WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

FLOW INVESTIGATION OF THE NISQUALLY RIVER LOWER REACH THURSTON COUNTY, WASHINGTON

November 2001

Publication No. 01-11-015
printed on recycled paper

This report is available on the Department of Ecology home page on the World Wide Web at http://www.ecy.wa.gov/biblio/0111015.html

For additional copies of this publication, please contact:

Department of Ecology Publications Distributions Office

Address: PO Box 47600, Olympia WA 98504-7600

E-mail: ecypub@ecy.wa.gov

Phone: (360) 407-7472

Refer to Publication Number 01-11-015

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

FLOW INVESTIGATION OF THE NISQUALLY RIVER LOWER REACH THURSTON COUNTY, WASHINGTON

by
Tom Culhane

Water Resources Program
Olympia, Washington 98504-7710

November 2001

Water Resource Inventory Area 11

Publication No. 01-11-015
printed on recycled paper

Table of Contents

Page

List of Figures and Tables

Page

Figures

Tables

Abstract

In 1988 Chapter 173-511 Washington Administrative Code (WAC) established minimum instream flow requirements for the lower reach of the Nisqually River. This WAC referenced a river mile (RM) 4.3 control point, however, a gage at this location was never established. The Department of Ecology (Ecology) is required to consider instream flows when acting upon water applications within the watershed. Consequently, the purpose of this study was to collect and analyze data for this location to determine whether instream flows were being met. Furthermore, by comparing these data with those collected by the U.S. Geological Survey (USGS) upstream, a relationship was sought which could be used to analyze whether RM 4.3 minimum flows have been met in the past and are being met in the future.

Due to hydrologic, logistic and access considerations, the site measured during this study was located at RM 4.6. The study method included developing a rating curve based on discharge measurements collected with a Swoffer flow meter on four occasions. A vented pressure transducer was also used to collect stage data from 8/8/00 through 11/5/01, excepting a four-hour hiatus on 8/17/00, a 32-day hiatus from 12/1/00 to 1/2/01, and a 1-day hiatus on 3/1/01. A linear correction factor was then applied to account for instrumentation drift, and stage data were converted to flows by means of the flow rating curve.

In November of 2000 Washington State moved into a period of drought and Tacoma Power dropped its releases from Alder Lake. This reduction resulted in a decline in flows measured at the RM 4.6 site. Nonetheless, the data collected suggests that Nisqually River flows were above the established minimum flows during all but portions of six days during the gaged period. Based on the potential for streamflow measurement error, there is actually a range of 0 to portions of 31 days over which minimum flows might not have been met. The timing of the 32-day data gap when the gaging equipment was removed makes it possible that there were additional days when minimum instream flows were not met.

The combined flows at the upstream USGS 12089208 and 12089500 gages were used as an indication of flows at the RM 4.6 site. A comparison indicates a shift from higher upstream to higher downstream flows starting in November 2000. There are many possible causes for this including measurement errors, and changes in tributary contribution, bluff seepage, and power canal seepage - as well as any influences caused by the drought.

Regression analyses of the RM 4.6 flow data versus the combined upstream data were used to develop a tool for predicting whether Nisqually River instream flows likely have been met in the past. These analyses produced the equation $y = 19.85x^{0.5792}$, where y equals the expected flows near RM 4.6 and x equals the combined data from the two USGS gages. Based on the historical upstream flow data and this equation, WAC 173-511 minimum instream flows were met all days at RM 4.3 from 6/9/88 through 8/8/00. This equation failed to detect the failure to meet minimum flows during January of 2001 (suggested by the corrected Ecology data) and the likely failure to meet minimum flows during December 2000 (suggested by the combined raw USGS upstream data). Consequently results produced by this equation are not entirely accurate.

Acknowledgements

The author wishes to thank Ecology's Environmental Assistance Program, and particularly Brad Hopkins, for producing the rating curve which was essential to measuring the river flows. Additionally, I wish to thank both Kirk Sinclair and Chris Neumiller who provided thoughtful review and input regarding this report.

Introduction

The Nisqually River drains the 720 square mile area of Water Resource Inventory Area (WRIA) 11. In 1988 Chapter 173-511 Washington Administrative Code (WAC) established an Instream Resources Protection Program (IRPP) for the basin. The WAC divides the river into four reaches and establishes minimum instream flow requirements or partial-year closures for each. This report focuses on the farthest downstream reach, which extends from the farthest upstream influence of mean annual high tide at river mile (RM) 4.3, to the outlet of the Centralia City Light power plant at RM 12.6 (Figure 1). The WAC identifies the control point for this reach as "New gage Nisqually River," but a gaging station was never established at this location.

The Department of Ecology (Ecology) is required to consider instream flows when acting upon surface or ground water applications within the watershed. The purpose of this study was to collect and analyze data from the designated control point to determine whether Nisqually River instream flows were being met. Furthermore, by comparing these data with those collected by the U.S. Geological Survey (USGS) upstream, a relationship was sought which could be applied to the USGS data to analyze whether instream flows likely have been met in the past. This relationship will also be available to determine whether flows are being met in the future.

Initially the plan was to conduct flow monitoring at the study site for one year starting in August 2000. When preliminary results were presented to the WRIA 11 Watershed Planning Committee on 5/9/01, however, this group asked that measurements continue at least through one additional dry season. For this reason the data collection period was extended through October 2001.

Background

Chapter 173-5-11 WAC specifies the following minimum instream flows for the "New gage Nisqually River":

Table 1. Nisqually River RM 4.3 minimum instream flows.

Month	Day	Flow (cfs)	Month	Day	Flow (cfs)
Januray	1	900	July	1	800
	15	900		15	800
February	1	900	August	1	800
	15	900		15	800
March	1	900	September	1	600
	15	900		15	600
April	1	900	October	1	700
	15	900		15	700
May	1	900	November	1	700
	15	900		15	700
June	1	900	December	1	800
	15	850		15	900

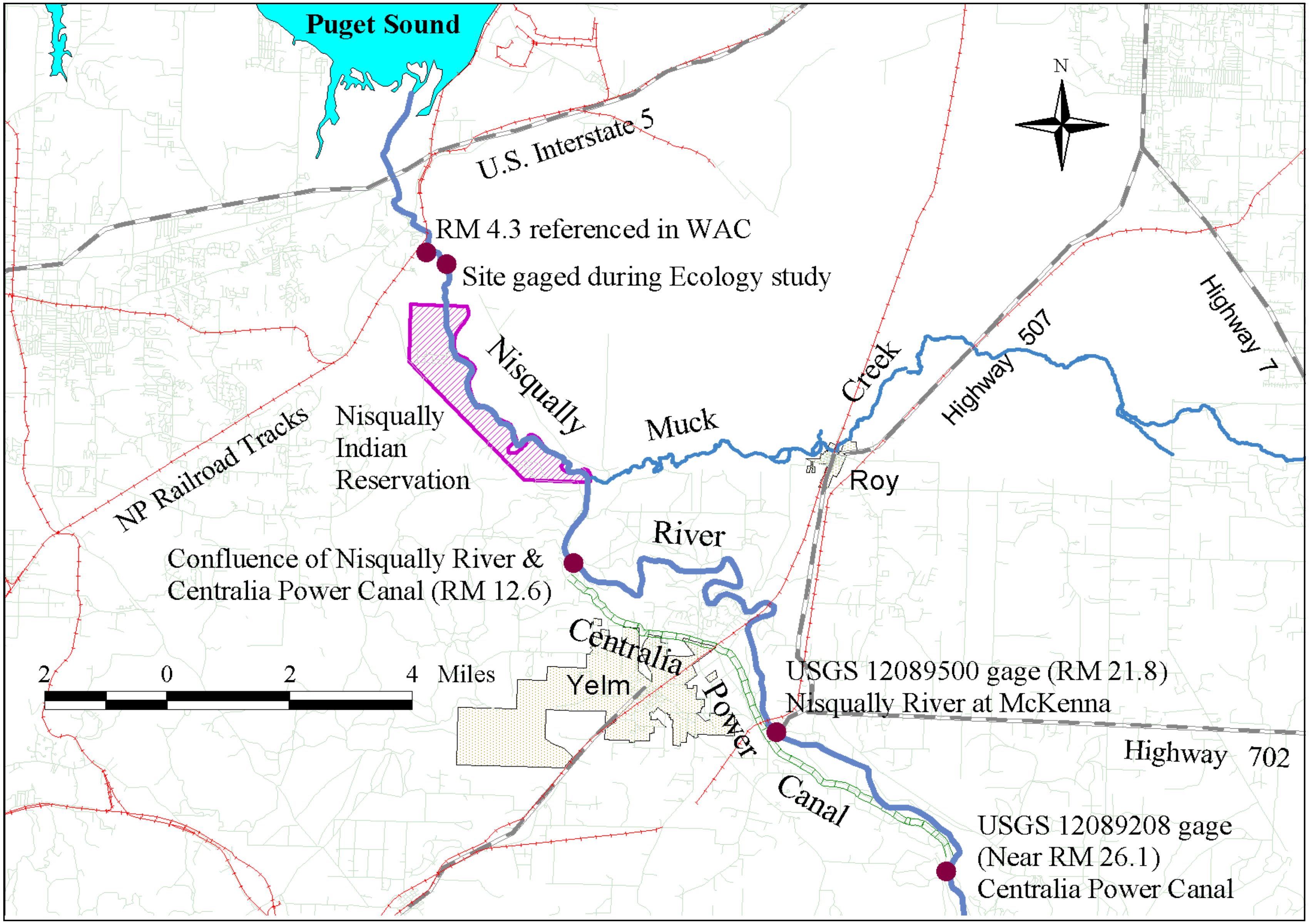

Figure 1. Location of Nisqually River and gages.

