Toward a Working TMDL: A Watershed Plan for The Van Duzen River Basin

Agreement # 06-149-551-0

Annual Monitoring Report

October 2007

Van Duzen Watershed Project

Project Director ___________________________ **Date** ___________________

Grant Manager ___________________________ **Date** ___________________

Introduction

This Monitoring Report is a continuation of the report submitted in May 2007. Data submitted in May primarily depicted turbidity as a function of stage. Since that report was submitted, discharge at the monitoring sites was calculated for most of the streams using a variety of methods, thereby allowing turbidity to be viewed as a function of discharge as well.

The monitoring reports submitted on behalf of the Van Duzen Watershed Project will describe volunteer monitoring activities conducted by The Van Duzen Watershed Project (VDWP) within the Lower Van Duzen River Basin. Through the work of volunteers, Friends of the Van Duzen River (FOVDR) has been monitoring streams of historic significance to salmon populations since 2001. As an offshoot of FOVDR, the Van Duzen Watershed Project promotes continued monitoring of water quality by volunteers and cooperation between our research activities and state agencies. Monitoring efforts are intended to record water quality conditions, including levels of suspended sediment and turbidity, and to better understand the relationship between water quality and land use within the basin.

Geographical Setting.

The Lower Van Duzen River Basin comprises the extent of the study area, and extends from the town of Bridgeville, CA upstream, to the point where the Van Duzen River merges with the Eel River near the town of Alton, CA, including the large Yager Creek drainage area (Map 1). The Lower Basin is approximately 244 square miles in area (or 155,989.5 acres or 631.3 sq. kilometers). The headwaters of the Van Duzen River originate in Trinity County, but the entire lower basin is located in Humboldt County.

Parameters and Conditions to be Monitored.

As the project focuses strongly on the survival of salmon populations, the major parameters of concern are those that tend to degrade stream habitat, including suspended sediment and turbidity, temperature, pH, and dissolved oxygen, and discharge. Secondarily, we are also concerned with the physical makeup of stream habitats (habitat types), physical recognition of sedimentation including bedload in stream cross-sections and degree of embeddedness, macro invertebrate populations as indicators of water quality, and other flora and fauna such as vegetation types, fish species, and reptiles, birds, and amphibians. This report focuses on the results of the turbidity grab sampling program that took place from October 2006 through April 2007.

Methods

The TTS station at Cummings Creek.

Early in HY07, a TTS station was constructed and outfitted on Cummings Creek (Site VDC), roughly 3 miles upstream of where Highway 36 crosses Cummings Creek. Personnel at the Redwood Sciences Lab, located adjacent the campus of Humboldt State University, developed turbidity Threshold Sampling (TTS) over 10 years ago (Eads & Lewis 2002). Redwood Sciences Lab is a research station for the USFS and has an extensive network of these stations on Caspar Creek to monitor sediment in the Jackson State Forest in Mendocino County. Redwood Sciences Lab provides all information and software for TTS sampling for free on their website. Implementation files, sampling software, and TTS literature can be found at http://www.fs.fed.us/psw/topics/water/tts/.

TTS is used to calculate annual suspended sediment loads by measuring turbidity (an optical parameter) every 10 minutes as a surrogate for suspended sediment measurements. A Druck 1830 pressure transducer and an in-stream DTS 12 Turbidimeter were installed in conjunction with an ISCO pump sampler to take water samples at direction from TTS sampling software. An algorithm is used to trigger an ISCO pump sampler to take water samples at specified rising and falling turbidity thresholds. During water year 2007, flow and turbidity data, as well as TTS samples were collected at station VDC between January 24, 2007 at 18:40 and June 17, 2007 at 12:40. The resulting 10-minute data file is called a flo file and displays raw and corrected stage and turbidity data side by side for easy comparison.

