A Department of Ecology Report

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Streamflow Summary for Gaging Stations on the Naches River and Rattlesnake Creek, 2004

Abstract

From June through October 2004, the Department of Ecology (Ecology) conducted a streamflow assessment on the Naches River and Rattlesnake Creek, a mid-basin tributary to the Naches River.

The assessment was conducted in support of a temperature Total Maximum Daily Load (TMDL) study developed by Ecology's Environmental Assessment Program. The purpose of the TMDL study was to (1) characterize the water temperature in the Naches River basin, and (2) establish load and wasteload allocations for the heat sources to meet Washington State water quality standards for surface water temperature.

Continuous stage height recorders and staff gages were installed at three sites for this study, and five to six discharge measurements were taken at each site. Discharge rating curves were developed for each site by relating several stage height values to corresponding discharge measurements. A continuous discharge record was developed at each site by applying these rating curves over the range of stage height encountered.

Potential error of streamflow data collected from these three monitoring sites ranged from ±13% to ±20%.

By Chuck Springer
September 2007

Publication Number: 07-03-042
Waterbody Numbers: (see page 2)

Publication Information

This report is available on the Department of Ecology's website at
www.ecy.wa.gov/biblio/0703042.html

Author: Chuck Springer
Washington State Department of Ecology
Environmental Assessment Program
E-mail: cspr461@ecy.wa.gov
Phone: (360) 407-6997
Address: PO Box 47600, Olympia WA 98504-7600

Waterbody numbers for this study:

WA-38-1010 - Naches River near Naches
WA-38-1030 - Naches River at Nile Road
WA-38-1035 - Rattlesnake Creek near Nile Road

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600
Olympia, WA 98504-7600

E-mail: jlet461@ecy.wa.gov
Phone: 360-407-6764

Washington State Department of Ecology - www.ecy.wa.gov/

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

Table of Contents

List of Figures

Introduction

From June through October 2004, the Environmental Assessment Program of the Washington State Department of Ecology (Ecology) conducted a streamflow assessment on the Naches River and Rattlesnake Creek, a mid-basin tributary to the Naches River. This monitoring was conducted in support of a temperature Total Maximum Daily Load (TMDL) study developed by the Environmental Assessment Program. The purpose of the TMDL study was to (1) characterize water temperatures in the Naches basin, and (2) establish loading capacity, and load and wasteload allocations, for heat sources in the watershed to meet water quality standards.

The study was initiated because of federal Clean Water Act 303(d) listings of Naches River segments which are water quality limited for temperature (LeMoine and Brock, 2004).

Sampling Sites

The Naches River is a tributary of the Yakima River. The Naches River flows east from the Cascade Mountain Range to its confluence with the Yakima River in the city of Yakima. The Naches River basin covers an area of 1,120 square miles, and is heavily managed for agricultural water use.

For this streamflow study, Ecology established continuous stage height recorders at three locations in the basin: two on the mainstem Naches River, and one on Rattlesnake Creek, a mid-basin tributary to the Naches River:

- On the Naches River, the lower station was located at the Highway 12 bridge, upstream of the confluence with the Tieton River at river mile 17.6 (Figure 1, Site 1). The upper station on the Naches River was located at Nile Road, at river mile 27.0 (Site 2).

- On Rattlesnake Creek, the station was located near the mouth, 100 yards upstream of Nile Road (Site 3).

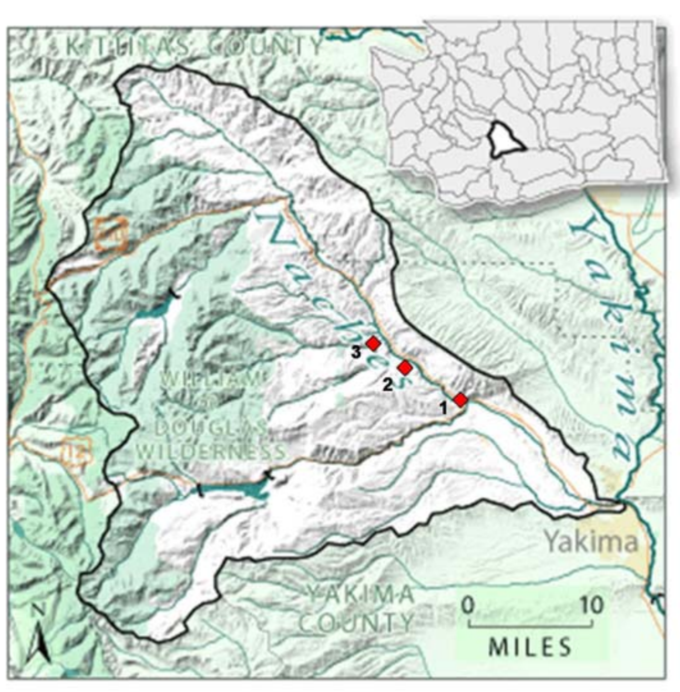

Figure 1: Map of Naches River Basin Study Sites.

Methods

Each of the three continuous gaging stations 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 November 2004. Five to six discharge measurements were taken at each station to establish discharge rating curves, which model the relationship between stage and discharge. These rating curves were then used to calculate the average daily discharges for each site.

Discharge measurements were made following the U.S. Geological Survey 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).

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, result in erroneous discharge values. These erroneous stage height values are typically corrected by applying time-weighted adjustments to the data set, which pivot on the stage height values observed directly by staff in the field. 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 estimates were calculated for each site for the two primary sources of error: pressure transducer drift and the discharge rating curve.

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

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

where Q_{rec} is the corresponding discharge for the recorded stage values, and Q_{obs} is the corresponding discharge for the observed stage height values.

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

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

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

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 records produced by the dataloggers.

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 and poor, based on physical conditions encountered at each site.

- 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 2004 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%.

Once a discharge rating curve was established for a 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, poor cross-sectional characteristics, and high bottom roughness during low-flow conditions contributed to the measured and predicted discharge differences for individual flow measurements ranging from 0.4% to 6%. This range of differences between measured and predicted discharge demonstrates the ability of the rating curves to predict stream discharge for each site.

Stage Height Record

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, 2.6).

During the 2004 study period, the accuracy of each transducer was addressed by using staff gage versus transducer regressions. The correlation coefficient (r) values for the regressions of raw pressure transducer readings against the final data set, which had been adjusted to the discrete observed stage height values, ranged from 0.938 to 1.0, with 1.0 being a perfect correlation. These correlations provide an indication of the severity of pressure transducer drift (discussed above in *Methods* section) at each site.

Results

Site 1: Naches River near Naches

The average daily discharge for Site 1 ranged from 202 cfs in early October to 1,990 cfs during snowmelt in mid-June. Peak streamflow during the study was 2,090 cfs on June 10 (Figure 2). Daily discharge averages are presented in Appendix A, Table A1. The measured range of discharge for this site encompassed only 53% of the range of discharge encountered, with flow measurements ranging from 204 to 1,260 cfs (Figure 3). However, discharge exceeded the highest measured flow only 10% of the time, and exceeded the lowest measured flow only 4% of the time over the duration of the study (Figure 4).

Within the range of measured flows, the fit of the rating curve was fair. Three of the five discharge measurements taken at Site 1 were within 5% of the flow predicted by the rating curve, and one of those three measurements was within 2%. The other two discharge measurements, taken in September and October respectively, did not fall on the established rating curve due to backwater conditions from the Tieton River, which flows into the Naches River approximately 200 feet downstream of the gaging station.

