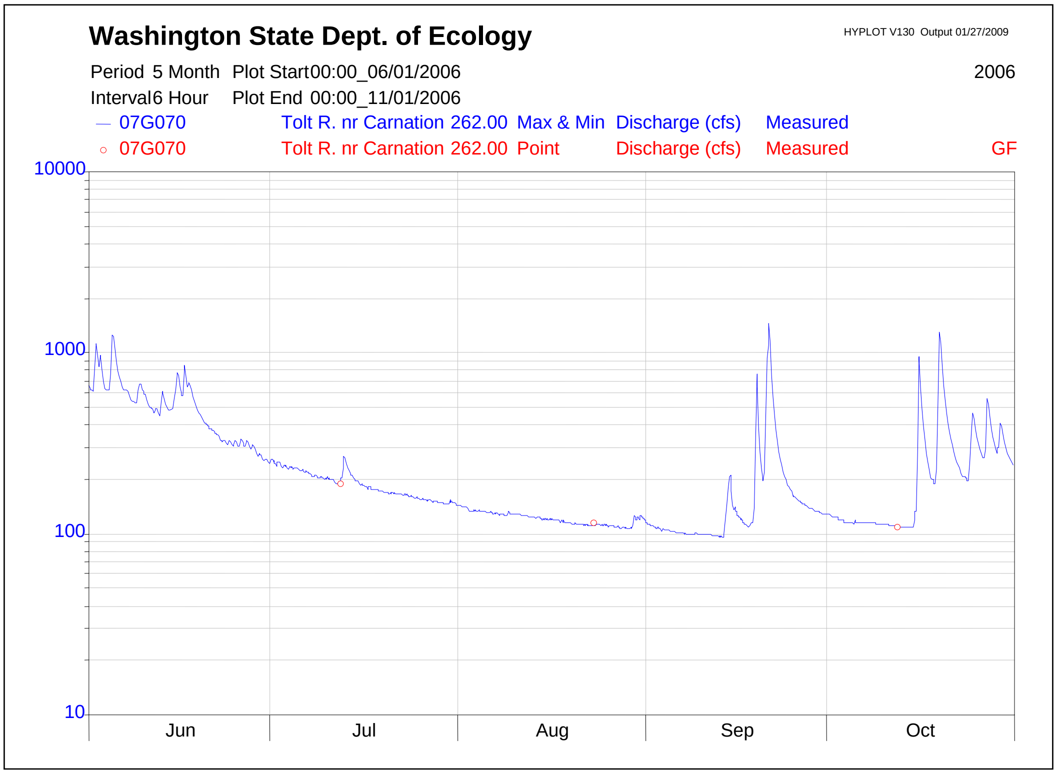

Figure 7: Discharge hydrograph for Site 2.

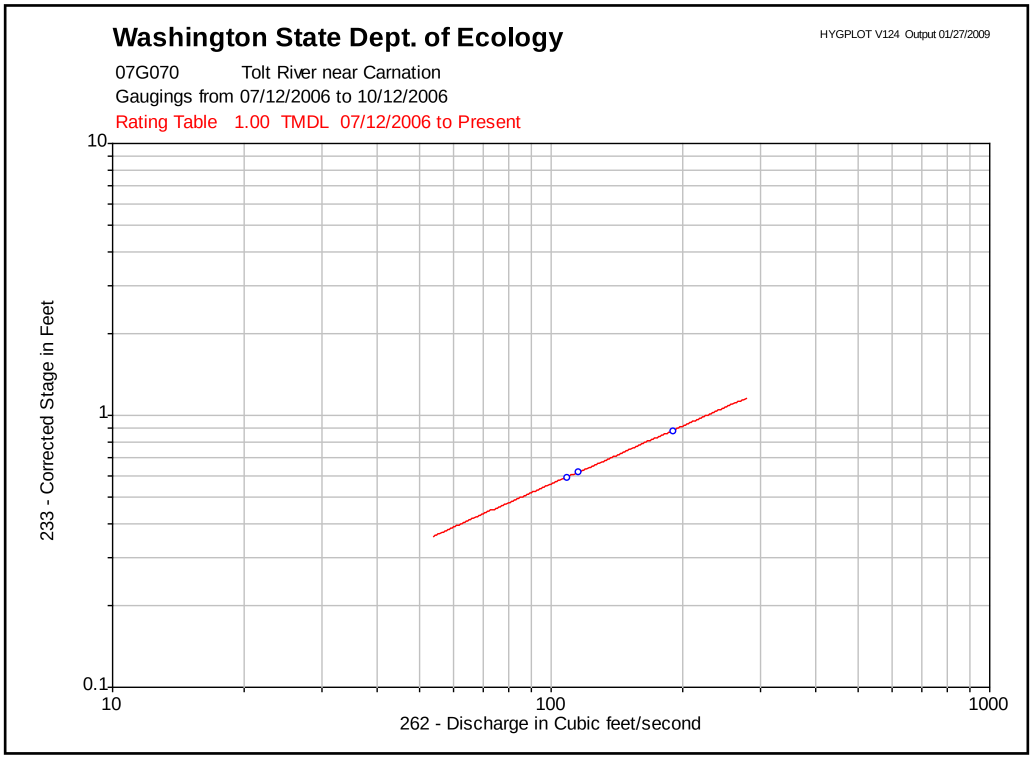

Figure 8: Discharge rating curve for Site 2.

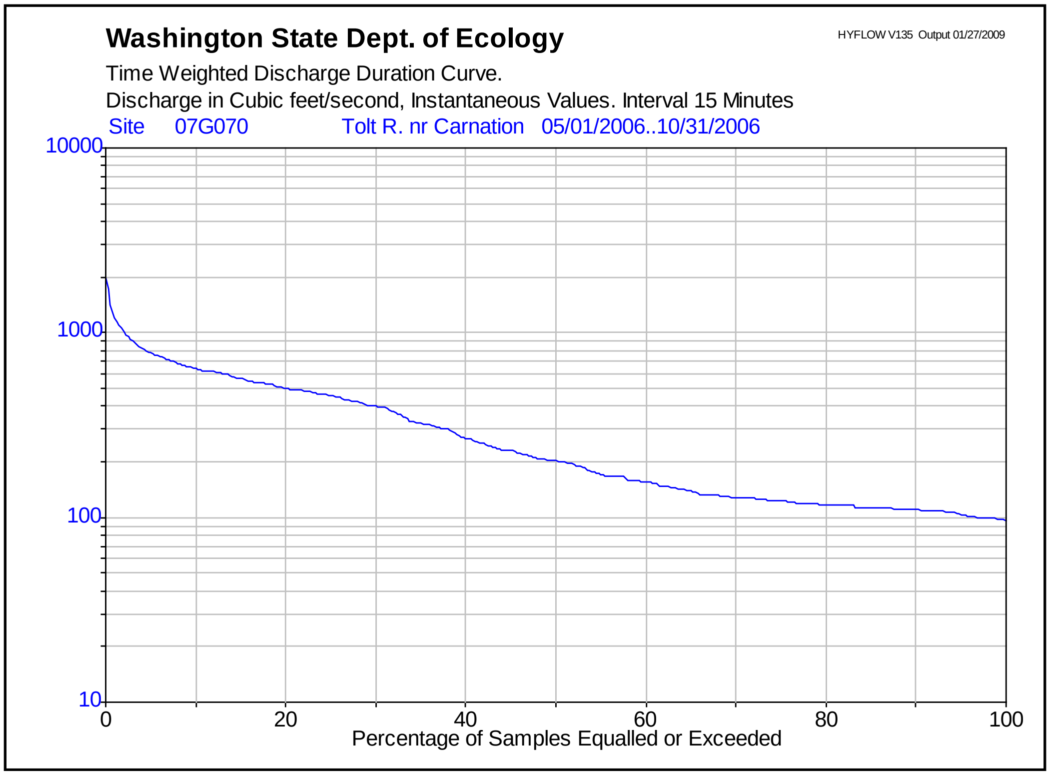

Figure 9: Discharge exceedance graph for Site 2.

Site 3: Raging River at Fall City

Continuous data were not collected at Site 3. Instead, continuous data from a USGS gage located 2.3 river miles upstream (12145500 - Raging R. near Fall City, Site 7) was used to estimate a continuous record of discharge for Site 3. To do this, a discharge rating curve was developed for Site 3 based on the relationship between stage and discharge at the site. The measured discharges at Site 3 were then regressed against discharges at Site 7 to produce a linear equation ($y = 0.918x + 2.866$, $r^2 = 0.992$) by which Site 7 discharges could be transformed to estimate Site 3 discharges (Figure 10). The resulting continuous discharge record was further adjusted to the discrete discharge measurements taken at Site 3 using time-weighted adjustments. The analyses below are based on this estimated continuous discharge record.