Water samples were taken to North Coast Laboratories (Arcata, California) for determination of suspended sediment concentration. A regression was developed for the original OBS-3+ and the subsequent DTS 12 turbidity versus suspended sediment concentration. Using this regression, the 10-minute turbidity data are converted to 10-minute calculated suspended sediment concentration. A discharge rating curve is developed so flow rate is known for every 10-minute stage reading. The product of flow rate (CFS) times suspended sediment concentration provides an estimate of pounds of sediment passing by the station. TTS Adjuster software is used for data correction (Appendix 1), and R Sed 2.2.0 software is used to calculate suspended sediment loads (Appendix 2). The best equation fit for the turbidity vs. suspended sediment concentration from bottles sampled from each storm is used to calculate loads for each storm and the loads are summed up for the year.

The discharge rating curve used to calculate total discharge from the stage data collected was a two-part curve. At stages less than 1.16 feet, the total discharge in cubic feet per second was calculated as $41.919(\text{stage})^{1.3982}$. At stages greater than 1.16 feet, discharge was calculated to be $27.327(\text{stage})^{4.2264}$. These curves were created using four total data points, with 1.57 feet the stage at which the highest discharge was recorded.

Location of Monitoring Sites.
There are currently 11 monitoring sites designated for grab sampling of turbidity and suspended sediment concentration (SSC) for this project within the Lower Van Duzen River Basin (Map 2). Due to difficulty in arranging for adequate coverage, one of the original 10 sites (Little Golden Gate) was abandoned as a monitoring site. Several new sites, however, have since been added. Of the 11 monitoring sites, seven are considered to be of key importance to the project, and have been consistently monitored for temperature, pH, dissolved oxygen, and conductivity, in addition to turbidity and SSC throughout the hydrologic year (Map 3). These key monitoring sites include: Wolverton Gulch, Yager Creek, Cummings Creek, Fox Creek, Hely Creek, Mainstem Van Duzen River at Weares, Grizzly Creek, and Mainstem Van Duzen River at Rainbow Bridge. Several of the remaining (secondary) sites have been problematic and numbers of samples have been less than satisfactory. These sites include: Wilson and Flanigan Creeks.

Sampling Schedule.
Volunteers collected turbidity grab samples at each site throughout the hydrologic year (rainy season) on a regular basis at each of the monitoring sites, and more frequently during storm events. Suspended sediment grab samples are generally collected at designated times during storm events in order to provide suspended sediment measurements that correspond to a range of turbidity values. Given a sufficient number of measurements that cover an accepted range of values, turbidity samples should provide satisfactory estimates of suspended sediment. The water quality analyst collects data twice per month throughout the entire year on discharge, temperature, dissolved oxygen, pH, and conductivity at seven sites. Macro invertebrates are sampled at the same seven sites where bi-monthly samples for physical-biochemical sampling occur. Macros were sampled during the Summer and Fall seasons, to depict the effect of temperature and habitat conditions on these populations.

Sampling Method.

Water was collected primarily as grab samples for turbidity. During HY07, each turbidity sample consisted of dipping 3 Hach cells (replicates) into the stream simultaneously, to facilitate an estimate of sample accuracy and precision. Approximately 650 grab samples were collected during the 2007 hydrologic year (HY), and as it appeared to be a relatively dry year, at least 1,000 samples are anticipated for HY 2008. Due to the timing of funding availability in HY 2007, fewer grab samples were available for sediment analysis that anticipated, and will only reach approximately 40 to 60 samples that will be processed to determine the suspended sediment concentrations. During HY 2008, approximately 100 to 150 grab samples will be processed for suspended sediment concentration.

To supplement the grab sampling, a continuous sampling station was installed at Cummings Creek to measure turbidity and suspended sediment variation with time. Data from continuous samples are compared with those from grab samplings collected at the same time to identify differences or biases between the two sampling methods. A continuous, turbidity-controlled sampling station (Lewis, 1996) has been installed at Cummings Creek. This station includes a continuous turbidity probe, stage recorder, and an ISCO automatic sampler capable of collecting 24 samples. Sample collection is controlled by the rate of change of turbidity and stage. At least one additional continuous suspended sediment monitoring station will be installed on the mainstem VDR at Rainbow Bridge adjacent the USGS gauging station.