The purpose of these flows is to retain perennial rivers, streams, and lakes in the Nisqually Basin with instream flows and levels necessary to provide protection for wildlife, fish, scenic, aesthetic, environmental values, recreation, navigation, and to preserve water quality. The WAC prohibits further surface water withdrawals during times when these flows are not met. The WAC also established minimum flows for control points for three upstream reaches of the river.

Flows in the Nisqually River are heavily influenced by operation of the Alder and La Grande dams, as well as the river diversion through the Centralia City Light power project. These projects were built prior to establishment of Chapter 173-511 WAC and thus are not subject to the WAC's minimum flows. These projects are, however, regulated by the Federal Energy Regulatory Commission (FERC). According to FERC Docket No. P-1862-001, stipulation and settlement agreements between the Tacoma Power subdivision of Tacoma Public Utilities and the Nisqually Tribe, and also between Centralia City Light and the Nisqually Tribe, established minimum flow levels outside those set forth in the WAC. Accordingly, flows in the bypass section and the Nisqually River mainstem from the La Grande powerhouse (RM 40.8) to the Centralia City Light power canal diversion (RM 26.2) are established in the docket as follows:

Table 2. FERC-related minimum instream flows.

	Bypass	Mainstem
October 1 - December 15	550 cfs	700 cfs
December 16 - May 31	600 cfs	900 cfs
June 1 - July 31	500 cfs	750 cfs
August 1 - September 30	370 cfs	575 cfs

As a result of these agreements, Tacoma's releases at the La Grande Dam must be sufficient, "so that the flow in the mainstem portion of this Nisqually River, measured as flow reaching the Yelm Project Diversion Dam, shall at all times equal or exceed the greater of: (a) those flows specified in paragraph (1) above for the bypass, less 120 cfs, plus the lesser of 720 cfs or the calculated natural inflow at the Yelm Project Diversion Dam; or (b) the flows specified in paragraph (1) above for the mainstem." By comparison, the WAC's minimum flows for nearly the same "Mid Reach" of the Nisqually River (from RM 40.4 to RM 26.2) are as follows:

Table 3. Nisqually River RM 26.2 minimum instream flows.

Month	**Day**	**Flow (cfs)**	**Month**	**Day**	**Flow (cfs)**
Januray	1	900	July	1	800 (closed)
	15	900		15	800 (closed)
February	1	900	August	1	800 (closed)
	15	900		15	650 (closed)
March	1	900	September	1	600 (closed)
	15	900		15	600 (closed)
April	1	900	October	1	700 (closed)
	15	900		15	700 (closed)
May	1	900	November	1	700
	15	900		15	700
June	1	800 (closed)	December	1	800
	15	800 (closed)		15	900

Flows for the intervening dates not specified in the WAC, ramp gradationally between the preceding and subsequent flows specified in this table. The control point for these flows was established as gage 12086500, which has not existed since 1979. Further complicating matters is the fact that the WAC control point was located at RM 32.6, while the FERC docket control point is the Yelm Project Diversion Dam located at RM 26.2. The 120 cfs figure mentioned in the docket, presumably is meant to account for the influence of tributary inputs above the diversion dam. Nonetheless, the differences in minimum flows and control points in the WAC versus those established for Tacoma, make it difficult to compare the two.

Previous Attempts at Determining Lower Nisqually Flows

The nearest locations on the Nisqually River system continuously gaged by the USGS are a gage on the Nisqually River located near McKenna at RM 21.8 (Station Number 12089500) and a gage on the Centralia City Light power canal diversion, which returns water to the Nisqually at RM 12.6 (Station Number 12089208). These locations are considerably upstream of the RM 4.3 control point for the lower reach of the Nisqually River established in the WAC. Below these control points, the Nisqually receives local inflows from perennial springs, baseflow, and other sources, including Muck Creek at RM 10.6.

Between 1959 and 1991 the USGS collected 11 sets of non-storm event, miscellaneous discharge measurements at the Nisqually River I-5 bridge (approximately RM 2.4). In 1998 Northwest Hydraulic Consultants, subcontracting to Pacific Groundwater Group (PGG), calculated monthly flow duration plots by performing a regression analysis on this miscellaneous data and McKenna and Centralia City Light power canal gage data collected by the USGS. The results are presented in the 1998 PGG report, *McAllister Springs Wellfield – Phase II Supplemental Analysis of Pumping Effects and Proposed Mitigation*. Based on their analysis for April 1979 through June 1994, there were no significant violations of minimum instream flows for most months, with minor exceptions in August. There are concerns regarding this analyses, however, due to limited downstream data points and the possibility that the downstream data may have been tidally influenced. Consequently, while this analysis provides a useful estimate based upon the available information, it is inadequate for regulatory purposes.

Methods of Investigation

The WAC identifies the control point for the lower reach of the Nisqually River as being located at RM 4.3 in Section 9, T. 18 N., R. 1 E. The river mile index for the Nisqually River published by the Pacific Northwest River Basins Commission (1989) indicates that the Northern Pacific Railroad bridge crosses the river at RM 3.8. The site measured during this study is located upstream of this crossing, at approximately RM 4.6. This site located slightly upstream of the official control point was selected based upon the following considerations:

- Hydrologic - the river is straight both up and downstream of the study site, which provided suitable conditions for accurate measurements. RM 4.3 is located quite near a major bend in the river, which would make measurements less accurate due to differential flow across the width of the channel.
- Logistic - the site has well-placed trees, to which a portable stilling well could be attached. Additionally, the selected site receives less traffic from the public than the official gaging location, thus making it less susceptible to vandalism.
- Access - permission to install equipment was available from the landowners.

On four occasions between 8/18/00 and 2/27/01, Ecology's Environmental Assessment Program measured river flows at the study site using a Swoffer Model 2100 current meter and standard USGS discharge measurement techniques (Rantz, 1982). At the same time river stage (water-level height) was also recorded relative to a fixed staff gage located at the site. The flow data were then correlated with the river stage data in order to produce a flow rating curve for the site (Figure 2). This rating curve provides a means of estimating flows during times when only water-level data is collected.

River stage data were collected by Ecology's Water Resources Program 8/8/00 through 11/5/01 using an In-Situ Inc. mini-Troll vented pressure transducer and data logger. This unit automatically corrects pressure data for variations in temperature and barometric pressure. The transducer was mounted in a stilling well constructed from perforated, 2-inch galvanized steel pipe, with a 1¼ -inch slotted PVC inner liner. The stilling well was secured to the river bottom and a tree overhanging the river, and referenced to the staff gage used for rating curve development. Measurements were taken every 10 minutes initially, with this frequency decreased to every 20 minutes beginning 11/13/00. On 3/20/01 measurement frequency was further reduced to every 30 minutes in order to conserve data logger storage. Pressure data were converted to water-level depth equivalents based upon an assumed water density, the site latitude, and the land surface elevation of the site. During the first six weeks of the study, the site land surface elevation was incorrectly entered into the data logger software as 75 feet as opposed to 19 feet, the correct value. The site elevation is used by the program to estimate water density, which then is used to convert pressure to water head, however, this error did not significantly effect the measurements.

Factors Affecting Flows

Releases from the Alder and La Grande dams dominate flows in the lower reach of the Nisqually River. There are, however, many other factors which also affect flows such as tributary input, baseflow conditions (ground water contribution), and spring discharge. These factors, as well as the amount and timing of the dam releases, are all dependant upon climatic patterns. On 3/14/01, under recommendation from Ecology and the Executive Water Emergency Committee, Governor Gary Locke authorized Ecology to declare a drought emergency in Washington State. The onset of this drought had a major effect on the Nisqually River. In order to place the data collected during this study in perspective, it is necessary to develop an understanding of the factors which influenced Nisqually River flows.