The average daily discharge for Site 3 ranged from 8.9 cfs in late August to 164 cfs in early June. Peak flow during the study was 191 cfs during snowmelt in early June (Figure 11). Daily discharge averages are presented in Appendix B, Table B-3. The measured range of discharge for this site encompassed only 60% of the range of discharge encountered, with flow measurements ranging from 9.8 to 117 cfs (Figure 12). Those flows that exceeded the measured range occurred 15% of the time. 10% of flows were less than the lowest measured flow, and 5% of flows were higher than the highest measured flow (Figure 13). The discharge measurements taken at this station are listed in Appendix C, Table C-3.

Within the measured range of flows, the fit of the rating curve was poor. Eight of the ten discharge measurements taken at Site 3 were used to develop the rating curve. Six of these measurements were within 5% of the discharge predicted by the rating curve. The other two measurements had discharges that were more than 10% different from the discharge predicted by the rating curve. Two of the discharge measurements were excluded from the rating curve development. These measurements, taken in mid-August and mid-September, respectively, had much higher discharges than surrounding measurements. These two measurements were also contradictory to the continuous discharge record at Site 7.

Overall, the potential error for discharge data for this site is estimated to be ±27%. Of this, 12% of the error is from the continuous stage data, and 15% is from the rating curve.

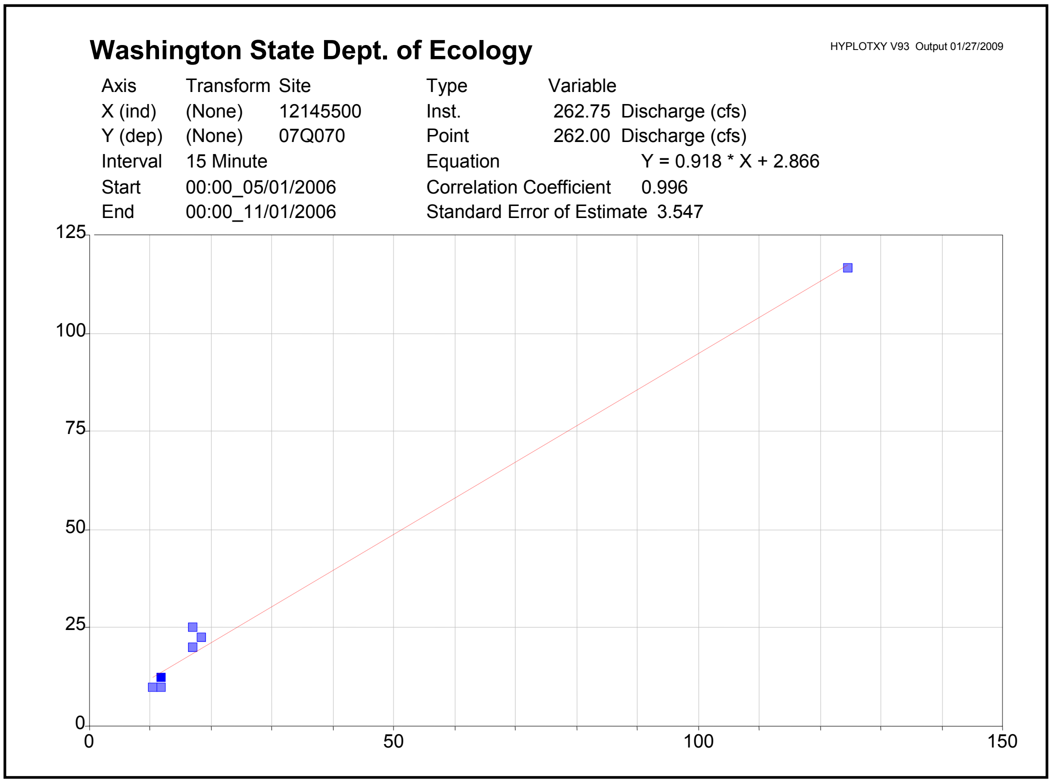

Figure 10: Linear regression of discharges for Site 3 versus Site 7.

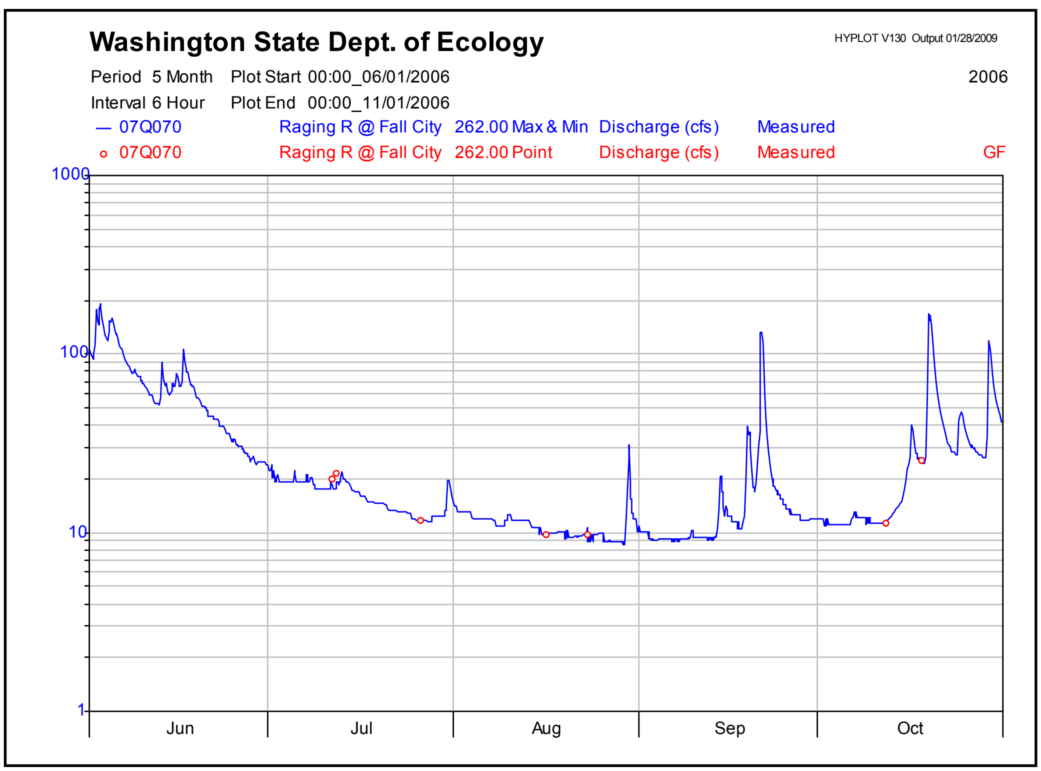

Figure 11: Discharge hydrograph for Site 3.

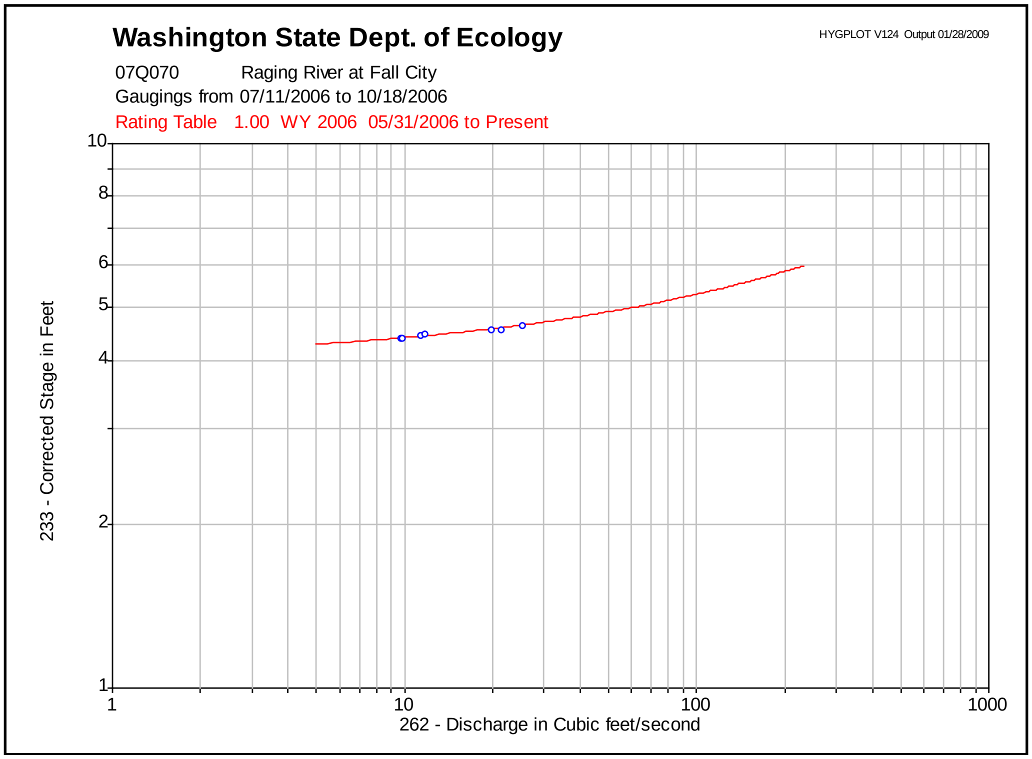

Figure 12: Discharge rating curve for Site 3.