During the fall drawdown of Rimrock Lake, from mid-August to mid-October, flows in the Tieton River were sufficiently high to impede river flow in the Naches River, elevating stage levels. During this period, the relationship between stage and discharge became unpredictable. Since stage height data from the Naches River at Nile Road (Site 2) correlated very well with stage height data from Site 1 ($r^2 = 0.992$), the continuous stage record was used to estimate what the stage levels at Site 1 would have been in the absence of backwater from the Tieton River. This stage record was inserted into the data set for Site 1 and was adjusted based on the relationship between stage height at the two sites ($S_1 = 1.11 * S_2 – 150$). The record was then adjusted using the established rating curve at Site 1 and the individual discharge measurements taken during September and October.

In mid-October the relationship between stage and discharge returned to normal. A linear regression of pre- versus post-adjusted continuous discharge data showed a correlation coefficient (r) of 0.938 and a standard error of 125 cfs (46% of median flow for the study), indicating considerable instrument drift at this site (Figure 5).

Overall, the potential error for discharge data for this site is estimated to be ±16%. Of this, 8% of the error is from the continuous stage data, and 8% is from the rating. The large error associated with the continuous stage data is due to the period of backwater discussed above.

This station was monitored to estimate discharge at the mouth of the Tieton River. See Appendix B for a detailed analysis and estimated flows for the mouth of the Tieton River.

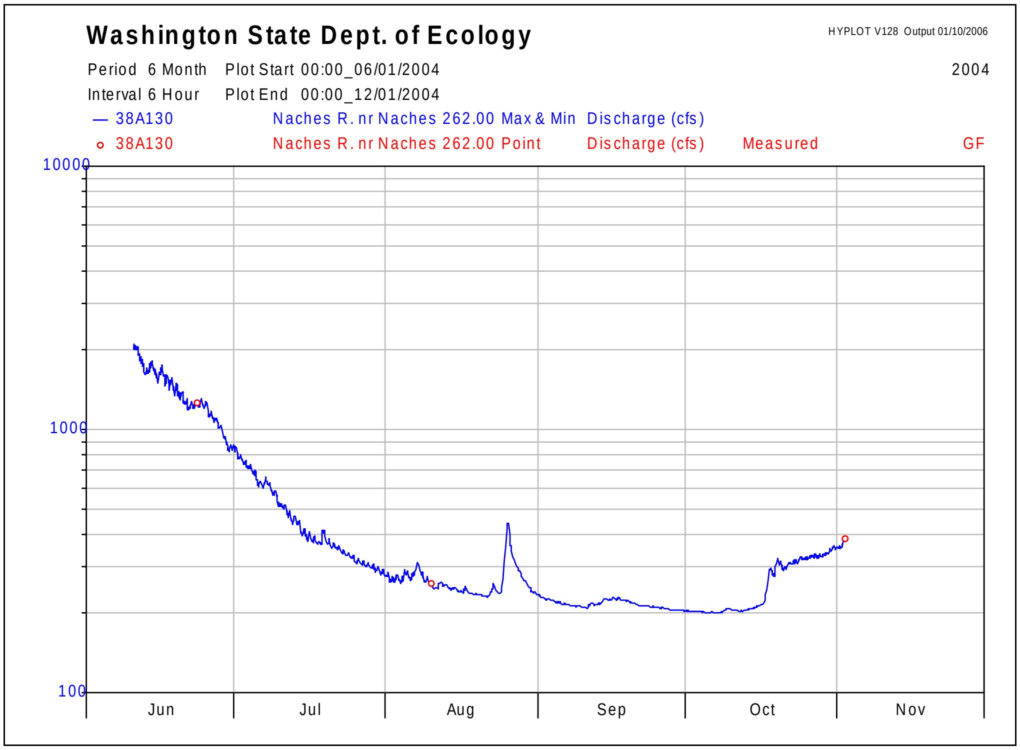

Figure 2: Discharge hydrograph for Site 1.

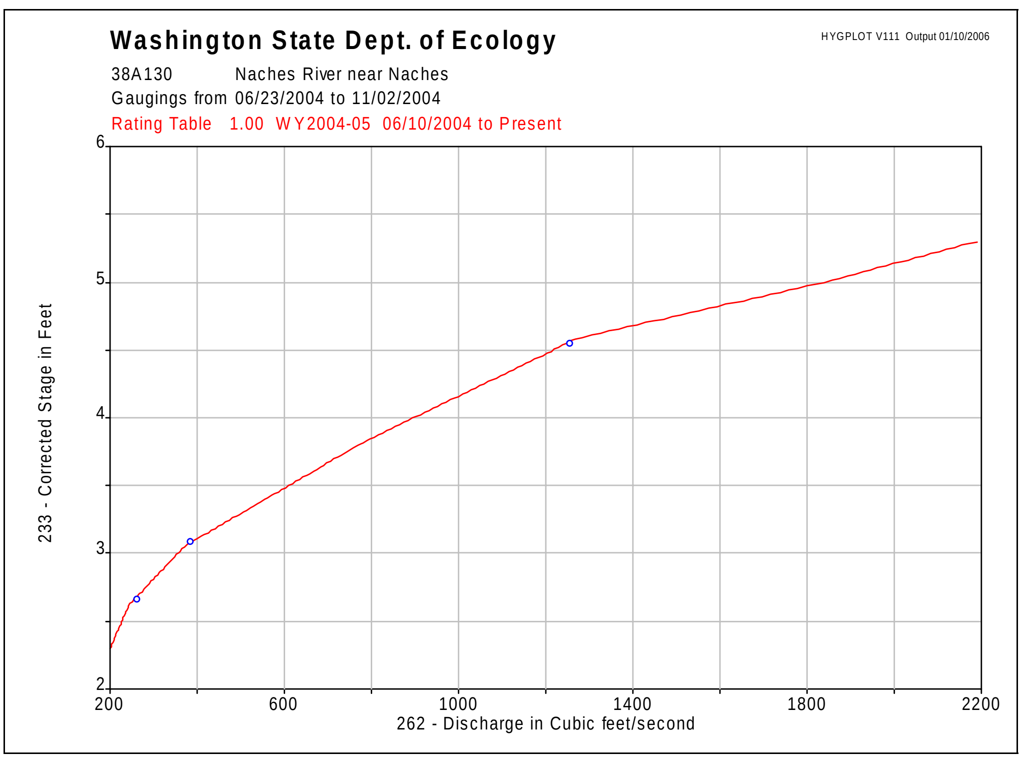

Figure 3: Discharge rating curve for Site 1.