In agreement with USEPA Handbook standards, turbidity grab samples are transported to a laboratory setting and measured using a USEPA-approved Hach turbidimeter within 48 hours (usually less than 24 hours) after collection of the sample. Stream samples are processed at four different laboratory type facilities, established at the residences of the Lab Manager and three Lab Assistants who have been certified in the reading of turbidity using USEPA approved turbidimeters. Samples that register higher than the 1000 NTU maximum reading available with the Hach 2100P models in use, were brought to the Lab Manager, who then uses a standard dilution technique to measure and calculate the actual turbidity levels of these high concentration samples. Quality Assurance Protocol developed by Salmon Forever is used, which requires rapid processing of samples to avoid the complications of algae growth within the samples.

Additional measurements required to evaluate the impacts of turbidity and SSC are also performed. These measurements include stream discharge or stage at sites where a rating curve has been or is being established. Either a direct (discharge) or indirect (stage) measurement must be recorded at the time water samples are collected. When possible, position on the storm hydrograph (rising, peak, or falling limb) is also noted. Suspended sediment samples will be transported to the Salmon Forever Sediment Lab in Sunny Brae within the required time period, for turbidity and SSC determination. The Quality Assurance protocol developed by Salmon Forever requires rapid processing of samples to prevent algae growth.

Data on temperature, dissolved oxygen, pH, and conductivity were also collected throughout Hydrologic Year 2007 (HY07) twice per month at seven monitoring sites considered most important, based on stream size, perennial nature, catchment area, and ease of access. These metrics are sampled and measured on site, using appropriate meters and/or instruments that will be described in full in the standard operating procedures (SOP). Additional water samples were taken at each monitoring site and transported to the laboratory at Humboldt State University, where they were analyzed for turbidity and suspended sediment concentration.

Data Management.
Turbidity readings were copied onto a paper record sheet that also contained supplemental information regarding the sample date, including weather, stage, and flow rate. Data sheets were later photocopied and entered into a computer (spreadsheet) database. Data were reviewed and checked by the data analyst prior to analysis. Regular analyses of data occur with review by appropriate project personnel. Technical Advisory Committee (TAC) members will facilitate timely detection of errors or the need for modification of protocols. Sediment grab samples, taken by volunteers, were transported to the Sunnybrae Salmon Forever Lab for analysis of turbidity and suspended sediment concentration (SSC). Data analysis is conducted after sample processing has been completed, data sheets submitted and verified for accuracy, and data entered into spreadsheets.

Calculation of Discharge for Interpretation of Grab Samples.
Stream discharge is not a metric that can be calculated directly, but rather must be estimated based on a given set of criteria. The most common estimate of discharge is based on the development of a discharge rating curve, which requires recording the stage or volume, and then measuring stream flow in incremental units across the stream to establish the stream profile in cross section that allows calculation of area (square feet), and the average rate of stream flow (in feet per second) for that particular stage or volume of water as measured on gauging plate. Thus, the product of area and flow will provide discharge given in units of cubic feet per second (CFS) (ft^2 x ft/sec = ft^3/sec). This process is repeated at several different stages of stream volume so that a rating curve or function of stage to discharge can be developed. Once the function is considered valid and acceptable, discharge can be to estimated for any given stage.

With regard to the TTS station at Cummings Creek, stage is measured automatically using a pressure transducer that has been calibrated to the stage or gauging plate. Therefore, using standard techniques and methods proven to yield high precision, it is possible to collect data on turbidity, suspended sediment, stage, and discharge, all automatically, once the relationships between stage and discharge, and pressure and stage have been established. Thus, because turbidity grab samples are collected in association with stage readings, it was possible to estimate discharge for the samples at Cummings Creek based on the discharge rating curve that was developed for that stream in HY07.