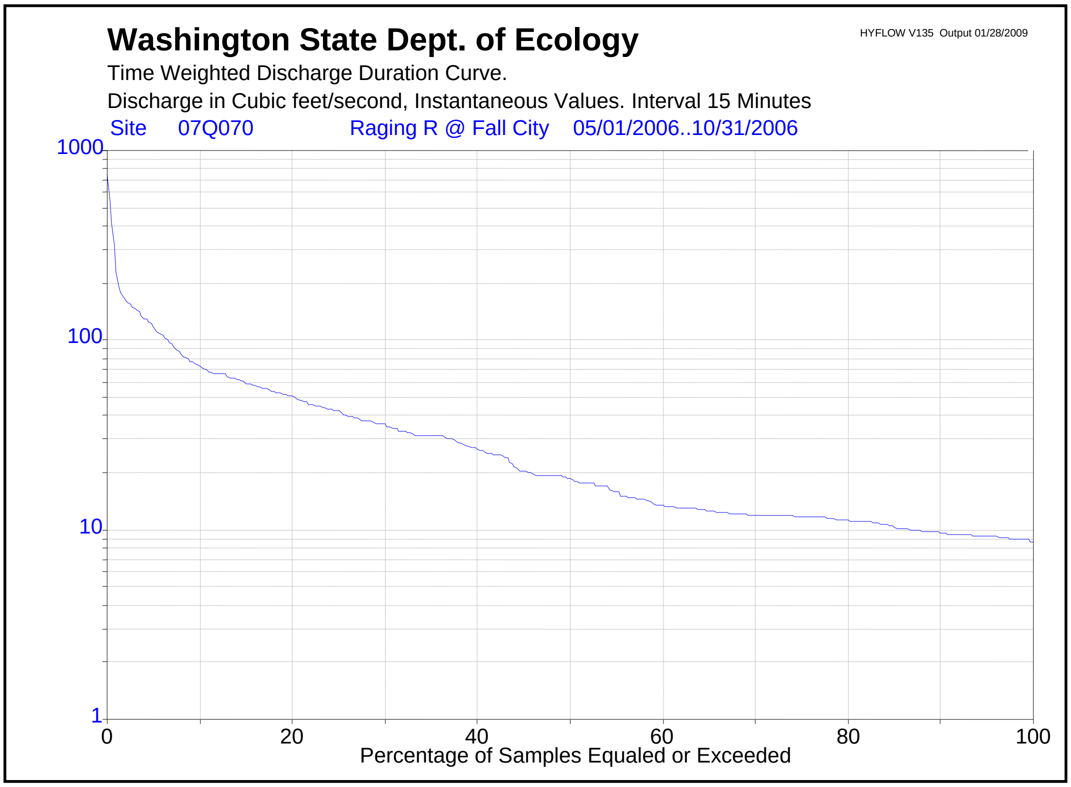

Figure 13: Discharge exceedance graph for Site 3.

Site 4: North Fork Snoqualmie River near Ellisville

Continuous data were not collected at Site 4. Instead, continuous data from a USGS gage located 8.9 river miles upstream (12142000 - N.F. Snoqualmie R. near Snoqualmie Falls, Site 8) was used to estimate a continuous record of discharge for Site 4. To do this, a discharge rating curve was developed for Site 4 based on the relationship between stage and discharge at the site. The measured discharges at Site 4 were then regressed against discharges at Site 8 to produce a linear equation ($y = 1.35x + 2.051$, $r^2 = 0.998$) by which Site 8 discharges could be transformed to estimate Site 4 discharges (Figure 14). The resulting continuous discharge record was further adjusted to the discrete discharge measurements taken at Site 4 using time-weighted adjustments. The analyses below are based on this estimated continuous discharge record.

The average daily discharge for Site 4 ranged from 54.4 cfs in mid-September to 1,720 cfs in early June. Peak flow during the study was 2,300 cfs during snowmelt in early June (Figure 15). Daily discharge averages are presented in Appendix B, Table B-4. The measured range of discharge for this site encompassed only 45% of the range of discharge encountered, with flow measurements ranging from 67.6 to 1,010 cfs (Figure 16). Those flows that exceeded the measured range occurred 24% of the time. 11% of flows were less than the lowest measured flow, and 13% of flows were higher than the highest measured flow (Figure 17). The discharge measurements taken at this station are listed in Appendix C, Table C-4.

Within the measured range of flows, the fit of the rating curve was poor. Seven of the eight discharge measurements taken at Site 4 were used to develop the rating curve. Five of these measurements were within 5% of the discharge predicted by the rating curve. The other two measurements had discharges that were more than 10% different from the discharge predicted by the rating curve. One of the discharge measurements was excluded from the rating curve development. This measurement, taken in mid-September, had a much higher discharge than surrounding measurements. This measurement was also contradictory to the continuous discharge record at Site 8.

Overall, the potential error for discharge data for this site is estimated to be ±20%. Of this, 3% of the error is from the continuous stage data, and 17% is from the rating curve.

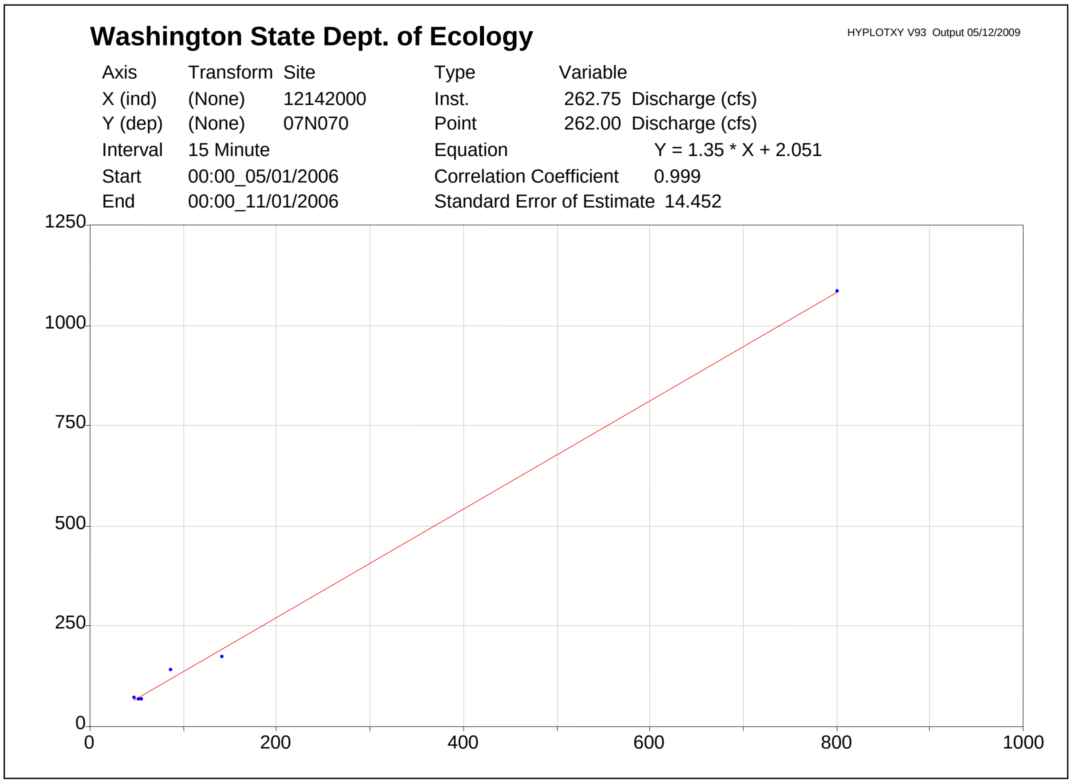

Figure 14: Linear regression of discharges for Site 4 versus Site 8.