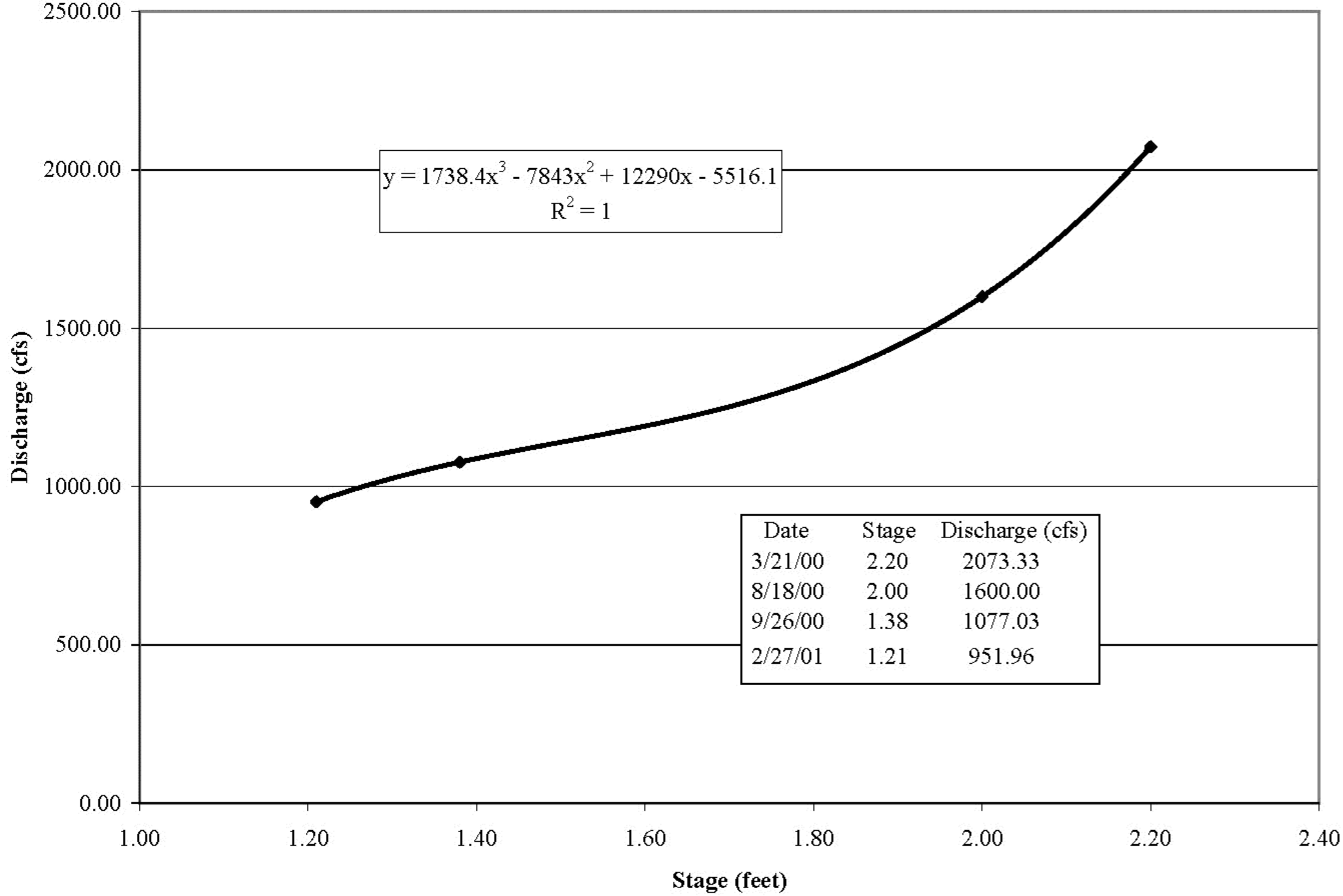

Figure 2. Flow rating curve for Nisqually River RM 4.6 site.

Snowpack on Mount Rainier

The Alder and La Grande dams are operated by the Tacoma Power subdivision of Tacoma Public Utilities and the release of water from these is largely a function of snow pack on Mount Rainier. In analyzing trends in the water supplying the two associated reservoirs, data were obtained from the National Resource Conservation Service (NRCS) Snotel site at Paradise Ranger Station in Mount Rainier National Park. This site is the only snow gage in the upper reaches of the Nisqually watershed. Cumulative data from Snotel sites are provided in water years. Water years correspond with the 12–month period from October 1 through September 30, and are designated by the calendar years in which they end. Water-year 2000, therefore, ends on 9/30/00. Analyses of precipitation by water years are useful in western Washington because they do not break any one winter rainy season into separate years.

In general, data from the Paradise site suggest that cumulative precipitation was slightly above average throughout most of water-year 2000, with the exception of August. Cumulative snow water content at Paradise was also above average for most of water-year 2000. The maximum difference between actual and average cumulative snow water content occurred in May 2000, at about the same time that snow stopped accumulating. At that time the snow water content was about 20 inches greater than the 65-inch average. Cumulative precipitation for water-year 2001 remained well below average and ended the year in October of 2001 at about 32 inches below the 109 inch per year average. The cumulative snow-water content was roughly 12 inches below average by 5/1/01. Snow-water content at Paradise was zero by July, as opposed to early August which is normally the case. In short, water-year 2001 was a very dry year.

Alder Dam

Tacoma Power calculates natural flows entering Alder Lake based upon a combination of discharge from the La Grande Dam and change in storage at Alder Lake (pers. com. Todd Lloyd, Tacoma Power, 1/16/01, 3/30/01 and 11/29/01). In essence these are predictions of the flows that would be expected in the Nisqually River in the vicinity of the lake, if the dams were not there. Figure 3 depicts Tacoma Power's predictions for October 1999 through October 2001. It is clear from this figure that Alder Lake inflow was far below normal during most of the study period. When these inflow predictions dropped off in November of 2000, the Nisqually River Coordinating Committee convened via conference call. This committee was formed as an outgrowth of previous FERC license proceedings and includes membership by Tacoma Power, the Nisqually Tribe, the National Marine Fisheries Service, the Washington State Department of Fish and Wildlife, and Centralia City Light. Concerned with the prospect of maintaining minimum flows throughout a potentially protracted drought, the committee agreed to reduce La Grande Dam discharge to 730 cfs (+/- 20 cfs) beginning in late November 2000. Thus at that time, Tacoma Power began to significantly restrict its releases of water to the middle and lower reaches of the Nisqually River.

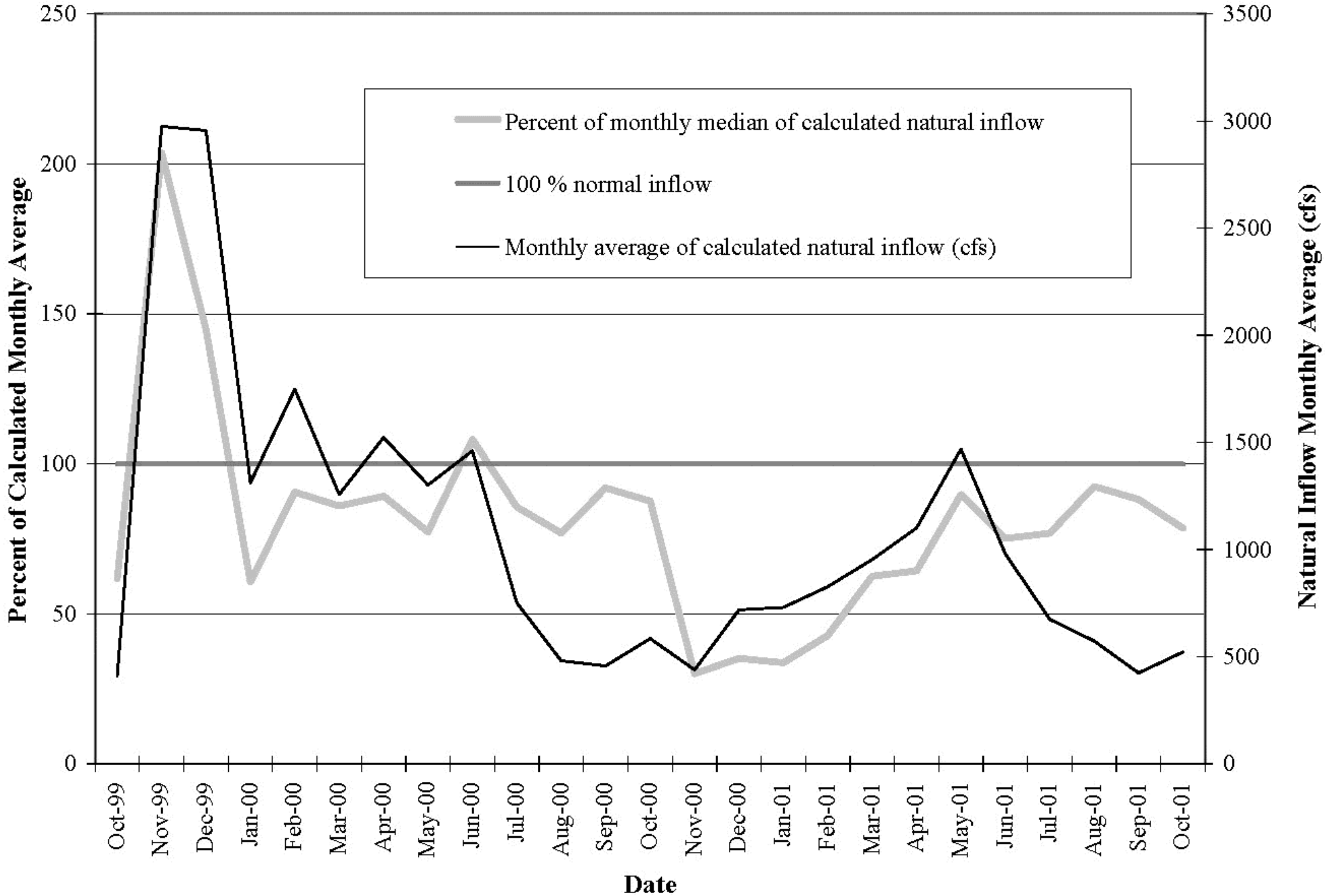

Figure 3. Estimated Alder Lake inflows October 1999 - October 2001 (Tacoma Power, pers. com. Todd Lloyd, 2001).

Other Basin Precipitation

Although snow pack on Mount Rainier is the largest factor affecting Nisqually River flows, rainfall lower in the watershed also contributes. For this reason National Weather Service data were analyzed for the Olympia airport site. The Olympia site is actually located a bit to the west of the study area within the Deschutes basin, but is close enough to pick up general trends. Figure 4 depicts precipitation data for Olympia available October 1999 through October 2001. This figure indicates that Olympia precipitation was higher than normal in November and December of 1999, then roughly normal through the summer of 2000. During the winter and spring of water-year 2001, however, precipitation was far below normal. The cumulative data for Olympia indicates that the year-end total for the water year was 20 inches below the 51-inch average by September 2001.