At most of the other monitoring sites, the orange peel float method was used to estimate stream flow. This method consists of measuring the rate at which an orange floats from one point to another (usually 10 or 20 feet apart). Calculation of discharge with this method depended implicitly upon knowing the area of the water column in cross-section. This was possible by measuring the cross-sectional profiles of all of the streams with engineering equipment (rod and transit) at the beginning of the winter season. Using an algorithm developed by the U.S. Forest Service Redwood Sciences lab at Humboldt State University, the area of the stream cross section was then calculated for each stage recorded during the grab sampling process. Thus, it was possible to use the product of the orange peel float method (feet per second) and the stage-cross-sections (square feet), to estimate discharge (CFS).

The third method of estimating discharge was simply a matter of obtaining data from the USGS/DWR gauging station at Rainbow Bridge near Bridgeville, CA. These data in the form of stage and discharge, are provided on the internet in near real-time format, and offer a unique opportunity to quantify turbidity and suspended sediment as a function of discharge. Values provided on the website, are based on a similar discharge to stage rating curve function as described above.

Results and Discussion

This report focuses on the continued analyses and completed results of data 1) collected from the TTS continuous monitoring station at Cummings Creek, 2) by volunteer grab sampling at 10 monitoring sites during HY07, and 3) the additional biophysical data collected at seven high priority monitoring sites on a bi-monthly basis. Grab sample data were collected from October 2006 through April 2007. Time of day was recorded by all volunteers, but was not considered a factor in reviewing the data due to sampling frequency. Sampling was dependent upon when volunteers were able to visit the streams and, except in the case of Cummings Creek, samples usually did not exceed one per day.

<u>The TTS station at Cummings Creek</u>

All data from the TTS (turbidity threshold sampling) station at Cummings Creek (CC) for hydrologic year 2007 (HY07) have been recorded, analyzed, and adjusted for instrument variability and/or unexplained fluctuation (Appendix 1). Results have been analyzed for overall turbidity, flow, suspended sediment, and discharge. During the course of the rainy season plotting turbidity and stage showed a proportional and parallel relationship (Fig. 1). Plotting suspended sediment versus turbidity values collected at the CC TTS station produced a relationship describing a power function, with an associated correlation coefficient (R^2) of 0.77 (Fig. 2). However, to achieve maximum precision, individual turbidity-SSC functions were developed for each storm event after using the software *ttsAdjuster* to correct for unexplained fluctuations. SSC was estimated for each event, and the sum for all events used to estimate total suspended sediment for the year (Appendix 2).