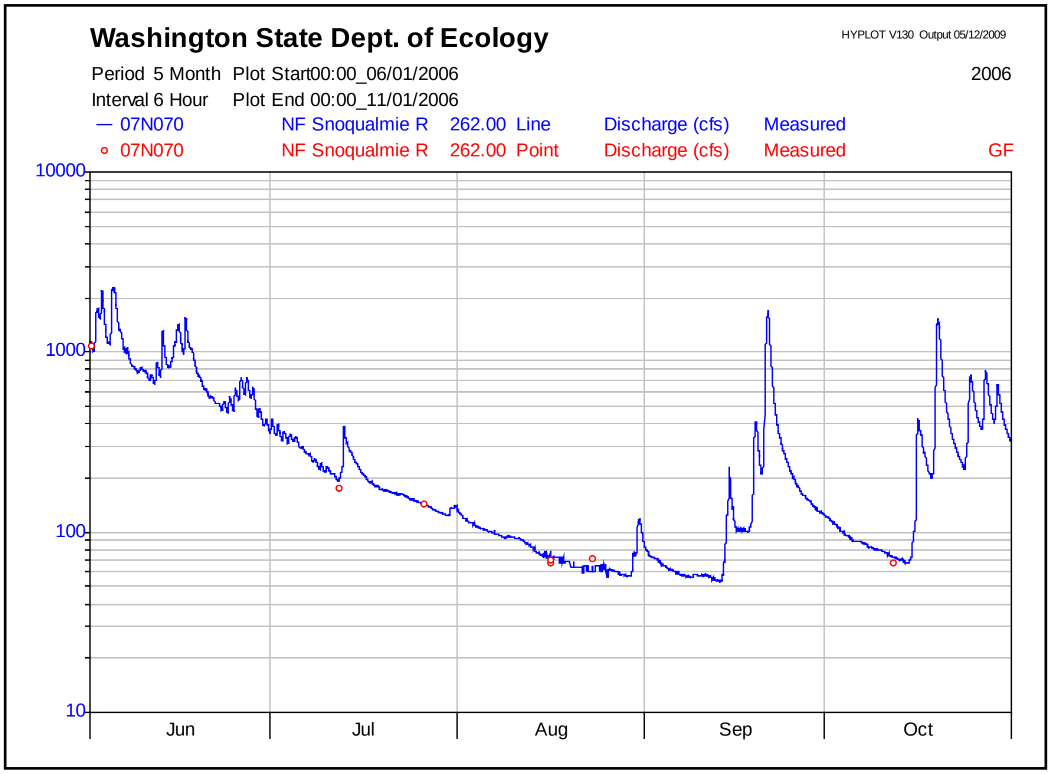

Figure 15: Discharge hydrograph for Site 4.

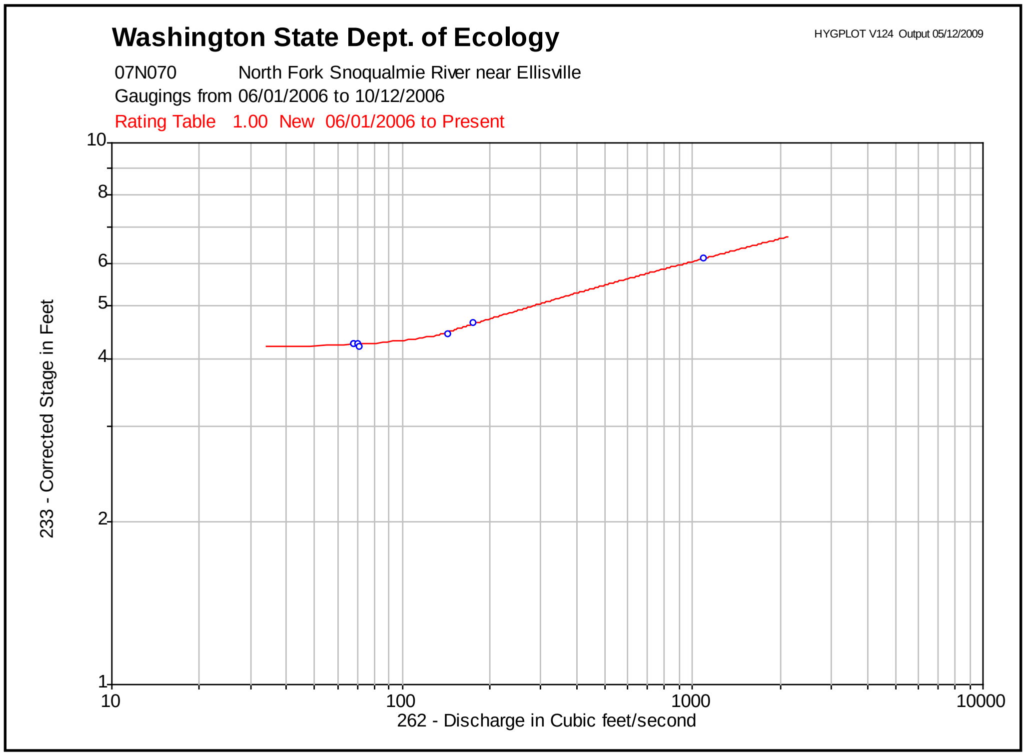

Figure 16: Discharge rating curve for Site 4.

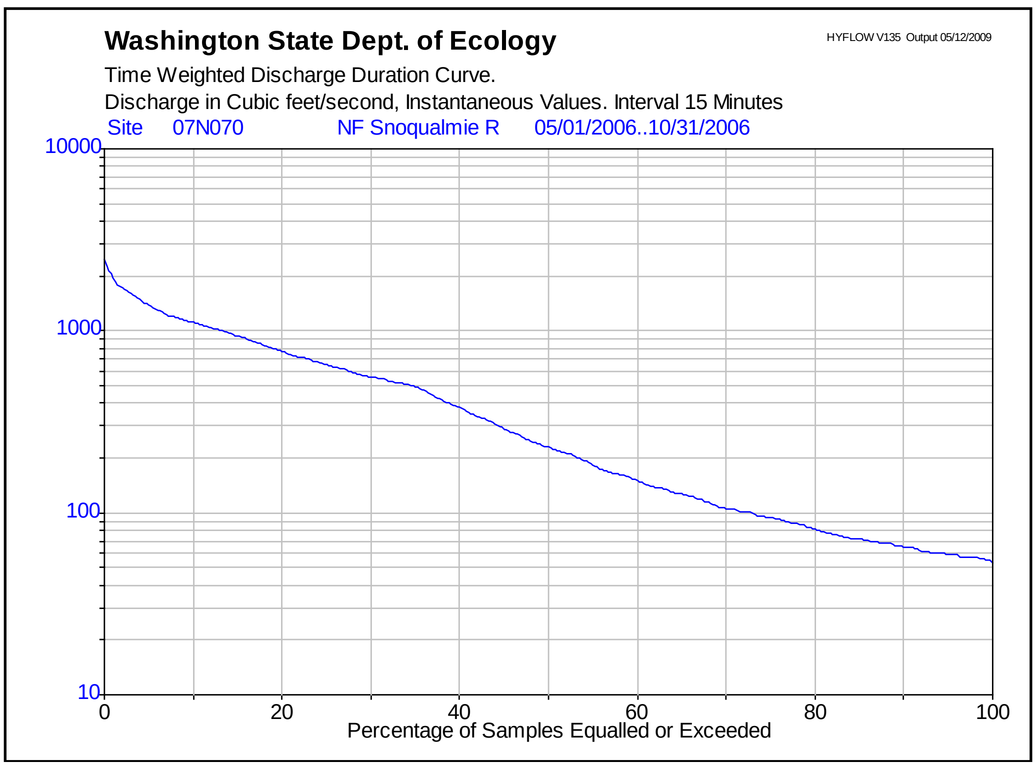

Figure 17: Discharge exceedance graph for Site 4.

Site 5: Middle Fork Snoqualmie River near Ellisville

Continuous data were not collected at Site 5. Instead, continuous data from a USGS gage located 10.3 river miles upstream (12141300- M.F. Snoqualmie R. near Tanner, Site 9) was used to estimate a continuous record of discharge for Site 5. To do this, a discharge rating curve was developed for Site 5 based on the relationship between stage and discharge at the site. The measured discharges at Site 5 were then regressed against discharges at Site 9 to produce a linear equation ($y = 1.003x - 0.169$, $r^2 = 1.0$) by which Site 9 discharges could be transformed to estimate Site 5 discharges (Figure 18). The resulting continuous discharge record was further adjusted to the discrete discharge measurements taken at Site 5 using time-weighted adjustments. The analyses below are based on this estimated continuous discharge record.

The average daily discharge for Site 5 ranged from 131 cfs in mid-October to 3,320 cfs in early June. Peak flow during the study was 4,040 cfs during snowmelt in early June (Figure 19). Daily discharge averages are presented in Appendix B, Table B-5. The measured range of discharge for this site encompassed only 42% of the range of discharge encountered, with flow measurements ranging from 142 to 1,800 cfs (Figure 20). Those flows that exceeded the measured range occurred 20% of the time. 5% of flows were less than the lowest measured flow, and 15% of flows were higher than the highest measured flow (Figure 21). The discharge measurements taken at this station are listed in Appendix C, Table C-5.

Within the measured range of flows, the fit of the rating curve was fair. Four of the five measurements were within 5% of the discharge predicted by the rating curve, and all five were within 8%.

Overall, the potential error for discharge data for this site is estimated to be ±8%. Of this, 1% of the error is from the continuous stage data, and 7% is from the rating curve.