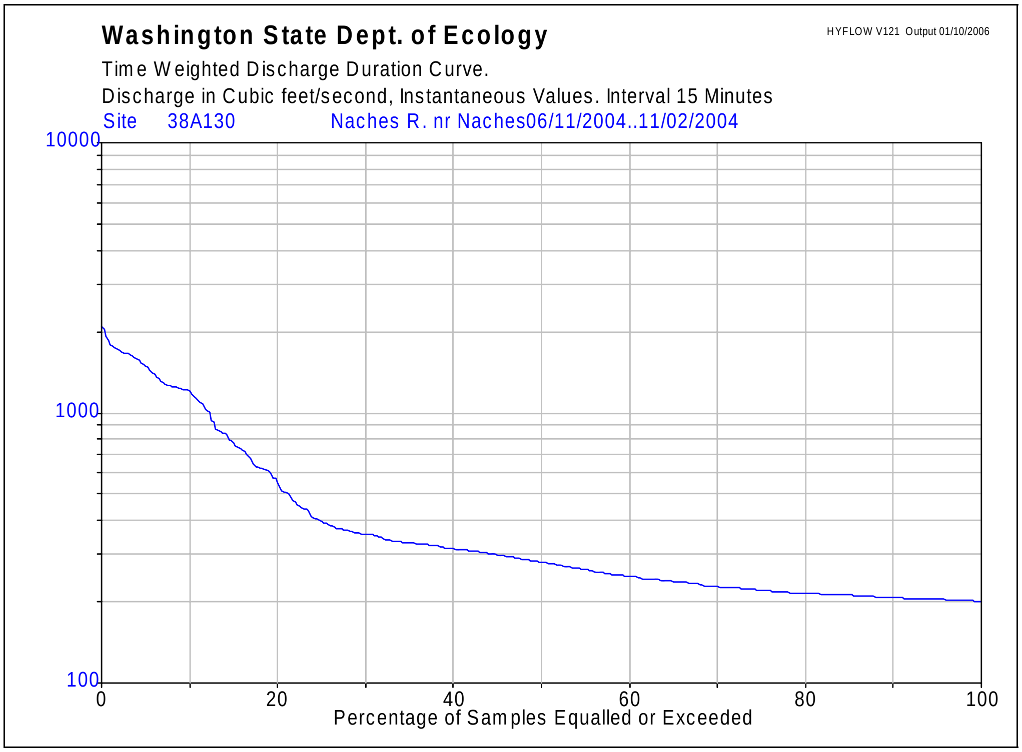

Figure 4: Discharge exceedence graph for Site 1.

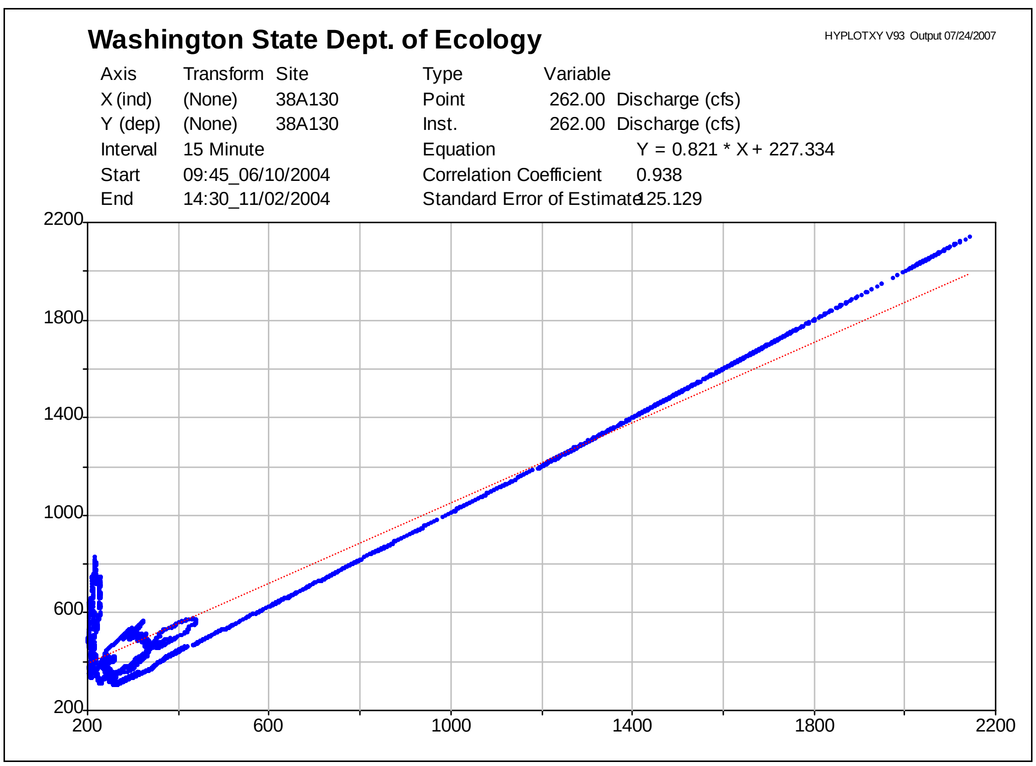

Figure 5: Linear regression of pre- versus post-adjusted discharge data for Site 1.

Site 2: Naches River at Nile Road

The average daily discharge for Site 2 ranged from 279 cfs in mid-October to 1,790 cfs during snowmelt in June. Peak streamflow during the study was 1,880 cfs on June 10 (Figure 6). Daily discharge averages are presented in Appendix A, Table A2. The measured range of discharge for this site encompassed over 95% of the range of discharge encountered, with flow measurements ranging from 283 to 1,900 cfs (Figure 7). Discharge exceeded the lowest measured flow less than 2% of the time, and did not exceed the highest measured flow over the duration of the study (Figure 8).

Within the range of measured flows, the fit of the rating curve was excellent. Five of the six discharge measurements taken at Site 2 were within 2% of the discharge predicted by the rating curve, and all six were within 3%. During a four-day period in October, the river stage dropped below the pressure transducer at this site. Continuous stage data from Rattlesnake Creek near Nile Road (Site 3) were used to estimate stage levels during this period. Several time-weighted adjustments were made to the continuous stage height data at Site 2 to compensate for drift in the pressure transducer readings. A linear regression of pre- versus post-adjusted continuous discharge data showed a correlation coefficient (r) of 0.999 and a standard error of 12.8 cfs (less than 4% of median flow for the study), indicating nominal instrument drift at this site (Figure 9). Data were adjusted only in cases where discharge predicted for individual stage observations differed from that predicted for the corresponding logged stage values by 5% or more.

Overall, the potential error for discharge data for this site is estimated to be ±13%. Of this, 4% of the error is from the continuous stage data, and 9% is from the rating.