Much of the precipitation which falls in the Nisqually basin initially becomes ground water recharge, which affects river flows through baseflow contribution. In analyzing precipitation data, therefore, it is important to acknowledge the lag effect whereby reduced precipitation in the winter months can affect spring and base flow contribution during the summer months.

Other Surface Water Contributions

Flows which occur below La Grande Dam, but above the previously mentioned Nisqually gages, are supplemented by numerous tributaries, including Ohop Creek, Tanwax Creek, and Muck Creek, as well as springs and ground water conditions. Muck Creek is the largest tributary to the Nisqually below RM 12.6 (the confluence with the Centralia City Light power canal).

An investigation of the Nisqually Lake area by the USGS (Pearson and Dion, 1979) produced once-a-month synonymous discharge measurements for Muck Creek at the mouth and Muck Creek at Roy, August 1975 though August 1977. These data indicate a complex relationship between loosing and gaining conditions, which were significantly different from one year to the next. More recently, a gage was established on Muck Creek at Roy as part of a basin characterization study initiated by Pierce County (CH2M/Hill, 2000). Although the historical data presented in the USGS report indicate potentially significant changes between Muck Creek flows at Roy and at the mouth, the more recent data do provide an indication of Muck Creek's contribution to the Nisqually River during a portion of the study period.

Figure 5 presents monthly flow data for Muck Creek at Roy collected April 2000 through February 2001. These data indicate mean monthly flows ranging from a maximum of 129 cfs during April of 2000, to a minimum of 0.08 cfs during August and during September of 2000. As one indication of the variability, however, the recent data indicate a maximum flow of 17 cfs and a mean flow of 9 cfs for January 2001. By comparison, the older USGS spot measurement data indicate that flows in Muck Creek at Roy were 367 cfs on 1/14/76 (computed discharge from gage height and a rating table) and 1.51 cfs on 1/11/77 (actual discharge measurement, but with ice on the water surface).

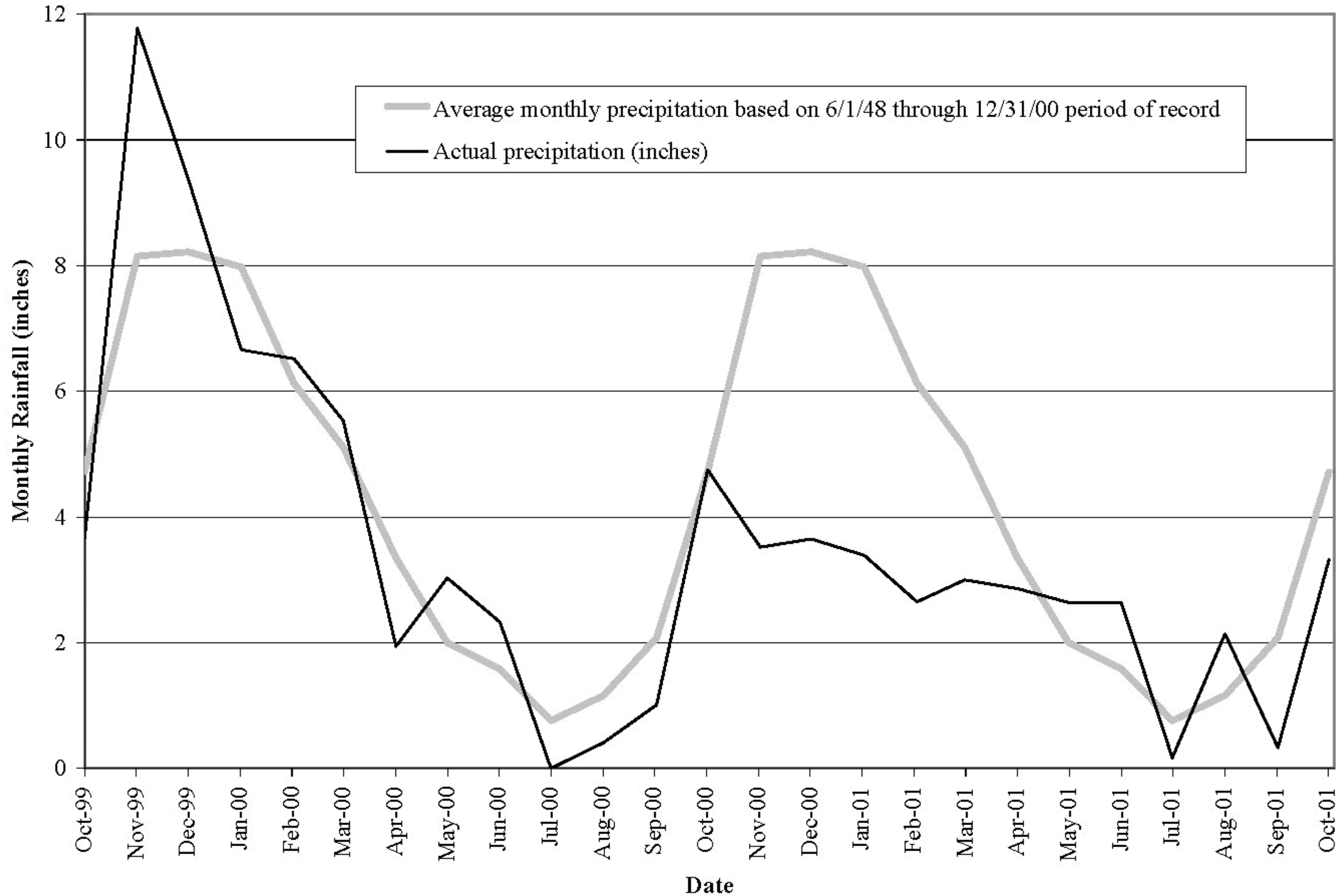

Figure 4. Olympia airport precipitation (National Weather Service).

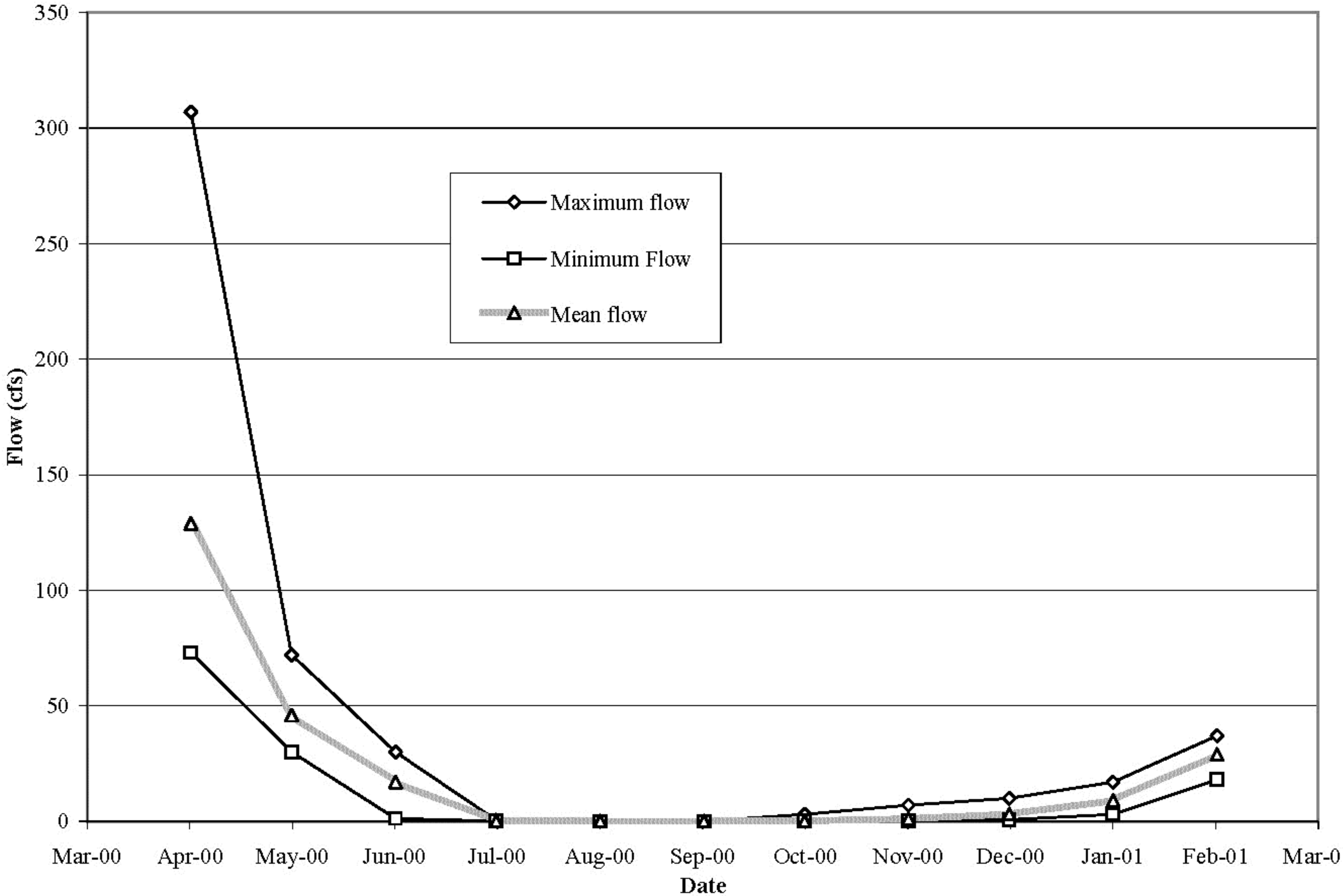

Figure 5. Flows in Muck Creek at Roy April 2000 - February 2001 (CH2M/Hill, 2000).