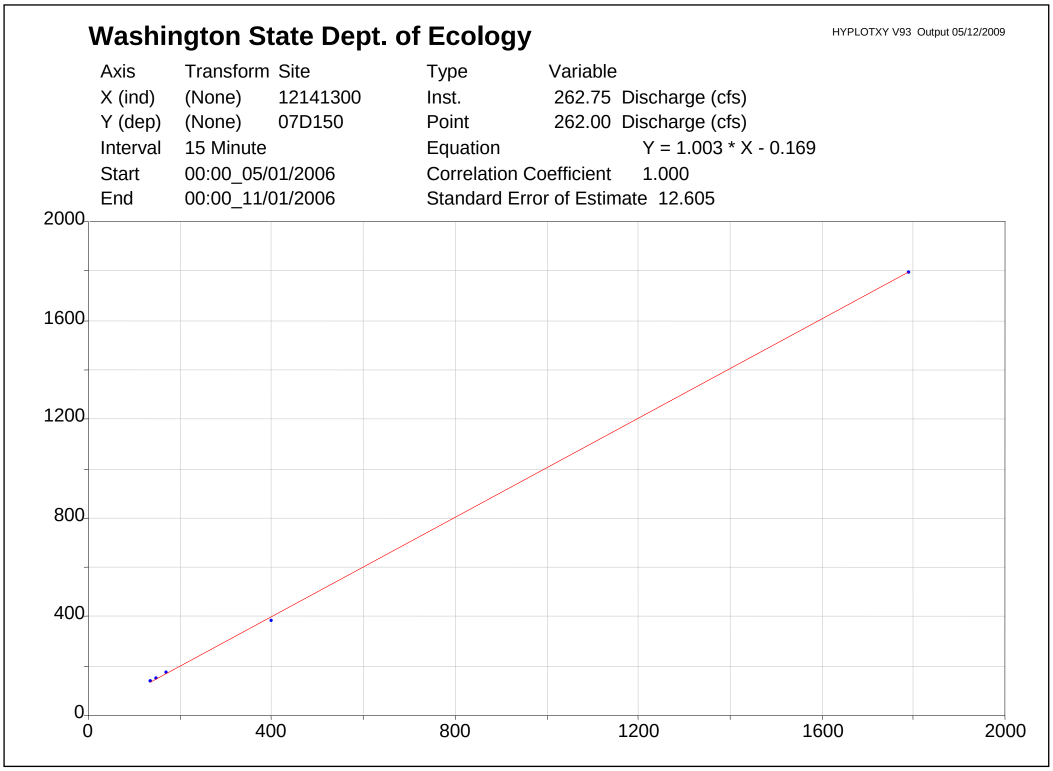

Figure 18: Linear regression of discharges for Site 5 versus Site 9.

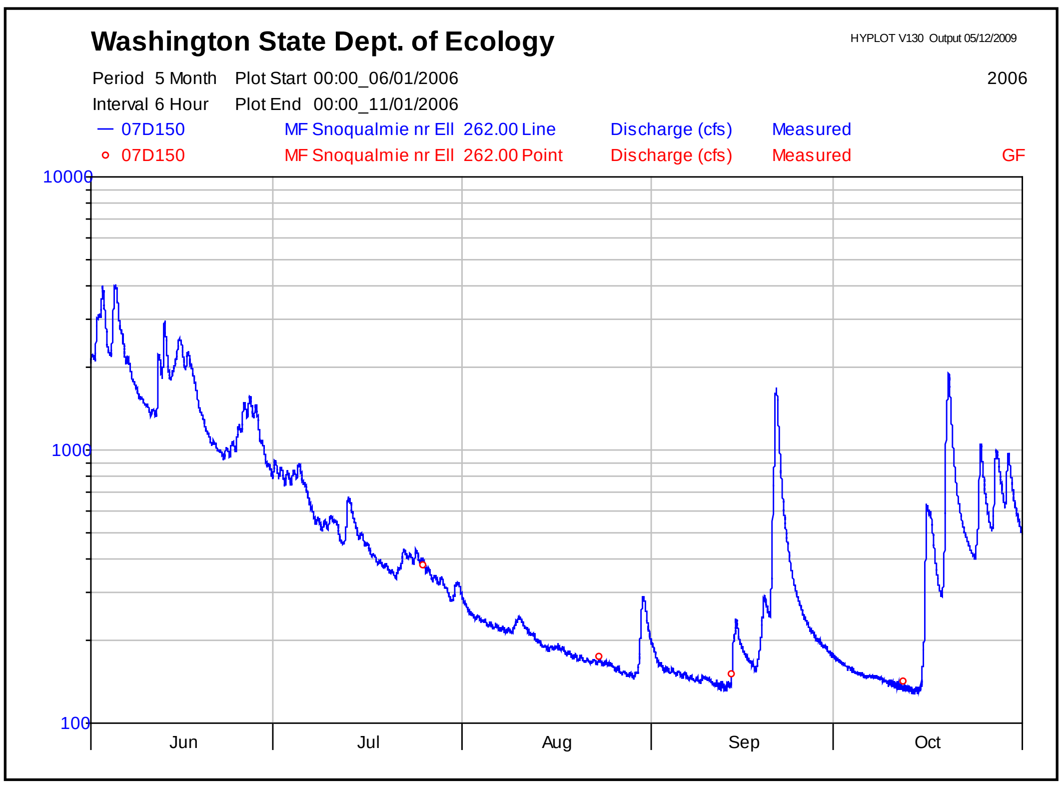

Figure 19: Discharge hydrograph for Site 5.

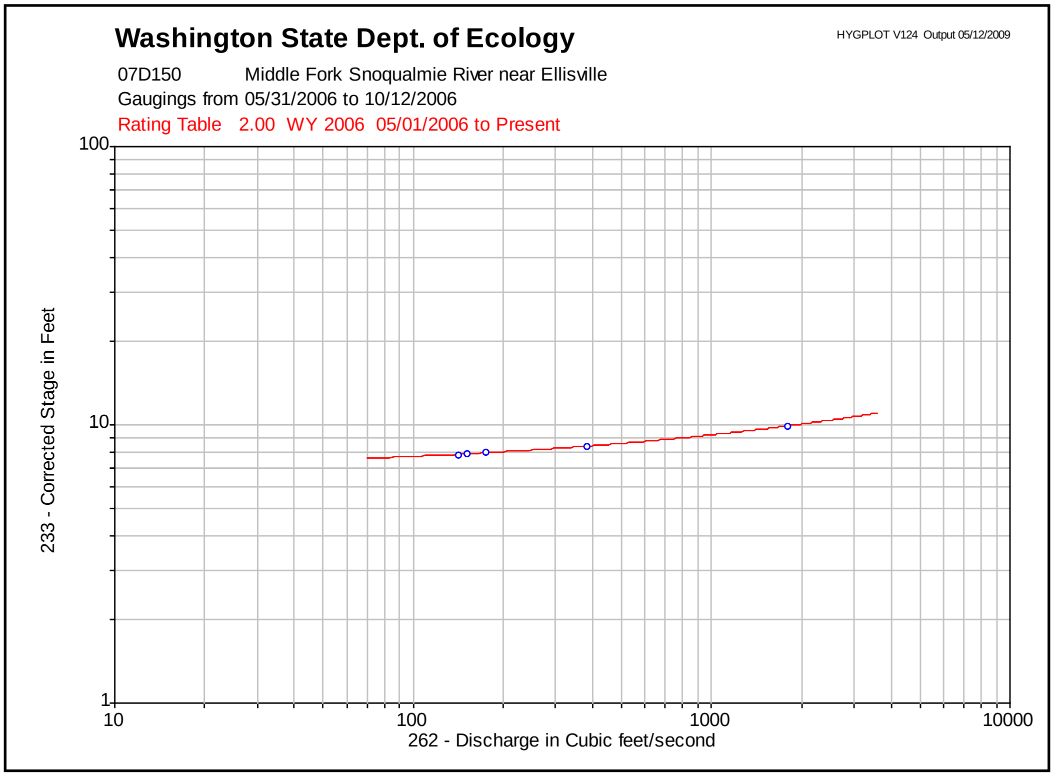

Figure 20: Discharge rating curve for Site 5.