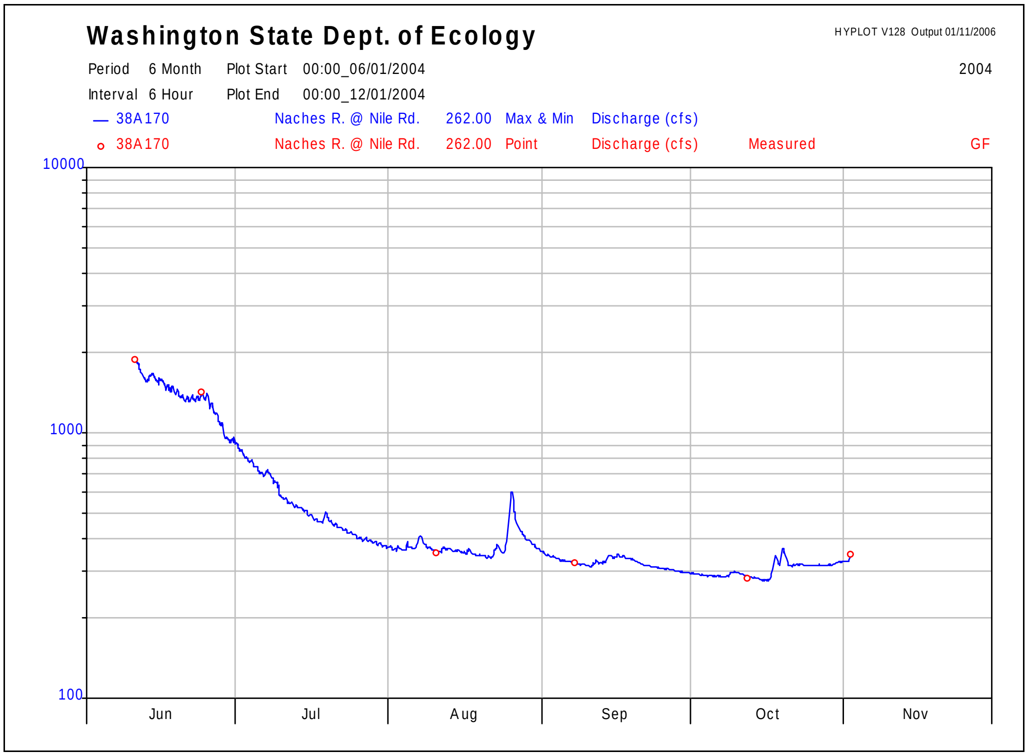

Figure 6: Discharge hydrograph for Site 2.

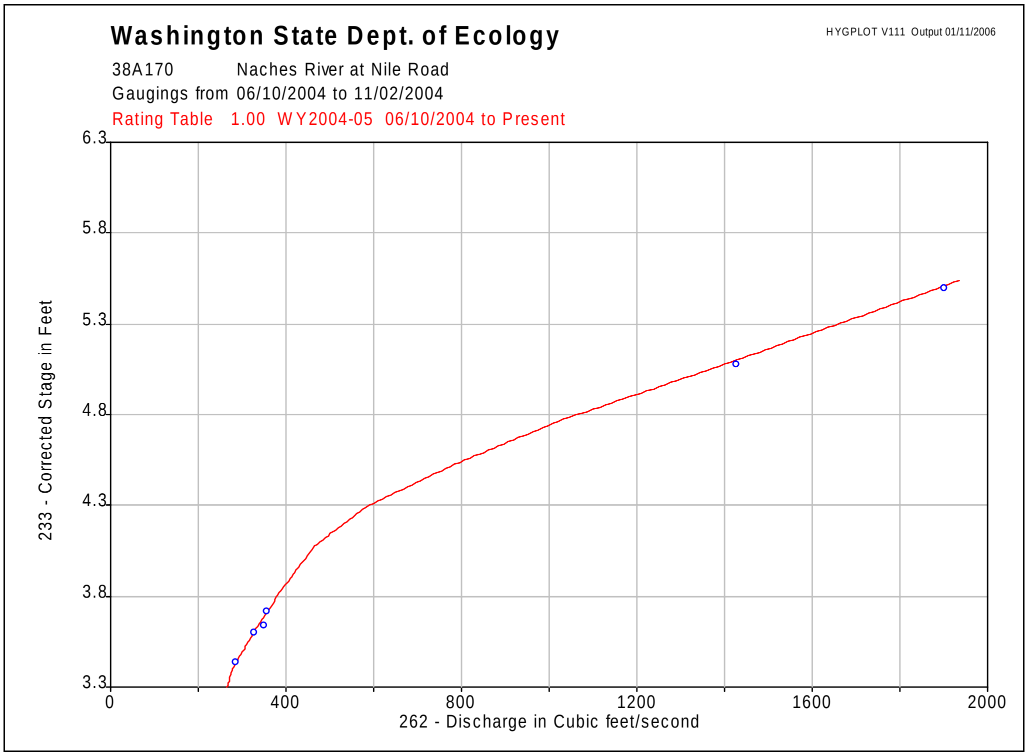

Figure 7: Discharge rating curve for Site 2.

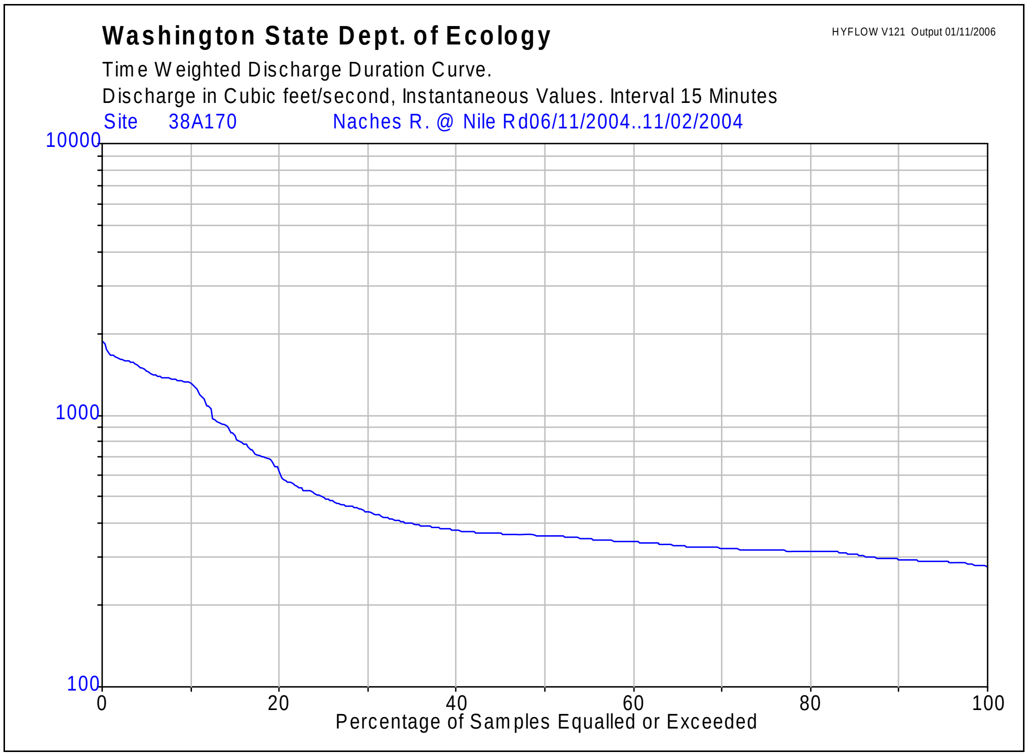

Figure 8: Discharge exceedence graph for Site 2.