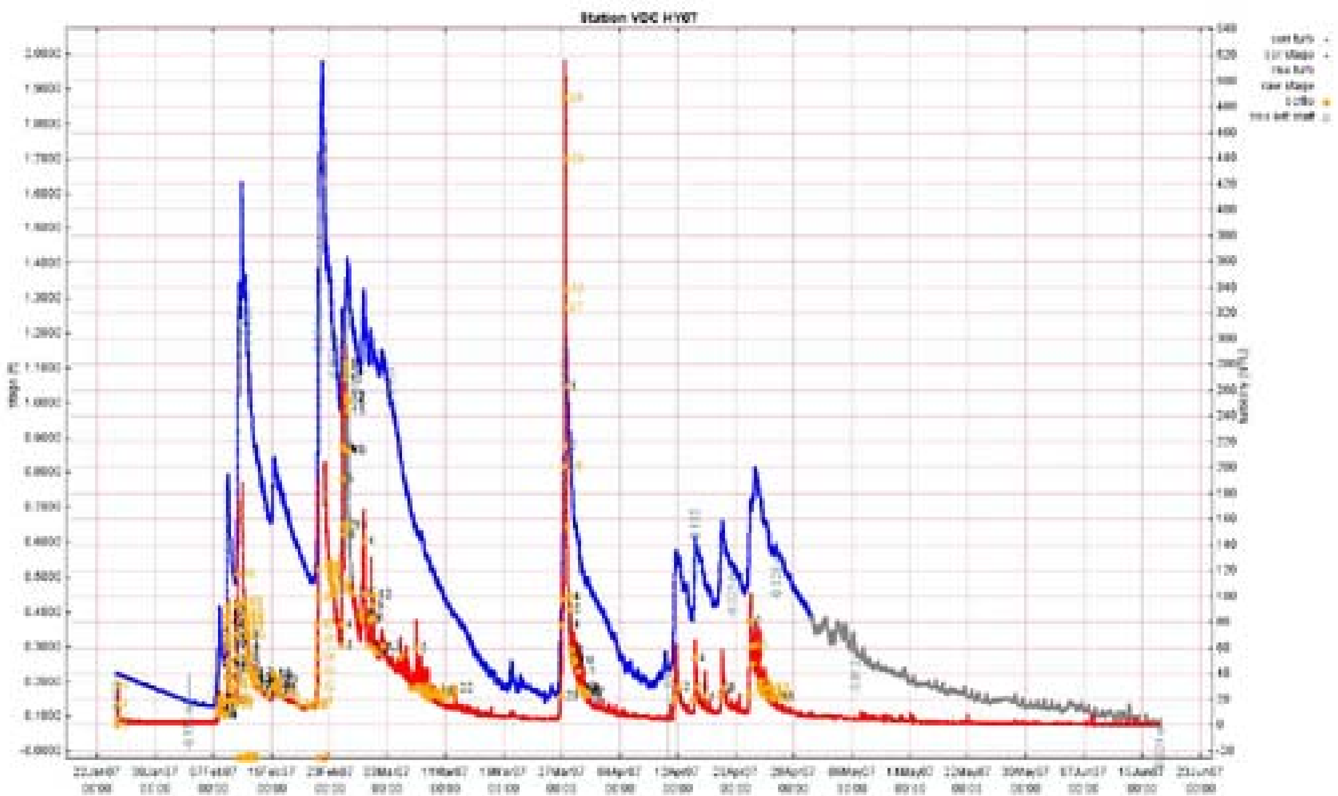

Fig. 1. Plot for turbidity (in red) and stage (in blue) at Cummings Creek TTS station during the hydrologic year 2007 (HY07), adjusted for instrument and sampling inconsistencies..