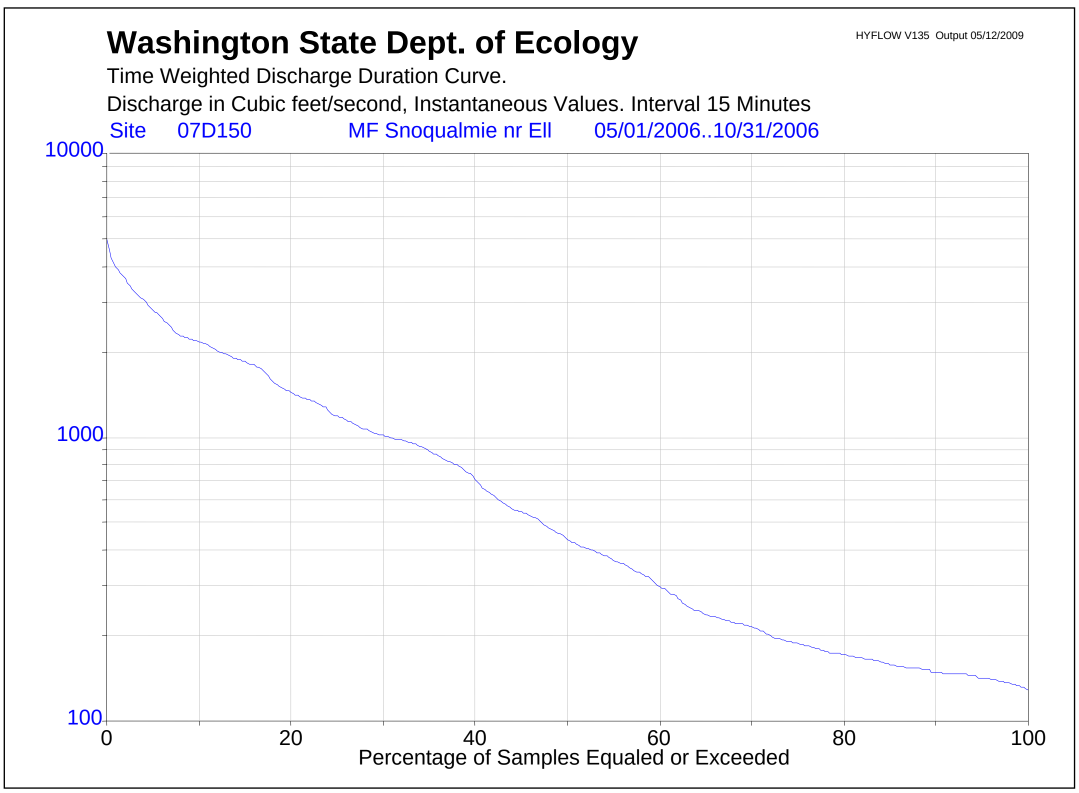

Figure 21: Discharge exceedance graph for Site 5.

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Appendices

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Appendix A. 2006 Average Daily Discharges for USGS Gaging Stations

Table A-1: Site 6, Tolt River near Carnation.

Day	Jun	Jul	Aug	Sep	Oct
1	546R	229R	143R	120R	131R
2	792R	223R	140R	117R	127R
3	613R	217R	136R	114R	124R
4	742R	214R	136R	118R	122R
5	778R	212R	135R	125R	122R
6	555R	206R	134R	132R	122R
7	509R	202R	132R	140R	122R
8	461R	196R	131R	147R	122R
9	530R	191R	133R	154R	120R
10	475R	190R	132R	161R	120R
11	418R	187R	131R	169R	119R
12	413R	187R	129R	176R	118R
13	475R	224R	128R	183R	116R
14	425R	198R	127R	190R	116R
15	576R	184R	125R	154R	135R
16	559R	177R	124R	128R	538R
17	560R	172R	124R	120R	263R
18	464R	169R	123R	122R	190R
19	390R	165R	121R	363R	718R
20	352R	163R	120R	277R	485R
21	327R	163R	120R	823R	299R
22	303R	162R	119R	344R	231R
23	286R	159R	118R	222R	198R
24	282R	156R	120R	181R	251R
25	284R	154R	119R	161R	338R
26	284R	153R	118R	150R	254R
27	276R	152R	116R	144R	378R
28	262R	150R	115R	139R	310R
29	243R	147R	114R	136R	308R
30	232R	147R	126R	132R	272R
31		147R	127R		[ ]
Mean	447R	181R	126R	188R	229R
Median	443R	177R	126R	149R	163R
Max.Daily Mean	792R	229R	143R	823R	718R
Min.Daily Mean	232R	147R	114R	114R	116R
Inst.Max	1040R	244R	144R	1200R	1080R
Inst.Min	224R	144R	114R	112R	116R

All recorded data are continuous and reliable except where the following tags are used:
R- Reference station data; [ ] - Data not recorded. Max – maximum; Min – minimum;
Inst – Instantaneous.

Table A-2: Site 7, Raging River near Fall City.

Day	Jun	Jul	Aug	Sep	Oct
1	106R	20.7R	14.7R	11.0R	12.0R
2	176R	18.4R	14.0R	10.6R	11.4R
3	153R	18.0R	13.8R	9.9R	11.0R
4	155R	18.0R	13.0R	9.9R	11.0R
5	137R	18.8R	13.0R	9.9R	11.0R
6	111R	18.0R	13.0R	9.8R	11.4R
7	91.9R	18.5R	13.0R	9.8R	12.4R
8	82.3R	17.7R	12.1R	9.9R	12.0R
9	76.4R	16.0R	12.5R	10R	11.3R
10	67.4R	16.0R	13.6R	10.1R	11.0R
11	59.2R	16.6R	13.0R	9.9R	11.0R
12	53.8R	16.9R	13.0R	9.8R	11.0R
13	77.2R	18.9R	12.8R	9.9R	11.0R
14	65.3R	17.6R	12.0R	15.3R	11.0R
15	74.5R	16.0R	11.5R	14.2R	13.5R
16	84.4R	15.3R	11.0R	12.5R	25.2R
17	82.2R	14.3R	11.0R	11.6R	22.7R
18	66.9R	14.0R	11.0R	12.9R	17.2R
19	57.2R	14.0R	10.7R	34.4R	115R
20	50.4R	13.8R	10.0R	20.7R	92.5R
21	45.6R	13.0R	10R	89.1R	43.4R
22	42.9R	13.0R	9.9R	39.4R	28.0R
23	39.0R	13.0R	10.1R	20.7R	21.8R
24	35.2R	12.8R	10.9R	17.1R	30.8R
25	32.0R	12.0R	11.0R	14.7R	34.4R
26	29.4R	12.0R	10.1R	13.3R	24.7R
27	26.5R	12.0R	9.9R	13.0R	21.4R
28	24.7R	12.6R	9.9R	12.1R	19.6R
29	23.9R	13.0R	9.9R	12.0R	71.3R
30	23.7R	14.3R	20.9R	12.0R	61.6R
31		18.6R	12.5R		[ ]
Mean	71.7R	15.6R	12.1R	16.5R	26.7R
Median	66.1R	16.0R	12.0R	12.0R	15.3R
Max.Daily Mean	176R	20.7R	20.9R	89.1R	115R
Min.Daily Mean	23.7R	12.0R	9.9R	9.8R	11.0R
Inst.Max	205R	23.0R	34.0R	143R	174R
Inst.Min	23.0R	12.0R	9.5R	9.5R	11.0R

All recorded data are continuous and reliable except where the following tags are used:
R – Reference station data; [ ] - Data not recorded. Max – maximum; Min – minimum;
Inst – Instantaneous.

Table A-3: Site 8, N.F. Snoqualmie River near Snoqualmie Falls.

Day	Jun	Jul	Aug	Sep	Oct
1	830R	281R	77.6R	56.9R	88.2R
2	1260R	264R	71.5R	51.8R	82.2R
3	1120R	249R	67.8R	49.5R	75.5R
4	1180R	244R	64.7R	46.5R	70.5R
5	1270R	234R	62.9R	44.3R	66.5R
6	836R	212R	61.6R	42.6R	64.0R
7	699R	195R	59.3R	41.4R	62.7R
8	599R	180R	57.3R	40.4R	60.2R
9	588R	168R	57.9R	41.5R	58.5R
10	553R	164R	58.1R	41.2R	56.5R
11	526R	152R	58.0R	41.1R	54.1R
12	602R	150R	56.3R	39.4R	51.9R
13	748R	235R	54.6R	38.8R	50.4R
14	667R	196R	52.1R	66.2R	49.2R
15	945R	167R	52.4R	120R	60.0R
16	865R	147R	51.9R	76.7R	233R
17	841R	133R	51.5R	75.2R	209R
18	634R	124R	50.7R	77.7R	156R
19	509R	117R	49.8R	235R	648R
20	440R	113R	48.9R	182R	650R
21	403R	109R	48.0R	947R	328R
22	373R	106R	47.1R	478R	232R
23	367R	101R	46.2R	257R	187R
24	381R	95.8R	45.3R	192R	226R
25	438R	90.6R	44.4R	156R	476R
26	479R	85.7R	44.0R	133R	315R
27	457R	82.7R	42.9R	118R	431R
28	388R	78.5R	41.8R	108R	391R
29	321R	76.4R	41.1R	99.5R	387R
30	288R	76.7R	55.5R	93.2R	340R
31		84.9R	76.2R		[ ]
Mean	654R	152R	54.8R	133R	205R
Median	594R	147R	52.4R	76.0R	122R
Max.Daily	1270R	281R	77.6R	947R	650R
Min.Daily	288R	76.4R	41.1R	38.8R	49.2R
Inst.Max	1700R	315R	87.0R	1270R	1140R
Inst.Min	262R	74.0R	40.0R	38.0R	49.0R

All recorded data are continuous and reliable except where the following tags are used:
R – Reference station data; [ ] - Data not recorded. Max – maximum; Min – minimum;
Inst – Instantaneous.