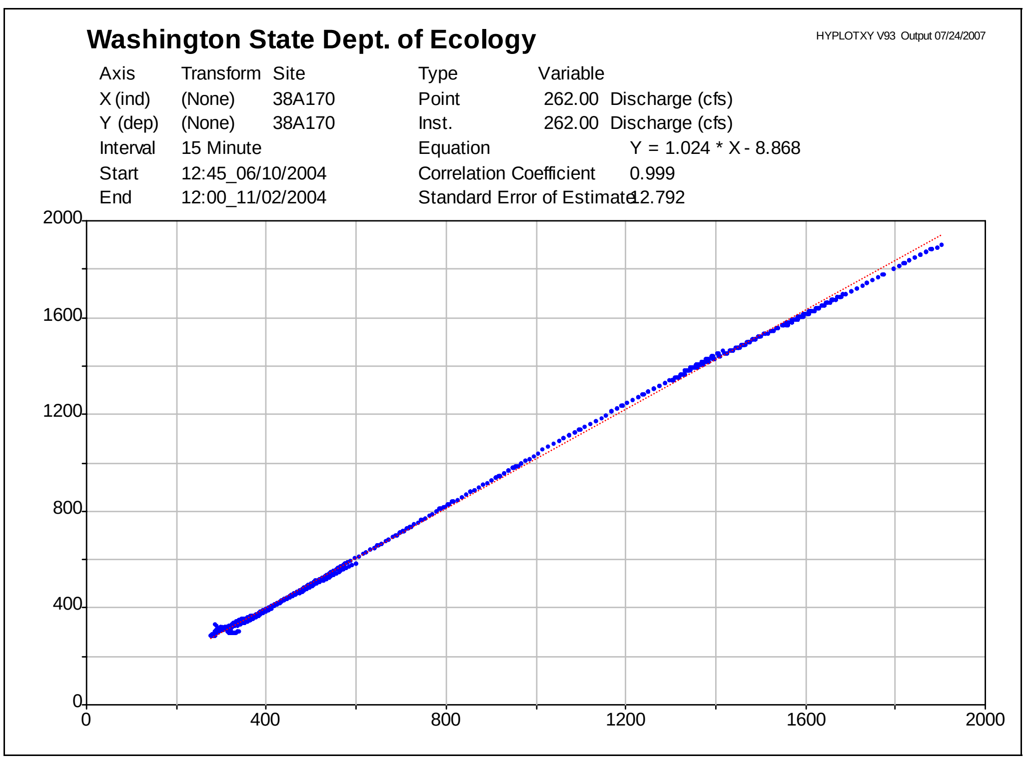

Figure 9: Linear regression of pre- versus post-adjusted discharge data for Site 2.

Site 3: Rattlesnake Creek near Nile Road

The average daily discharge for Site 3 ranged from 29 cfs in mid-October to 347 cfs during snowmelt in mid-June. Peak streamflow during the study was over 360 cfs on June 10 (Figure 10). Daily discharge averages are presented in Appendix A, Table A3. The measured range of discharge for this site encompassed only 63% of the range of discharge encountered, with flow measurements ranging from 29 to 255 cfs (Figure 11). However, discharge exceeded the highest measured flow less than 10% of the time, and did not exceed the lowest measured flow over the duration of the study (Figure 12).

Within the range of measured flows, the fit of the rating curve was fairly good. Four of the five discharge measurements taken at Site 3 were within 5% of the discharge predicted by the rating curve, and all were within 10%. Several time-weighted adjustments were made to the continuous stage height data at Site 3 to compensate for drift in the pressure transducer readings. A linear regression of pre- versus post-adjusted continuous discharge data showed a correlation coefficient (r) of 1.0 and a standard error of 1.0 cfs (2.4% of median flow for the study), indicating nominal instrument drift at this site (Figure 13). Data were adjusted only in cases where discharge predicted for individual stage observations differed from discharge predicted for the corresponding logged stage values by 5% or more.

Overall, potential error for discharge data for this site is estimated to be ±20%. Of this, 5% of the error is from the continuous stage data, and 15% is from the rating.

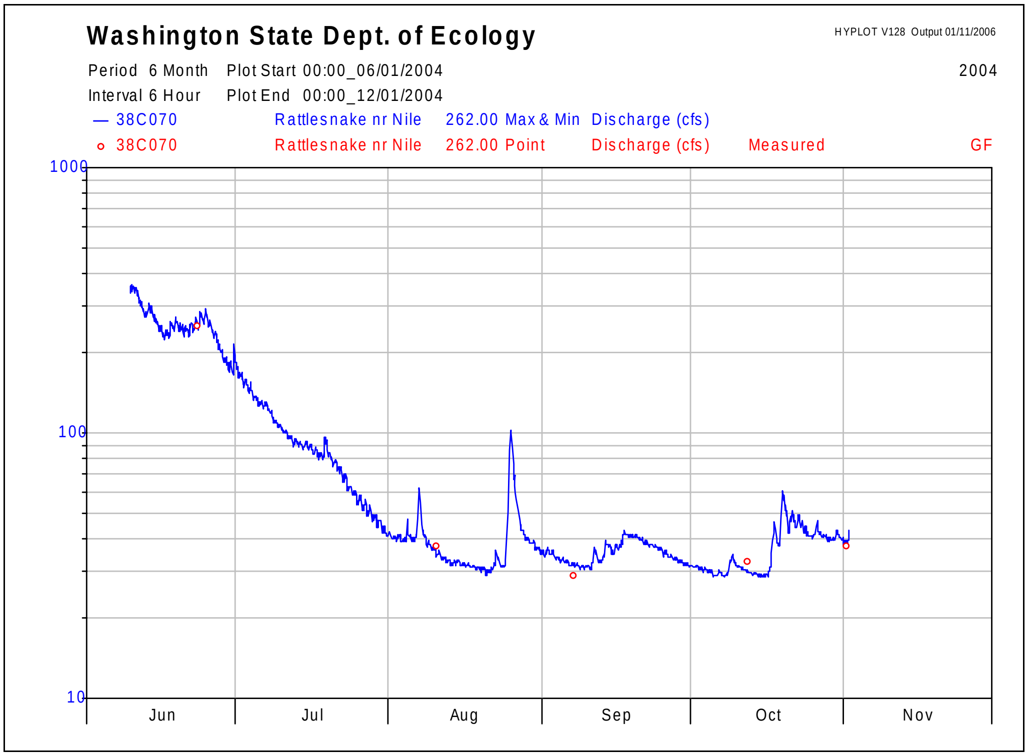

Figure 10: Discharge hydrograph for Site 3.

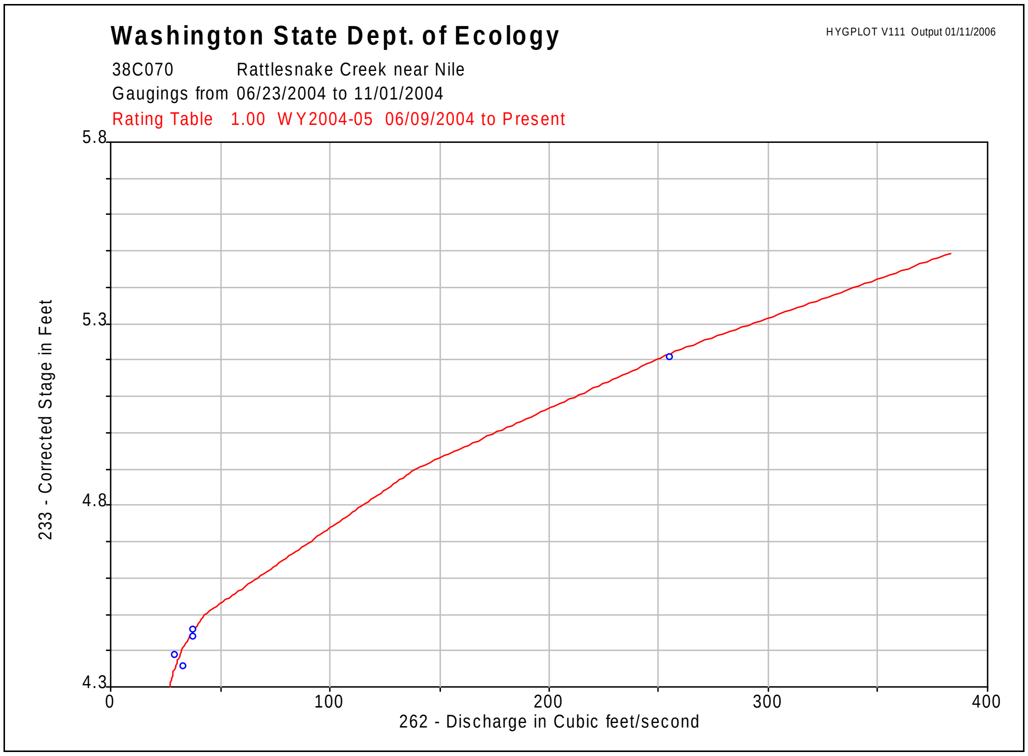

Figure 11: Discharge rating curve for Site 3.