Springs also contribute water to the lower reach of the Nisqually River. The Pearson and Dion report includes discharge data for the spring used by the Nisqually Tribe Clear Creek Hatchery, which emanates from a bluff just east of the Nisqually River at approximately RM 5.6. These data indicate discharge as high as 4.6 cfs on 5/14/76. Not surprisingly, anecdotal information provided by the hatchery manager suggests significantly less than normal spring flow during much of the study period (pers. com. Bill St. Jean, 4/19/01). The hatchery requires roughly 10,000 gallons per minute in order to operate, and during normal years spring water is able to meet all of the hatchery needs except during the months of September and October. Starting in September 2000 through at least 4/19/01, however, the Tribe pumped its wells at approximately 7,000 gallons per minute in order to augment its spring-fed supply.

Analysis of Flow Data

Ecology Data versus Established Minimum Flows

Figure 6 presents the results of the flow measurements for the study site collected between 8/8/01 and 11/5/01. There was a four-hour hiatus in data collection on 8/17, a 32-day hiatus from 2/1/00 to 1/2/01 (when the equipment was removed for warranty work), and a 1-day hiatus in data collection on 3/1/01 (due to equipment failure).

Streamflow measurements are never 100 percent accurate. One possible source of error during this study comes from instrumentation drift. Drift refers to the loss of pressure transducer accuracy over time. The potential for drift increases over time, thus regular site visits were made to recalibrate the transducer with the staff gage. The duration between site visits varied from 10 to 49 days and the stage errors detected ranged from 0 to 0.057 feet. Consequently, the raw data collected by Ecology were corrected for instrumentation drift through the application of a linearly distributed correction factor. The amount of drift which occurred between visits was divided by the number of measurements recorded, then added incrementally to each intervening measurement based upon a linear distribution. In order to make large data sets manageable during this procedure, data collected at more frequent time intervals were first averaged. Where available, the 10-minute data were averaged to 30-minute increments and the 20-minute data were averaged to 40-minute increments. These data were then corrected for instrumentation drift based upon a linear distribution of the drift detected.

As shown in Figure 6, Nisqually River flows were above established Chapter 173-510 WAC minimum levels during most of the gaged period. Flows ranged from 1031 to 1592 cfs August through early November 2000, which was at least 300 cfs greater than the minimum flows levels. Flows dropped as low as 816 cfs during one measurement on 11/23/00, then rebounded and leveled off to approximately 1,000 cfs on 12/1/00 before the equipment was removed for one month. After the equipment was reinstalled on 1/2/01, flows tended fluctuate in the 900 to1,000 cfs range for about one month, with variations including dips below the 900 cfs minimum level during portions of six days in January. Flows varied after that time, but in general they increased such that flows never again came close to dipping below minimum instream flow levels.

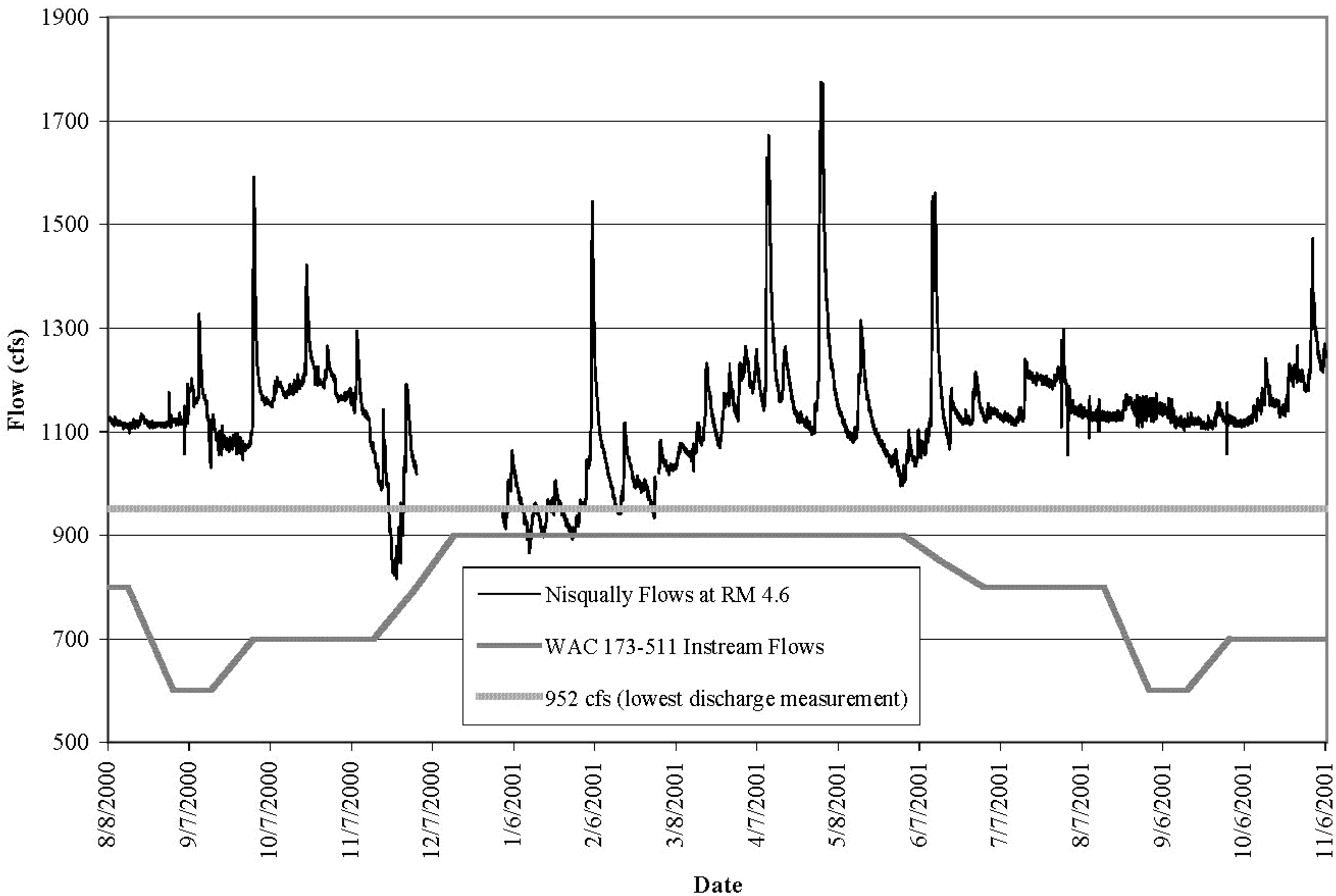

Figure 6. Nisqually River flows 8/8/00 - 11/6/01 at RM 4.6.

As mentioned above, Tacoma Power reduced La Grande Dam discharge to 730 cfs (+/- 20 cfs) in late November of 2000. This reduction was made in response to mounting drought conditions and resulted in an obvious decline in flows measured during 38 miles downstream at RM 4.6. The difference between the measured flows and this approximately 730 cfs release attests to the influence of the intervening tributaries, as well as springs, ground water and precipitation.

Tacoma Power is not required to meet the minimum flows established in Chapter 173-511 WAC, but the minimum flows associated with Tacoma's FERC license has some similarities to the "Mid Reach" Nisqually River flows established in the WAC. Even the farthest downstream point of this reach, however, is about 22 miles upstream of the WAC control point for the lower reach of the Nisqually River (RM 4.3). Considering the differences in the "Mid Reach" flow requirements and the distance between the upstream stretch in which Tacoma is striving to maintain instream flows, it is impressive that the WAC minimum flows for the lower reach were as closely met as described above, even during a drought.

It is also worthy of mention, however, that the timing of the 32-day data gap when the gaging equipment was removed for warranty work from 12/1/00 through 1/2/01, was unfortunate. Based on the flows depicted in Figure 6, it appears quite possible that there were additional days during that month when Nisqually River lower reach minimum instream flows were not met.

Potential Errors in Streamflow Measurements

There are a number of potential sources of error associated with discharge measurements other that those caused by instrumentation drift. The flow rating curve is the means by which flow data are created from stage measurements. The flow data which Ecology ultimately produced, therefore, are only as accurate as the flow rating curve. The rating curve used during this study was based upon four discharge measurements, with the lowest measured flow being 952 cfs. Below that amount, the rating curve has only been projected. Because flows below that amount are less accurate and some of the most critical, 952 cfs has also been depicted in Figure 6.

Another possible source of rating curve error relates to changes in the shape of the river channel. Ideally it would have been helpful to have discharge measurements taken in October 2001 to verify that the rating curve reflected river conditions toward the end of the study. The most recent measurements, however, were taken on 3/3/01. Fortunately, very few high flow events occurred beyond that time through November 2001. Consequently, it is unlikely that the channel morphology changed significantly.