Table A-4: Site 9, M.F. Snoqualmie River near Tanner.

Day	Jun	Jul	Aug	Sep	Oct
1	2270R	891R	273R	186R	172R
2	3280R	849R	251R	164R	165R
3	2880R	830R	243R	157R	159R
4	2830R	854R	235R	154R	154R
5	3320R	865R	229R	152R	150R
6	2360R	746R	225R	149R	147R
7	1980R	632R	221R	146R	148R
8	1680R	588R	217R	143R	146R
9	1530R	577R	223R	145R	142R
10	1420R	604R	239R	144R	140R
11	1410R	571R	222R	139R	137R
12	2090R	519R	210R	137R	135R
13	2360R	680R	198R	137R	132R
14	1960R	570R	190R	181R	131R
15	2440R	517R	187R	208R	160R
16	2160R	477R	188R	179R	552R
17	2040R	437R	185R	165R	450R
18	1590R	413R	180R	169R	311R
19	1310R	395R	175R	256R	1100R
20	1130R	373R	172R	286R	1750R
21	1060R	374R	169R	1230R	1570R
22	989R	426R	168R	787R	1400R
23	1010R	410R	168R	449R	1220R
24	1060R	411R	165R	329R	1040R
25	1240R	387R	162R	270R	871R
26	1450R	357R	157R	236R	572R
27	1470R	337R	153R	215R	778R
28	1290R	330R	150R	201R	777R
29	1020R	305R	151R	190R	792R
30	881R	291R	241R	180R	709R
31		314R	232R		[ ]
Mean	1780R	527R	199R	250R	537R
Median	1560R	477R	190R	180R	242R
Max.Daily Mean	3320R	891R	273R	1230R	1750R
Min.Daily Mean	881R	291R	150R	137R	131R
Inst.Max	4030R	949R	291R	1680R	1900R
Inst.Min	823R	278R	144R	130R	128R

All recorded data are continuous and reliable except where the following tags are used:
R – Reference station data; [ ] - Data not recorded. Max – maximum; Min – minimum;
Inst – Instantaneous.

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Appendix B. 2006 Average Daily Discharges for Ecology Gaging Stations

Table B-1: Site 1, Snoqualmie River near Monroe.

Day	Jun	Jul	Aug	Sep	Oct
1	[ ]	2230	873	753	670*
2	6360A	2170	833	678	655*
3	7160A	2070	809	636	637*
4	6030A	2020	793	614	619*
5	7720A	2020	778	600B	604*
6	6350A	1890	770	587B	599*
7	5270A	1710	763	577B	600*
8	4590	1570	749	571B	594*
9	4210	1480	748	567B	584*
10	3900	1450	757	570B	580*
11	3640	1430	763	564B	569*
12	4030	1360*	747	551B	568*
13	4950	1540*	733	541B	563B
14	4440	1600*	717	602*	558B
15	4660	1400*	699	737*	585B
16	4860	1310*	686	686*	875J
17	4840	1220*	686	637*	1360J
18	4240	1140*	683	628*	1160J
19	3590	1090*	673	897*	1250J
20	3220	1040*	665	977*	2930J
21	2960	968	658	2150*	2190J
22	2790	929	643	2300*	1560J
23	2690	976	638	1380*	1450J
24	2670	980	649	1070*	1270J
25	2800	995	649	918*	1640J
26	3120	965	637	829*	1830J
27	3310	928	627	774*	1550J
28	3190	900	615	736*	1940J
29	2740	882	604B	709*	1740J
30	2420	858	636	686*	2950J
31		870	756		3380J
Mean	4230A	1360*	711B	817*	1230*
Median	4030A	1310*	699B	682*	875*
Max.Daily Mean	7720A	2230*	873B	2300*	3380*
Min.Daily Mean	2420A	858*	604B	541*	558*
Inst.Max	8110A	2260*	886B	3260*	3510*
Inst.Min	2260A	844*	593B	539*	552*

All recorded data are continuous and reliable except where the following tags are used: * - Data estimated based on other stations; ? – Unreliable estimate; A – Above rating, reliable extrapolation; B – Below rating, reliable extrapolation; J – Estimated data. Max – maximum; Min – minimum; Inst – Instantaneous.

Table B-2: Site 2, Tolt River near Carnation.

Day	Jun	Jul	Aug	Sep	Oct
1	645*	249*	143*	114*	128*
2	951*	241*	139*	110*	122*
3	729*	234*	134*	106*	118*
4	889*	231*	133*	105*	116*
5	933*	228*	133*	103*	116*
6	656*	221*	131*	102*	116*
7	598*	216*	129*	100*	116*
8	539*	208*	127*	99.6*	116*
9	625*	203*	129*	100*	114*
10	556*	201*	128*	99.5*	114*
11	485*	197*	127*	99.2*	112*
12	479*	197*	125*	97.8*	111*
13	556*	243*	123*	97.1*	109*
14	494*	210*	122*	148*	109*
15	682*	194*	120*	156*	132*
16	662*	185*	119*	124*	635*
17	662*	178*	118*	114*	292*
18	542*	175*	117*	116*	201*
19	450*	170*	115*	416*	860*
20	403*	168*	114*	309*	569*
21	371*	167*	113*	990*	336*
22	342*	166*	113*	393*	252*
23	321*	162*	111*	241*	211*
24	316*	159*	113*	190*	277*
25	318*	157*	112*	165*	386*
26	318*	154*	110*	151*	280*
27	308*	154*	108*	143*	436*
28	290*	151*	107*	138*	351*
29	267*	147*	106*	133*	348*
30	253*	148*	121*	129*	303*
31		147*	122*		[ ]
Mean	521*	189*	121*	180*	249*
Median	516*	185*	121*	120*	167*
Max.Daily Mean	951*	249*	143*	990*	860*
Min.Daily Mean	253*	147*	106*	97.1*	109*
Inst.Max	1260*	268*	143*	1460*	1310*
Inst.Min	243*	143*	106*	96.4*	109*

All recorded data are continuous and reliable except where the following tags are used: * - Data estimated based on other stations; [ ] - Data not recorded. Max – maximum; Min – minimum; Inst – Instantaneous.

Table B-3: Site 3, Raging River at Fall City.

Day	Jun	Jul	Aug	Sep	Oct
1	100*	21.8*	13.8*	10.1*	11.9*
2	164*	19.7*	13.1*	9.7*	11.3*
3	144*	19.4*	12.8*	9.2*	11.0*
4	145*	19.4*	12.0*	9.2*	11.1*
5	129*	20.1*	12.0*	9.2*	11.1*
6	104*	19.4*	11.9*	9.1*	11.5*
7	87.2*	19.9*	11.8*	9.1*	12.4*
8	78.4*	19.1*	10.9*	9.3*	12.1*
9	73.0*	17.6*	11.3*	9.4*	11.5*
10	64.8*	17.6*	12.2*	9.6*	11.2*
11	57.2*	18.1*	11.7*	9.4*	11.3*
12	52.2*	18.4*	11.7*	9.3*	11.5*
13	73.7*	20.1*	11.5*	9.4*	12.8*
14	62.8*	18.7*	10.7*	14.4*	14.2*
15	71.3*	17.1*	10.3*	13.4*	17.9*
16	80.3*	16.3*	9.8*	11.9*	30.0*
17	78.3*	15.2*	9.9*	11.1*	29.1*
18	64.3*	14.8*	10.1*	12.3*	25.2*
19	55.3*	14.6*	9.9*	32.1*	115*
20	49.1*	14.3*	9.4*	19.5*	94.4*
21	44.7*	13.4*	9.5*	82.4*	49.2*
22	42.3*	13.2*	9.6*	36.8*	35.0*
23	38.6*	13.1*	9.4*	19.6*	29.3*
24	35.1*	12.7*	9.7*	16.4*	37.4*
25	32.2*	11.8*	9.9*	14.2*	40.6*
26	29.9*	11.7*	9.1*	13.0*	31.6*
27	27.2*	11.6*	8.9*	12.7*	28.6*
28	25.6*	12.1*	8.9*	11.9*	26.8*
29	24.8*	12.4*	8.9*	11.8*	74.2*
30	24.7*	13.6*	19.1*	11.9*	65.2*
31		17.4*	11.4*		[ ]
Mean	68.7*	16.3*	11.0*	15.6*	29.8*
Median	63.6*	17.1*	10.7*	11.8*	21.5*
Max.Daily Mean	164*	21.8*	19.1*	82.4*	115*
Min.Daily Mean	24.7*	11.6*	8.9*	9.1*	11.0*
Inst.Max	191*	24.0*	31.1*	132*	169*
Inst.Min	24.0*	11.6*	8.6*	8.8*	11.0*

All recorded data are continuous and reliable except where the following tags are used: * - Data estimated based on other stations; [ ] - Data not recorded. Max – maximum; Min – minimum; Inst – Instantaneous.