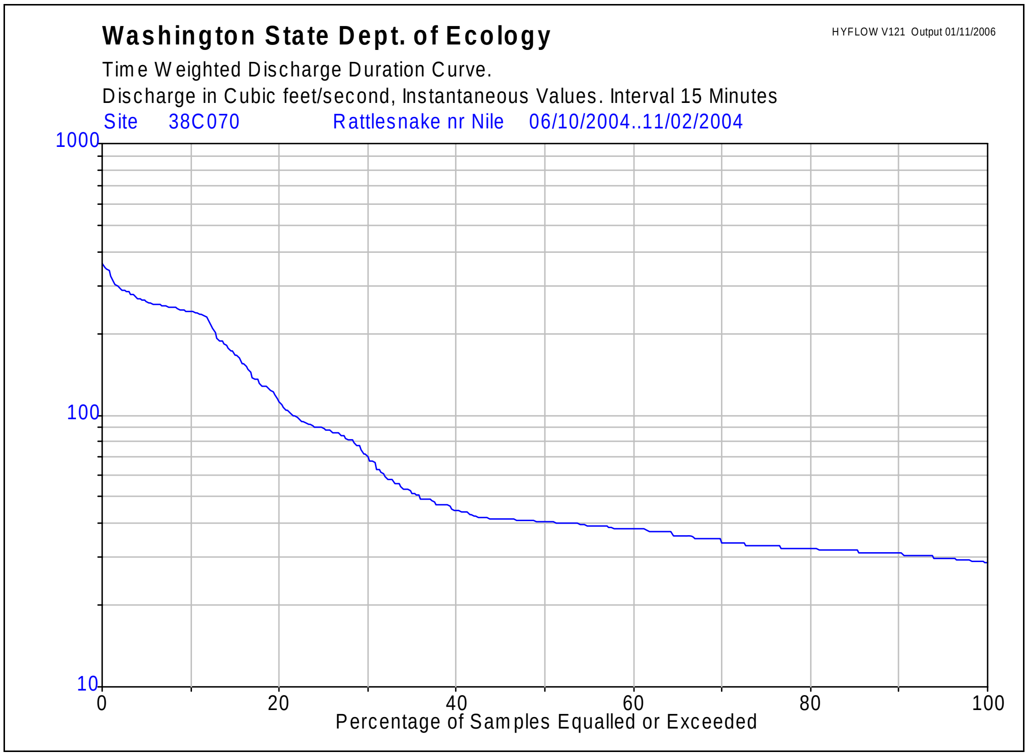

Figure 12: Discharge exceedence graph for Site 3.

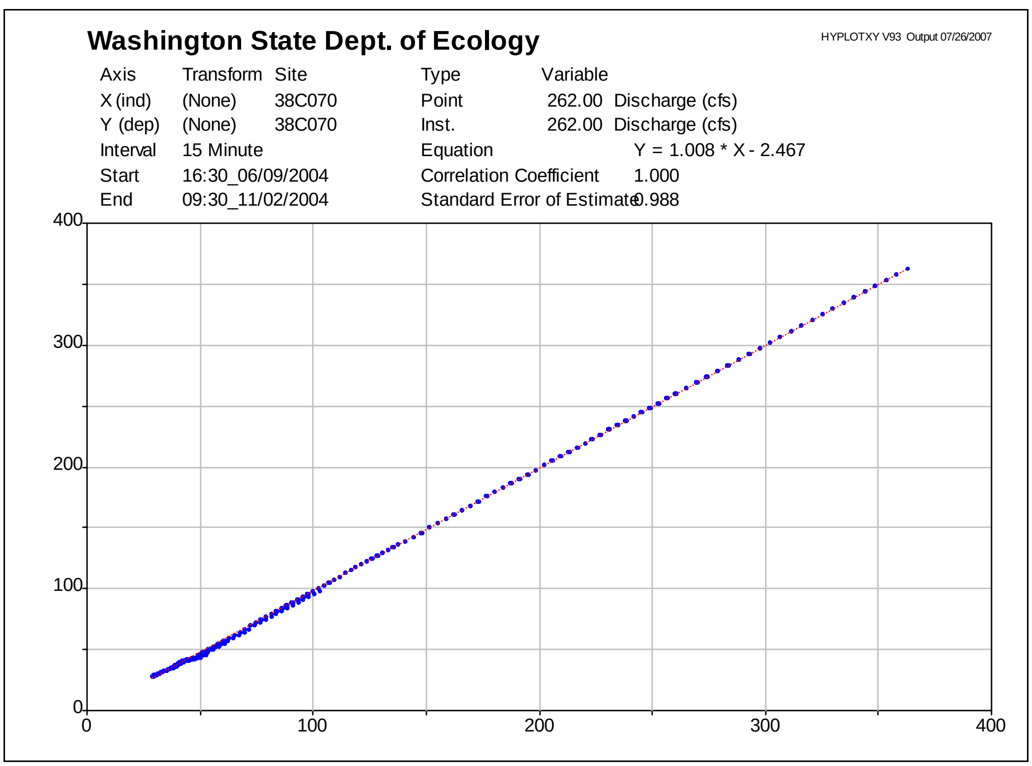

Figure 13: Linear regression of pre- versus post-adjusted discharge data for Site 3.

References

Butkus, S., 2005. Quality Assurance Monitoring Plan: Streamflow Gaging Network. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-204. www.ecy.wa.gov/biblio/0503204.html

Fletcher, T. Waterlog Model H-310 Owners Manual. Design Analysis Associates, Logan, UT. Revision 2.6.

Freeman, L.A. et al., 2004. Use of Submersible Pressure Transducers In Water-Resources Investigations. Techniques of Water-Resources Investigations 8-A3, U.S. Geological Survey, Reston, VA.

LeMoine, M. and S. Brock, 2004. Quality Assurance Project Plan: Naches River Temperature Total Maximum Daily Load. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-110. www.ecy.wa.gov/biblio/0403110.html

Rantz, S.E. et al., 1982a. Measurement and Computation of Streamflow: Volume 1, Measurement of Stage and Discharge. Geological Survey Water-Supply Paper 2175, U.S. Government Printing Office, Washington D.C.

Rantz, S.E. et al., 1982b. Measurement and Computation of Streamflow: Volume 2, Computation of Discharge. Geological Survey Water-Supply Paper 2175, U.S. Government Printing Office, Washington D.C.