A comprehensive study by Sauer and Meyer (USGS, 1992) suggests that standard errors associated with streamflow measurements, such as those used to develop the rating curve, range from three to six percent. As mentioned above, the recent Ecology data suggest that during January 2001, Nisqually River flows approached 900 cfs and minimum instream flows violations began occurring. For perspective, a six percent error compounded onto a 900 cfs flow would result in a flow error of 54 cfs. Applying a six percent error to the entire data set, then *subtracting* the resultant amounts from the data, suggests that flows would not have been met during portions of 31 days during the measured period. This compares with portions of six days based on the unadjusted Ecology data. *Adding* a six percent error, on the other hand, suggests that flows were met during the entire gaged period.

Analysis of Historical Flows

Relationship between Ecology Data and Upstream Flows

USGS gage 12089500 on the mainstem of the Nisqually River is located at the State Highway 507 bridge at McKenna at RM 21.8. The Centralia City Light power canal is used to divert water from the Nisqually River at approximately RM 26.1 and return water at approximately RM 12.6. USGS gage 12089208 is located on the power canal about 500 feet downstream of the headworks dam.

Figure 7 compares Nisqually River average daily flow data for Ecology's RM 4.6 site and the combined provisional flow data available for the upstream USGS 12089208 and 12089500 gages. This figure indicates that flows were generally higher upstream than downstream prior to 11/13/00, and downstream flows were generally higher than upstream flows after that time. It is appears significant that the relationship between upstream and downstream flows from August through November of 2000 is different than during those the same months in 2001. Specifically, the data indicate that the combined flows from the two USGS gages were higher than the RM 4.6 flows for a 86 of the 96 days from 8/9/00 through 11/12/00, and only 12 days thereafter (excepting days when the Ecology gage was not operating). The extremes ranged from a 10/1/00 event when upstream flows were 294 cfs greater than downstream flows, to a 5/30/01 event during which downstream flows were 178 cfs greater than upstream flows.

The potential causes for this apparent shift in the Nisqually River between RM 12.6 and RM 4.6 is unknown. As always, one possibility is that there were measurement errors at the Ecology site and/or the USGS gages. Changes in contributions from Muck Creek are another possibility. The CH2M/Hill flow data for Muck Creek collected at Roy indicate mean monthly flows of 0.08, 0.08, 0.26 and 1.2 cfs during August, September, October and November of 2000, respectively. Consequently Muck Creek did not provide much contribution during this period. A single spot measurement by the USGS of 24.6 cfs on 11/17/75, however, demonstrates the potential for a much greater contribution. Beyond this there is a great deal of seepage coming off the bluffs along the Nisqually Valley close to the river (pers. com. Brian Drost, USGS, 11/24/99). Both tributary and spring inflow, as well as the potential for the gain or loss of groundwater, would have affected flows measured at the lower Nisqually River study site.

In addition to the above, the unlined power canal may seep water along its 9.2 mile length. Based on the elevated nature of the canal, one would expect that some seepage could go downward to recharge the water table. For the roughly 4.5 mile stretch below the power canal diversion dam but above the 12089500 gage, therefore, such seepage theoretically could be counted twice. This could occur once as it passes the 12089208 gage and second time after it rejoins the Nisqually River then passes the 12089500 gage. Previously, little effort has been spent trying to quantify

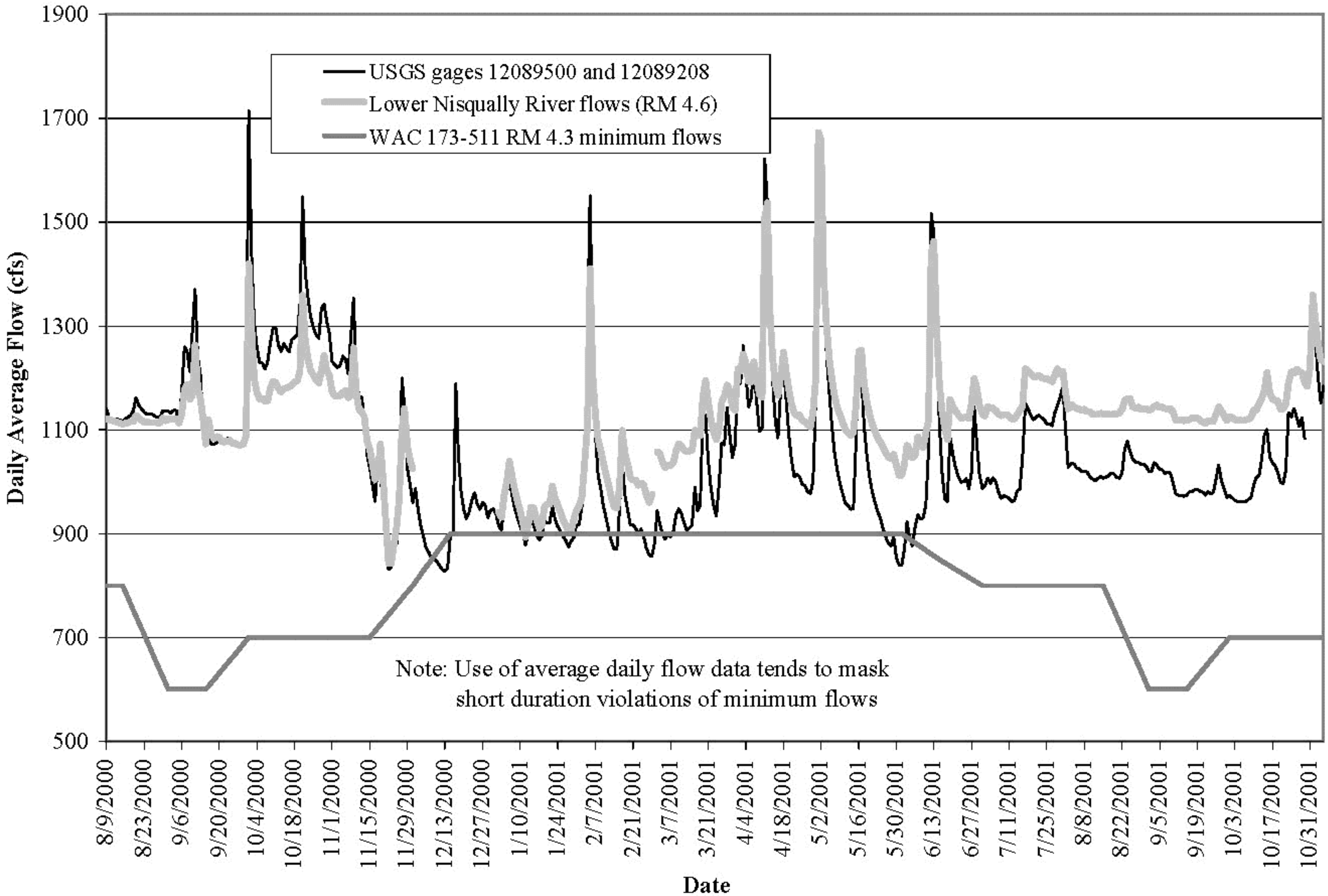

Figure 7. Daily Nisqually River RM 4.6 flows and combined USGS flows 8/9/00 - 11/5/01.

seepage losses from the power canal. (pers. com. Ron Whitman, Centralia City Light, 4/19/01). Weirs have been placed outside the canal at four locations to measure flow at places where obvious seepage is occurring through the levee. The combined surface flow at these locations was 83 gallons per minute (0.18 cfs) on 4/19/01 - an amount which is negligible in this analysis.

On two occasions Ecology's Environmental Assessment Program measured the flow in the power canal, at the bridge located roughly 500 feet upstream of the point where the canal enters the powerhouse penstocks. During the first site visit, measurements were made with both a Swoffer current meter and an RD Instruments, Inc. Rio Grande 1200 Acoustic Doppler Current Profiler (ADCP). During the second site visit measurements were made with the ADCP alone. The purpose of these measurements was to provide data to compare with provisional flow data available for the USGS 12089208 gage located roughly 9 miles upstream. The first measurement took place on 8/16/01, when flow at the USGS gage was about 630 cfs. On that occasion Ecology measured a flow of 670 cfs using the current meter and 660 cfs using the ADCP. During a site visit on 12/6/01 Ecology measured a flow of 804 cfs near the powerhouse, while the corresponding flow at the USGS gage was approximately 765 cfs. These data suggest an increase of about 30 to 40 cfs during the dry season, and about 39 cfs in December. As always, however, the potential for error must also be considered. As mentioned above, standard errors associated with streamflow measurements often range from three to six percent. A six percent error compounded onto a 670 cfs measurement, for example, produces a flow range between 630 to 710 cfs. If the flow was only 630 cfs on 8/16/01, this suggests that no gain occurred in the power canal.

Historical Data Versus Established Minimum Flows

Regression analyses were performed on the daily average of flow data collected at RM 4.6 and the combined upstream USGS data. Careful inspection, however, suggests a slight split in the data. When the data for flows prior to 11/13/00 are plotted with a different symbol, two separate trends emerge (Figure 8). Mid-November is the time period when conditions shifted from those of generally higher upstream flows to those of generally higher downstream flows. This shift complicates selection of single trendline to best fit all flow conditions. It would not be practical, however, to apply two separate trendline equations to the past and future data collected at the USGS gages, as there would be no reference to determine which equation was best to apply. For this reason, the data plotted in Figure 8 were treated as a single set when performing the trendline analyses.