Table B-4: Site 4, N.F. Snoqualmie River near Ellisville.

Day	Jun	Jul	Aug	Sep	Oct
1	1120*	381*	127*	78.8*	121*
2	1710*	358*	118*	71.9*	113*
3	1520*	339*	112*	68.9*	104*
4	1590*	331*	107*	64.8*	97.2*
5	1720*	317*	104*	61.8*	91.8*
6	1130*	288*	101*	59.6*	88.5*
7	946*	265*	97.4*	57.9*	86.7*
8	811*	245*	93.9*	56.6*	83.3*
9	796*	229*	93.9*	58.0*	81.0*
10	748*	223*	93.2*	57.6*	78.3*
11	712*	207*	91.2*	57.5*	75.1*
12	814*	205*	86.7*	55.3*	72.2*
13	1010*	322*	82.2*	54.4*	70.1*
14	903*	271*	76.6*	91.4*	68.4*
15	1280*	233*	74.7*	164*	83.1*
16	1170*	208*	72.3*	106*	317*
17	1140*	191*	72.3*	104*	285*
18	858*	181*	69.4*	107*	212*
19	689*	173*	67.2*	320*	877*
20	596*	169*	64.2*	247*	880*
21	546*	165*	63.8*	1280*	445*
22	505*	163*	63.0*	647*	316*
23	497*	159*	61.4*	350*	254*
24	516*	153*	64.5*	262*	308*
25	593*	148*	62.7*	212*	645*
26	649*	142*	61.5*	181*	427*
27	619*	138*	59.9*	162*	584*
28	526*	131*	58.5*	148*	529*
29	436*	128*	57.5*	136*	524*
30	391*	127*	77.0*	128*	462*
31		138*	105*		[ ]
Mean	885*	217*	81.9*	182*	279*
Median	804*	205*	76.6*	105*	167*
Max.Daily Mean	1720*	381*	127*	1280*	880*
Min.Daily Mean	391*	127*	57.5*	54.4*	68.4*
Inst.Max	2300*	427*	136*	1720*	1540*
Inst.Min	356*	123*	56.1*	53.4*	68.2*

All recorded data are continuous and reliable except where the following tags are used: * - Data estimated based on other stations; [ ] - Data not recorded. Max – maximum; Min – minimum; Inst – Instantaneous.

Table B-5: Site 5, M.F. Snoqualmie River near Ellisville.

Day	Jun	Jul	Aug	Sep	Oct
1	2280*	854*	274*	186*	173*
2	3290*	811*	252*	165*	165*
3	2890*	791*	243*	157*	159*
4	2840*	814*	236*	155*	154*
5	3320*	823*	230*	152*	151*
6	2350*	703*	226*	149*	148*
7	1980*	587*	221*	146*	148*
8	1670*	542*	218*	144*	146*
9	1520*	529*	224*	145*	142*
10	1410*	556*	239*	145*	140*
11	1400*	521*	222*	139*	137*
12	2080*	469*	211*	137*	135*
13	2350*	634*	199*	137*	132*
14	1950*	528*	191*	181*	131*
15	2430*	479*	188*	208*	160*
16	2140*	443*	189*	180*	554*
17	2030*	406*	185*	166*	451*
18	1570*	387*	180*	169*	312*
19	1290*	373*	175*	257*	1100*
20	1110*	354*	172*	287*	1200*
21	1040*	359*	169*	1230*	662*
22	964*	415*	169*	789*	506*
23	987*	404*	168*	450*	435*
24	1030*	409*	166*	330*	508*
25	1210*	388*	163*	271*	873*
26	1420*	358*	157*	237*	573*
27	1440*	338*	153*	215*	780*
28	1260*	331*	150*	201*	779*
29	983*	306*	152*	191*	795*
30	846*	292*	242*	181*	711*
31		315*	232*		[ ]
Mean	1770*	501*	200*	250*	415*
Median	1550*	443*	191*	180*	242*
Max.Daily Mean	3320*	854*	274*	1230*	1200*
Min.Daily Mean	846*	292*	150*	137*	131*
Inst.Max	4040*	913*	292*	1680*	1910*
Inst.Min	787*	279*	144*	130*	128*

All recorded data are continuous and reliable except where the following tags are used: * - Data estimated based on other stations; [ ] - Data not recorded. Max – maximum; Min – minimum; Inst – Instantaneous.

Appendix C. 2006 Instantaneous Discharge Measurements for Ecology Gaging Stations

Table C-1: Site 1, Snoqualmie River near Monroe.

Date	Time	Stage (ft)	Flow (cfs)	Area (ft^2)	Vel. (ft/sec)	Method	Comments
06/07/2006	1310	7.28	5330	2438	2.18	bridge	
07/25/2006	1730	2.435	1010	1458	0.65	ADCP	
08/23/2006	1335	1.795	616	1439	0.41	ADCP	
09/14/2006	1550	1.72	621	1311	0.41	ADCP	
08/08/2007	1040	2.79	830	1499	0.55	ADCP	

Table C-2: Site 2, Tolt River near Carnation.

Date	Time	Stage (ft)	Flow (cfs)	Area (ft^2)	Vel. (ft/sec)	Method	Comments
07/12/2006	1205	0.88	189.54	95.29	1.98	wade	
08/23/2006	1205	0.62	115.54	71.74	1.61	wade	
10/12/2006	1310	0.59	108.24	91.22	1.18	wade	

Table C-3: Site 3, Raging River at Fall City.

Date	Time	Stage (ft)	Flow (cfs)	Area (ft^2)	Vel. (ft/sec)	Method	Comments
05/31/2006	1425	5.39	116.72	45.4	2.57	wade	
07/11/2006	1730	4.56	19.82	24.46	0.81	wade	
07/12/2006	1020	4.55	21.43	17.81	1.2	wade	
07/26/2006	930	4.47	11.69	24.18	0.48	wade	
08/16/2006	855	4.31	12.07	18.52	0.65	wade	Not used in rating
08/16/2006	1315	4.4	9.81	20.61	0.48	wade	
08/23/2006	1050	4.39	9.76	22.03	0.44	wade	
09/20/2006	1030	4.68	67.65	27.21	2.49	wade	Not used in rating
10/12/2006	1205	4.44	11.32	13.4	0.84	wade	
10/18/2006	955	4.64	25.18	23.14	1.09	wade	

Table C-4: Site 4, N.F. Snoqualmie River near Ellisville.

Date	Time	Stage (ft)	Flow (cfs)	Area (ft^2)	Vel. (ft/sec)	Method	Comments
06/01/2006	800	6.12	1084.66	435.24	2.469	ADCP	
07/12/2006	745	4.65	174.83	251.31	0.69	wade	
07/26/2006	1010	4.44	142.94	204.97	0.7	wade	
08/16/2006	930	4.25	67.89	184.56	0.37	wade	
08/16/2006	950	4.25	70.01	184.28	0.38	wade	
08/23/2006	855	4.21	71.3	196.52	0.36	wade	
09/18/2006	1600	4.36	284.09	216.08	1.31	wade	Not used in rating
10/12/2006	1030	4.26	67.617	196.93	0.334	ADCP	

Table C-5: Site 5, M.F. Snoqualmie River near Ellisville.

Date	Time	Stage (ft)	Flow (cfs)	Area (ft^2)	Vel. (ft/sec)	Method	Comments
05/31/2006	845	9.91	1797.63	788.14	2.169	ADCP	
07/25/2006	920	8.35	382.18	457.58	0.819	ADCP	
08/23/2006	800	7.96	175	430	0.41	ADCP	
09/14/2006	710	7.88	151.52	385.2	0.381	ADCP	
10/12/2006	845	7.83	142.35	417.67	0.344	ADCP	

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Appendix D. Glossary, Acronyms, and Abbreviations

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which designated uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards, and are not expected to improve within the next two years.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Load allocation: The portion of a receiving waters' loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a waterbody can receive and still meet water quality standards.

Reach: A specific portion or segment of a stream.

Stage height: Water surface elevation.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Acronyms and Abbreviations:

ADCP	Acoustic Doppler current profiler
cfs	Cubic feet per second
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
Ell	Ellisville
Ft	Feet
Inst.	Instantaneous
M.F.	Middle Fork
N.F.	North Fork

Nr	near
PGI	Primary gage index
PSI	Pounds per square inch
RM	River mile
Sec	Second
USGS	United States Geological Survey
WY	Water year