Appendix A: Average Daily Discharges for the Three Sampling Sites, 2004

Table A1: Average Daily Discharge for Site 1 – Naches River near Naches

Day	Jun	Jul	Aug	Sep	Oct
1	[]	827	276	233*	204*
2	[]	777	269	228*	204*
3	[]	738	272	226*	203*
4	[]	713	271	222*	202*
5	[]	666	281	220*	202*
6	[]	619	277	217*	202*
7	[]	630	300	215*	202*
8	[]	603	281	213*	202*
9	[]	566	265	213*	208*
10	[]	516	254*	211*	207*
11	1990A	500	251*	214*	205*
12	1760A	470	259*	217*	204*
13	1670A	449	254*	217*	206*
14	1730A	428	249*	225*	209*
15	1610A	403	246*	225*	212*
16	1650A	389	242*	227*	216*
17	1520A	379	245*	227*	236*
18	1480A	369	238*	224*	289J
19	1410A	397	236*	222*	299J
20	1320A	369	235*	219*	308J
21	1250A	362	233*	216*	298J
22	1230A	352	243*	214*	310J
23	1240A	340	248*	213*	313J
24	1250A	332	245*	212*	321J
25	1210	322	361*	210*	323J
26	1130	315	373*	209*	327J
27	1070	309	310*	208*	329J
28	1000	304	283*	207*	331J
29	893	299	264*	206*	334J
30	851	291	249*	205*	343J
31		284	239*		356J
Mean	1360A	462	266*	217*	258*
Median	1280A	397	254*	216*	216*
Max.Daily Mean	1990A	827	373*	233*	356*
Min.Daily Mean	851	284	233*	205*	202*
Inst.Max	2090A	862	440*	236*	361*
Inst.Min	825	275	231*	204*	200*
Missing Days	10	0	0	0	0

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

Table A2: Average Daily Discharge for Site 2 – Naches River at Nile Road

Day	Jun	Jul	Aug	Sep	Oct
1	[]	896	368	353	295
2	[]	843	364	344	294
3	[]	801	365	341	291
4	[]	773	367	334	290
5	[]	735	370	330	289
6	[]	704	372	326	288
7	[]	710	401	323	288
8	[]	675	378	320	288
9	[]	635	367	319	298
10	[]	572	360	316	297
11	1790	556	359	320	293
12	1630	540	367	325	289*
13	1600	527	363	325	285*
14	1640	518	360	340	282*
15	1570	502	358	339	280*
16	1550	482	353	344	279*
17	1480	470	358	342	296*
18	1450	462	348	336	334
19	1400	487	346	333	339
20	1350	459	343	326	335
21	1340	448	340	319	316
22	1340	436	359	316	318
23	1350	427	366	313	320
24	1370	417	364	310	316
25	1340	406	500	308	316
26	1230	399	517	306	317
27	1140	397	435	303	317
28	1040	390	408	301	317
29	949	385	390	298	318
30	934	378	376	297	323
31		373	364		327
Mean	1380	542	377	324	304*
Median	1360	487	365	324	297*
Max.Daily Mean	1790	896	517	353	339*
Min.Daily Mean	934	373	340	297	279*
Inst.Max	1880	930	600	359	367*
Inst.Min	918	367	337	295	277*
Missing Days	10	0	0	0	0

------------------ Notes -------------------
All recorded data is continuous and reliable
except where the following tags are used...
* ... Data estimated based on other stations
[ ] Data Not Recorded

Table A3: Average Daily Discharge for Site 3 – Rattlesnake Creek near Nile Road

Day	Jun	Jul	Aug	Sep	Oct
1	[]	175	41.0	35.4	31.5
2	[]	160	40.1	35.8	31.1
3	[]	151	40.1	34.7	30.8
4	[]	143	40.9	33.4	30.4
5	[]	133	40.6	32.8	29.8B
6	[]	128	40.5	32.3	29.4
7	[]	126	50.8	31.8	29.5B
8	[]	116	39.9	31.4	29.9
9	[]	109	37.5	31.3	33.4
10	347A	103	35.7	31.2	31.7
11	325A	99.0	34.3	33.6	30.8
12	292A	94.4	33.2	33.1	30.1
13	290A	91.8	32.5	34.2	29.6
14	280A	89.9	32.3	38.1	29.3B
15	253A	89.4	32.4	35.7	29.1B
16	238	87.6	31.7	37.5	29.3B
17	239A	84.7	31.6	40.4	35.3
18	253A	81.9	30.9	41.0	40.5
19	254A	89.7	30.8	41.0	48.1
20	245	80.1	30.3	40.5	49.2
21	244	75.6	30.2	39.0	47.2
22	250A	70.7	32.9	38.4	46.1
23	260A	65.2	32.5	37.8	45.8
24	273A	60.9	32.8	36.8	42.4
25	266A	57.4	74.9	35.7	41.0
26	244A	54.6	69.1	34.6	43.1
27	222	52.3	48.5	33.6	41.0
28	197	50.0	41.5	33.0	40.7
29	181	47.5	39.1	32.6	39.9
30	183	44.9	37.6	32.1	40.9
31		42.6	36.4		40.2
Mean	254A	92.0	38.8	35.3	36.4B
Median	253A	89.4	36.4	34.6	33.4B
Max.Daily Mean	347A	175	74.9	41.0	49.2
Min.Daily Mean	181	42.6	30.2	31.2	29.1B
Inst.Max	363A	195	103	42.9	60.7
Inst.Min	166	41.1	29.2	30.4	28.6B
Missing Days	9	0	0	0	0

------------------ 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

[ ] Data Not Recorded

Appendix B: Discharge Estimates for the Tieton River at its mouth, 2004

As part of this 2004 study, discharge was modeled for the mouth of the Tieton River (38B050) using the Ecology streamgaging station 38A130 (Naches R. near Naches (Site 1)) and two streamgaging stations managed by the U.S Bureau of Reclamation (NACW – Naches R. near Naches; and WOPW – Wapatox Power Canal). The assumed discharge relationship between these three sites is:

$$Q_{38B050} = Q_{NACW} + Q_{WOPW} - Q_{38A130}$$

where Q represents discharge. This relationship assumes there are no groundwater inflows or outflows present in this stream segment (Figure 14).

A comparison of modeled data for this station (mouth of Tieton River) with data produced at the U.S. Bureau of Reclamation station TICW (Tieton R. near Tieton Canal Headworks) shows the two stations to be very similar in magnitude (Figure 15). A linear regression of the two stations shows a nearly one-to-one relationship between the two stations (Figure 16). Given the potential for error in each of the discharge records used to estimate discharge for the mouth of the Tieton River, and the striking similarity between the two discharge records, there is no discernible difference between Tieton River discharge near the Tieton Canal headworks and our estimated discharge at the mouth.