Various trendlines were projected onto the data in Figure 8, including those generated by linear, logarithmic, 2nd order polynomial, exponential and power analyses. A projection of the power trendline nearly crosses through the origin of the x and y axes. This suggests no local inflow between the upstream USGS gages and the Ecology site. Given the uncertainties in our understanding of the system, this is the most conservative interpretation. The formula for the power trendline is $y = 19.85x^{0.5792}$, where y equals the expected flows near RM 4.6 and x equals the combined data from the two USGS gages. The R squared coefficient for this trendline is 0.7. Considering the limited hydrogeologic information available, it also seems reasonable to assume that some inflow might occur over the stretch of river between the upstream USGS gages and the

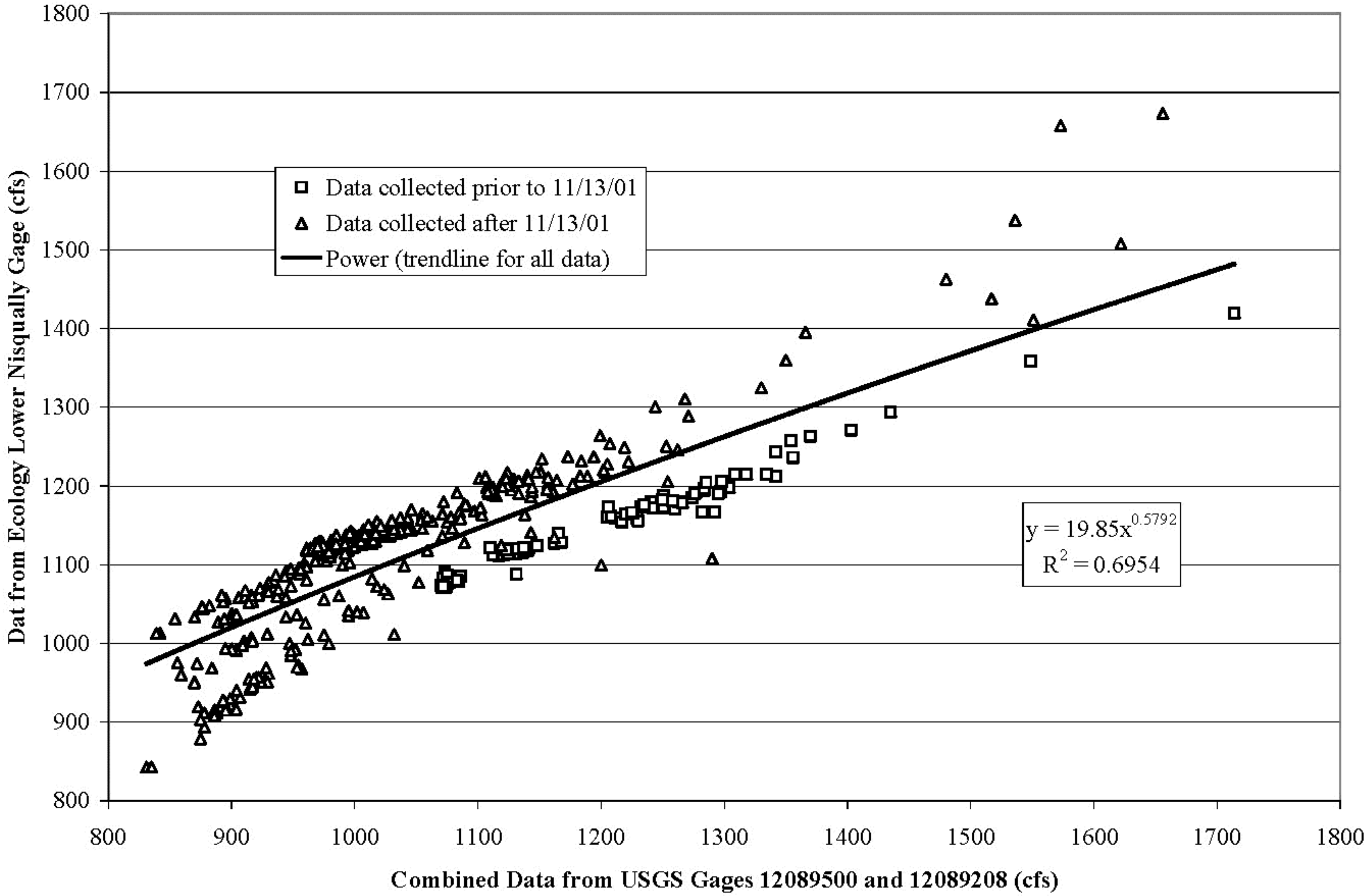

Figure 8. Correlation between Ecology RM 4.6 data and USGS upstream data.

Ecology site. The 2nd order polynomial crosses the y axis at the next least amount, however, the y intercept is nearly the same as that for the linear trendline. As the linear trendline is a simpler case, this trendline was also considered. The equation for the linear trendline is $y = 0.5917x + 493.67$, with an R squared coefficient of 0.71.

In order to select the best trendline for use in predicting flows at RM 4.6, the corrected Ecology data was plotted directly beside the predictive results for both the power and linear trendline equations. This plot indicated little differences between the predictions based on either of the two. The power equation did, however, predict slightly lower flows during January 2001, As this was the critical time with respect to minimum instream flows during the study period, this equation is considered a better predictor of flows at RM 4.6.

Figure 9 is a plot of the corrected Ecology data and the power equation predicted data. This graph demonstrates that the equation did not predict flows at RM 4.6 with a great deal of precision. The plot further suggests a shift beginning about 3/2/01, prior to which predictions based upon the equation were higher than those experienced at RM 4.6, and beyond which predicted flows were lower.

Bearing in mind all the limitations discussed above, the combined historical flow data for the two upstream USGS gages were applied to both the power trendline and linear trendline equations, in order to predict historical flows. These results were then compared with the WAC 173-511 RM 4.3 minimum flows in order to predict whether minimum flows were met. The results using both equations suggest that instream flows were met at RM 4.3 during the entire period from 6/9/88 (the date of the establishment of the WAC) through 8/8/00 (the start of the Ecology study).

Unfortunately, the results of the predictions of historical violations of instream flows based upon these equations were less than precise. For example, when these same formulas are used to predict flows during January of 2001, the results suggest that minimum flows were never violated. This clearly conflicts with results suggested by the actual Ecology data. One possible cause for this discrepancy relates to the fact that the analysis of the combined USGS data relied upon average daily flow data, since that is the format in which the USGS data are available. Averaging data collected at more frequent intervals tends to mask spikes of shorter intervals. To test the relevance of this, the Ecology data were subsequently averaged on a daily basis, then compared to the RM 4.3 minimum instream flows. This analysis indicates only one day during January of 2001 when instream flows were not met, versus the portions of six days suggested using the non-averaged Ecology data.

Discussion and Conclusions

Most of the Ecology flow measurements discussed in this report were collected while Washington was in the midst of a drought. Paradise station Snotel data, Tacoma Power's Alder Lake inflow estimates, and the Olympia airport weather station data all attest to this. In many respects this is fortunate, as it has led to results which reflect somewhat worst case conditions. Nonetheless, this study *began* during a period of slightly above average precipitation.

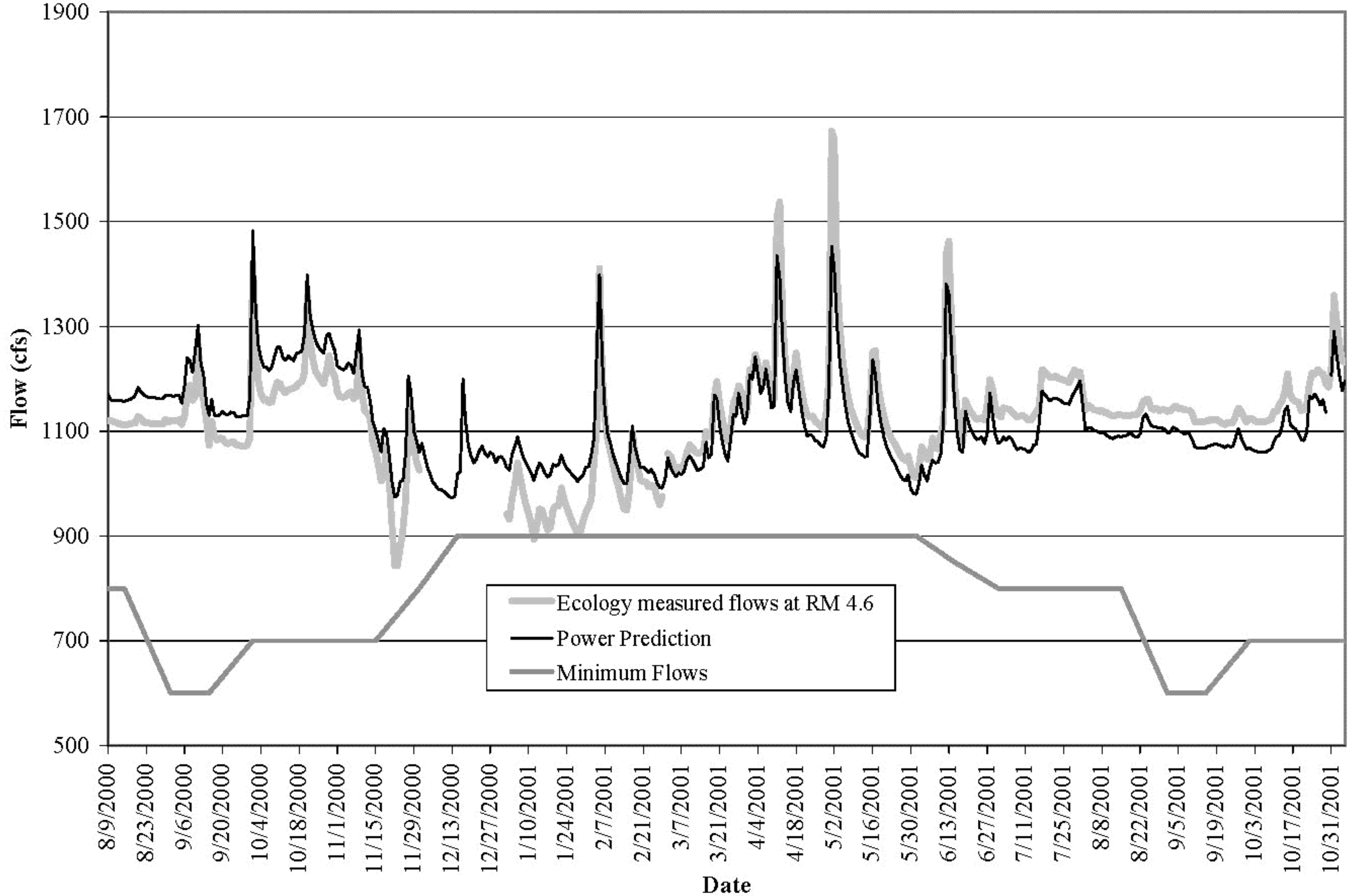

Figure 9. Actual Nisqually River RM 4.6 flows and flows generated by the power equation.