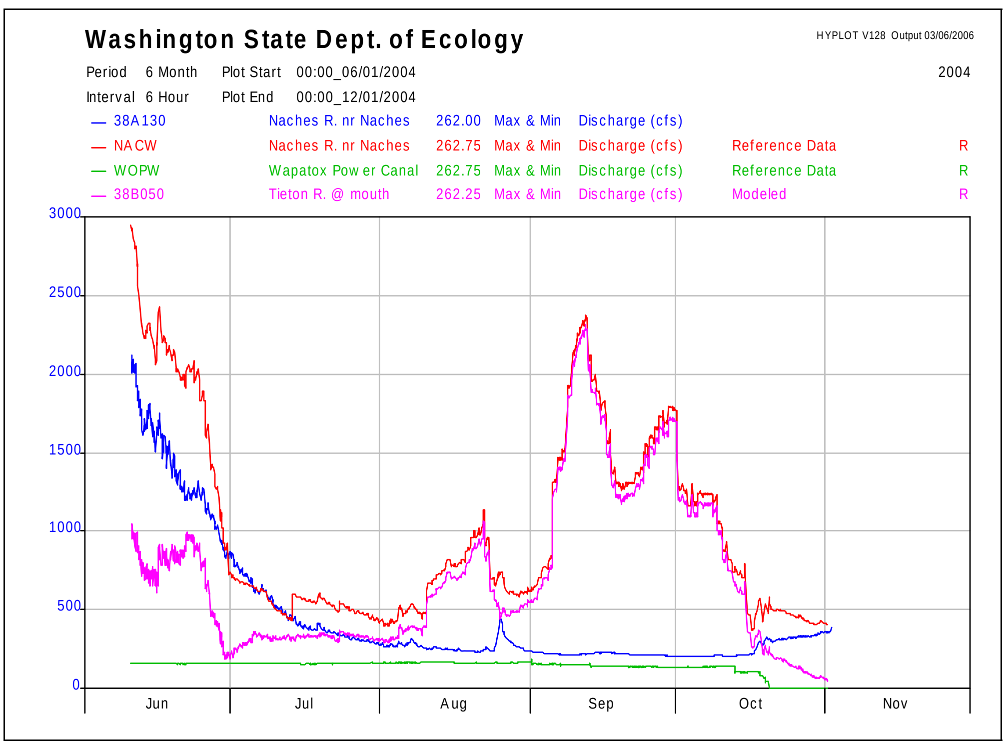

Figure 14: Comparison of streamflows near the Naches/Tieton confluence.

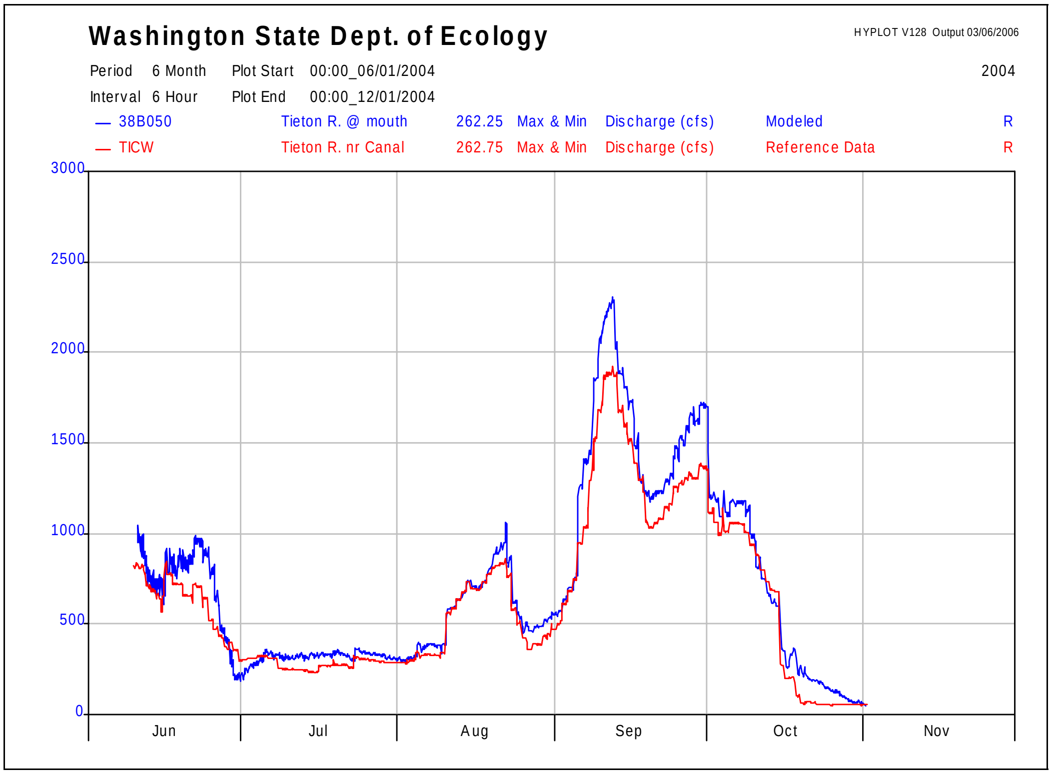

Figure 15: Comparison of streamflows at two locations on the Tieton River.

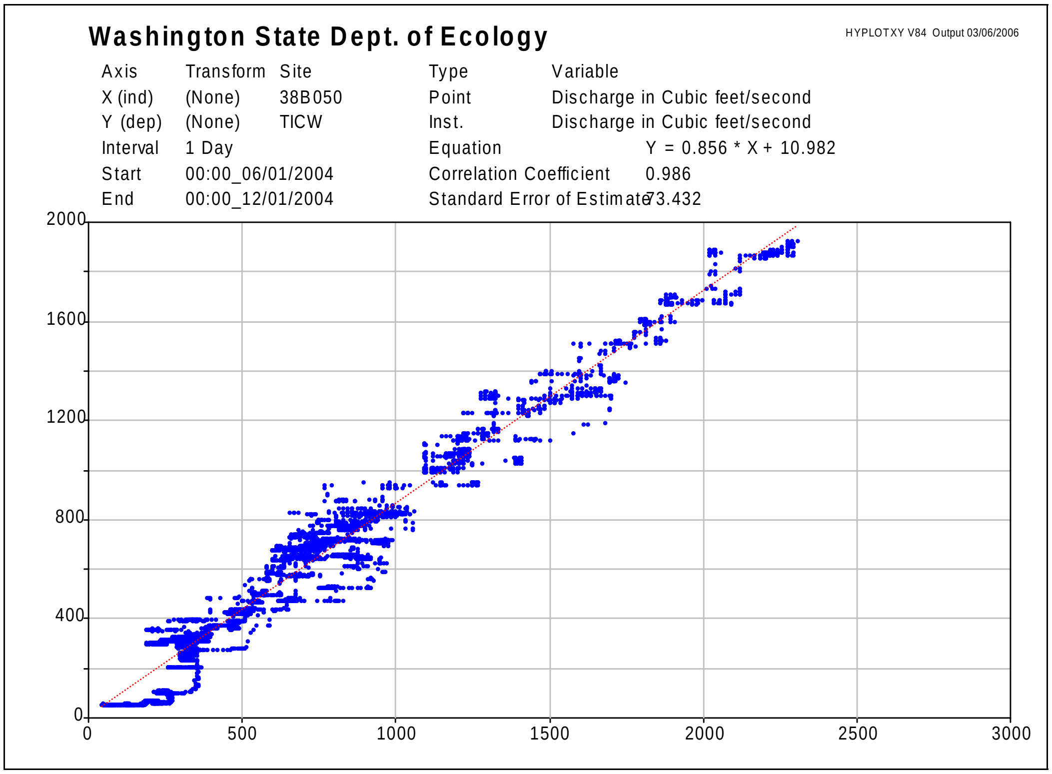

Figure 16: Linear regression of streamflows from two locations on the Tieton River.