The Ecology data (corrected for instrumentation drift) indicate that the lower reach of the Nisqually River met established minimum instream flows during late summer and early fall of 2000. In November of 2000, however, precipitation fell far short of normal conditions and Tacoma Power dropped it's releases from Alder Lake to a minimum 730 cfs. This reduction resulted in a clear decline in flows measured by Ecology at the RM 4.6 site. The difference between the Ecology measured flows and the 730 cfs dam release attests to the influence of the numerous intervening tributaries, as well as springs, ground water and precipitation. Based on the collected data, it appears the lower Nisqually River met minimum instream flows for all but portions of six days during the study period (in January 2001). Considering the differences in the "Mid Reach" flow requirements and the distance between the upstream stretch where Tacoma is striving to maintain instream flows, it is impressive that these minimum flows were so closely met, even during a drought.

The timing of the 32-day data gap when the gaging equipment was removed, however, was unfortunate. Based on the flows depicted in Figure 6, it is quite possible that there were additional days 12/1/00 through 1/2/01, when lower reach Nisqually River minimum instream flows were not met. On the other hand, standard errors associated with streamflow measurements could skew the number of days flows were not met in either direction. For example, an assumed six percent error *subtracted* from the entire data set suggests flows would not have been met during portions of 31 days during the measured period. An assumed six percent error *added* to the entire data set, on the other hand, suggests flows were met during the entire gaged period.

Figure 7 compares Nisqually River average daily flow data for RM 4.6 and the combined flows for the upstream USGS 12089208 and 12089500 gages. These data suggest that flows were higher upstream than downstream for a 86 of the 96 days from 8/8/00 through 11/12/00, and only 12 days thereafter. As always, there is the possibility that the perceived shift, at least in part, was a product of measurement errors by either Ecology or the USGS. It appears more than coincidence, however, that this began at roughly the same time as the onset of a drought.

A number of factors relating to this shift would be affected by changing climatic conditions. Muck Creek contributes flow to the Nisqually River between RM 12.6 and RM 4.6, as does seepage coming off the bluffs close to the river. Recent flow data collected by CH2M/Hill, suggest mean monthly flows of only 0.08 cfs during August and during September of 2000. This low tributary contribution corresponds with the period during which Nisqually flows downstream of Muck Creek were lower than those upstream. What is unknown, however, is what flows were during that same period in 2001.

The Centralia City Light power canal is unlined and may itself either gain or loose water. Based upon the locations of the two upstream USGS gages, it is theoretically possible that some canal water may have seeped out, then re-entered the Nisqually River above the McKenna gage, and thus essentially have been counted twice. Two flow measurements made by Ecology above the power plant, however, suggest that the canal actually *gained* 30 to 40 cfs both in August 2001 and December of 2001. Additional measurements would be needed to verify gaining and/or loosing conditions - especially on a year-round basis.

In general, all of the above relates to the *relative* importance of the various factors within the hydrologic system. Fortunately, data were collected during an August through November time frame for two years running, and this facilitates some comparisons. For example, upstream flows in the Nisqually River (as suggested by the combined flow at the USGS 12089500 and 12089208 gages) were generally less August through November of 2001, compared with flows during those same months in 2000 (due to the drought). If ground water contribution or spring flow during this period was less effected or nearly the same, than their relative importance of these would have been increased. This might, at least in part, explain why downstream flows could be greater than upstream flows at the conclusion of a drought, but not before.

In addition to the above, analyses were performed to determine whether it was likely that Nisqually River instream flows have been met in the past. Based upon regression analyses performed on plots of daily average flow data collected at RM 4.6 versus the combined upstream USGS data, equations for power and linear trendlines were derived. In order to select the best trendline for use in predicting lower Nisqually River flows, the corrected Ecology data was plotted directly beside the predictive results for both the power and linear trendline equations. The power equation predicted slightly lower flows during January 2001. As this was the critical time with respect to minimum flows during the study period, this equation is considered a better predictor. The formula for the power trendline is $y = 19.85x^{0.5792}$, where y equals the expected flows near RM 4.6 and x equals the combined data from the two USGS gages.

The combined historical flow data for the two upstream USGS gages were applied to both the power trendline and linear trendline equations, in order to predict historical flows for the control point for the lower reach of the Nisqually River (RM 4.3). These results were then compared with the WAC 173-511 flows in order to predict whether minimum flows had been met. The results using both equations suggest that instream flows were met at RM 4.3 during the entire period from 6/9/88 (the date of the establishment of the WAC) through 8/8/00 (the start of the Ecology study).

Figure 9 is a plot of the corrected Ecology data and the power equation predicted data. Unfortunately, this graph demonstrates consistent errors in the RM 4.6 predictions. When the trendline equations were used to predict flows during January of 2001, the results suggest that minimum flows were never violated during January of 2001. This conflicts with results suggested by the actual Ecology data. One possible cause for the discrepancy relates to the fact that the analysis of the USGS data relied upon average daily flow data. Averaging data collected at more frequent intervals tends to mask shorter interval spikes. To test the relevance of this, the Ecology data were averaged on a daily basis, then compared to the RM 4.3 minimum instream flows. This analysis indicates only one day during January of 2001 when instream flows were not met, versus the portions of six days suggested using the non-averaged Ecology data.

In short, predictions of violations of minimum instream flows for the lower reach of the Nisqually River based upon these equations are less than precise. Predictions of whether minimum flows are being met in the future based upon these same equations, therefore, can not be considered entirely accurate. In order to state with certainty whether flows are being met on the lower reach of the Nisqually River, a long-term stream gage would need to be established at or near the official control point at RM 4.3.

Finally, it is worth noting that the provisions of Chapter 173-511 WAC seem inconsistent with regard to reaches of the Nisqually River which are located up-gradient to the lower reach investigated during this study. Specifically, the Bypass Reach and the Mid Reach are both identified in the WAC as having partial year closures from June 1 through October 15, beyond the minimum flows set for these control points for the remainder of the year. The Upper Reach (that furthest up the watershed), however, has only year-round minimum flows set. That implies that water is provisionally available on that stretch of the Nisqually provided these minimum flows are met. Such conclusions are contradictory, however, given that any consumptive use of water on the uppermost reach June 1 through October 15, would also result in reduced flows in the Bypass Reach and the Mid Reach during their closure periods.

Selected References

Drost, Brian W., 1999. Hydrologist for U.S. Geological Survey, Washington District Water Resources Division, personal communication.

CH2M/Hill, 2000. Muck Creek basin study phase 1, basin characterization plan, draft report. Prepared for Pierce County Public Works and Utilities. 34 p., plus figures and appendices.

Lloyd, Todd, 2001. Power Analyst Tacoma Power subdivision of Tacoma Public Utilities, personal communication 1/16/01, 3/30/01 and 11/29/01 .

National Weather Service data available at the University of Washington Department of Atmospheric Sciences website at:
http://www-k12.atmos.washington.edu/k12/grayskies/nw_weather.html

Pacific Groundwater Group, 1998. McAllister Springs wellfield - Phase II supplemental analysis of pumping effects and proposed mitigation. 44 p., plus figures and appendices.

Pacific Northwest River Basins Commission, 1989. River mile index -- Deschutes River, Nisqually River, Puyallup River, Green River, Lake Washington and Snohomish River, Washington. 53 p.

Pearson, H.E., and Dion, N.P., 1979. Water resources of the Nisqually Lake area, Pierce County, Washington. U.S. Geological Survey Water-Resources Investigations 78-101, 34 p.

Rantz, S.F., et al., 1982. Measurements and computations of streamflow: volume 1. measurements of stage and discharge. U.S. Geological Survey Water Supply Paper 2175, 284 p.

Sauer, V.B. and Meyer, R.W., 1992. Determination of error in individual discharge measurements. U.S. Geological Survey Open-File Report 92-144, 21 p.

St. Jean, Bill, 2001. Hatchery Manager for Nisqually Tribe Clear Creek Hatchery, personal communication.

USGS provisional stream flow data available at http://water.usgs.gov/nwis/sw

Whitman, Ron, 2001. Centralia City Light power house manager, personal communication.