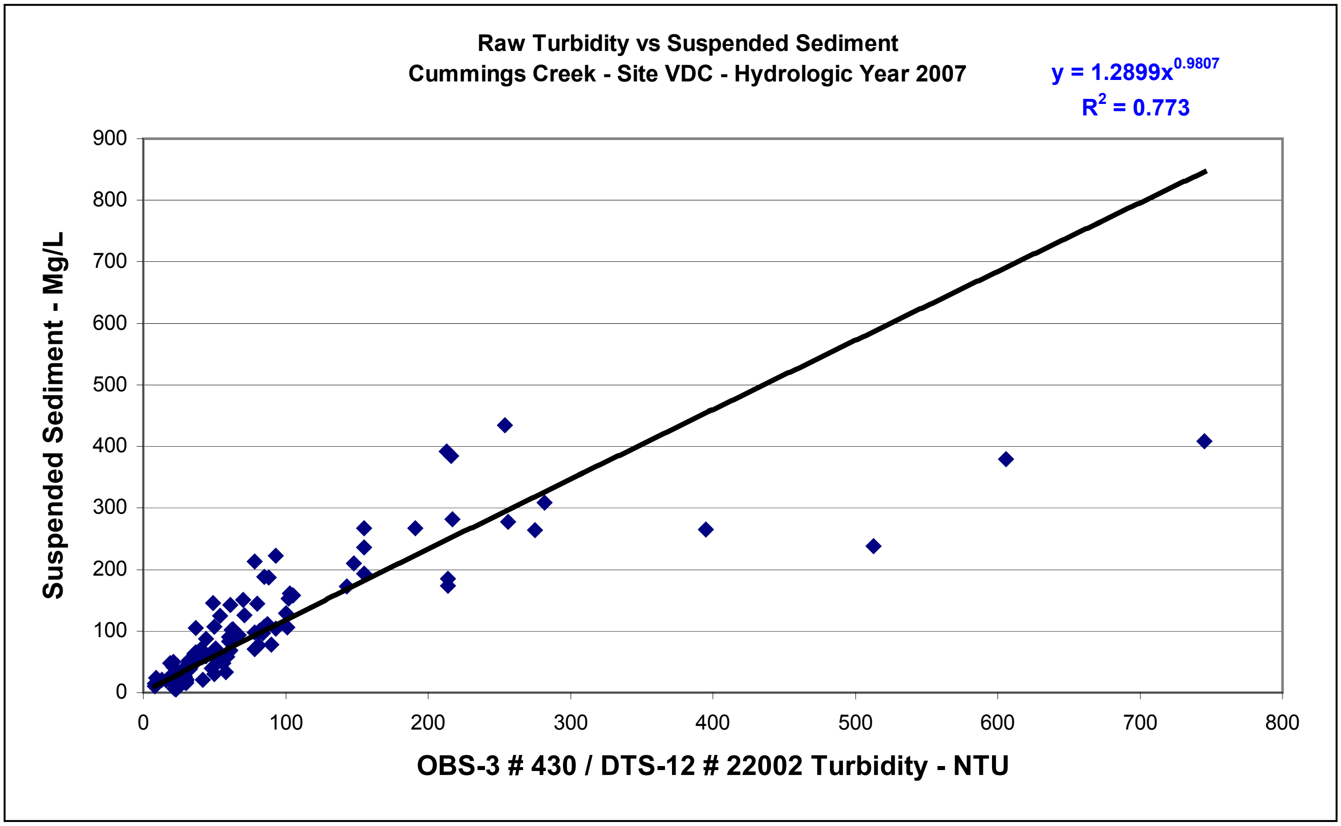

Fig. 2. The relationship between suspended sediment and turbidity, using data recorded at the Cummings Creek TTS station. A power function ($Y = 1.2899x^{0.9807}$, $R^2 = 0.77$) was fit to the data.

The total sediment load estimated for HY07 at Cummings Creek was 1,161,628 kg (1,280 tons US) (Table 1). The highest flow and estimated sediment load occurred during analysis period six. Between February 20 at 17:10 and February 24 at 13:00 an estimated 811,926 kg of sediment passed by the station, which was 70% of the total load for the year. There were two issues with calculating the sediment load for this period: a lack of sample bottles and missing turbidity data. As a result, the estimate for period six received a grade of "poor". The second largest sediment load was during analysis period four. Between February 10 at 01:50 and February 14 at 23:00 131,258 kg of sediment passed station VDC, which was 11% of the estimated total load for HY 07. Due to a lack of TTS samples collected and a period of missing turbidity data, the estimate for this period was graded as "fair to poor". The third largest flow and sediment load were during analysis period seven. Between February 24 at 13:10 and February 27 at 04:30 an estimated 99,513 kg (9% of the total load for HY 07) of sediment passed by station VDC. Due to the large number of TTS samples taken over the estimation period, this estimate was given a grade of "good".

The stage data collected from April 30 to June 17 show a large amount of semi-regular fluctuation. These fluctuations ranged from 0.05 to 0.10 feet over a period of approximately one day. This may be due to a number of factors, including water diversion/pumping upstream or a daily cycle of water use by riparian vegetation. This pattern may or may not have been present during the fall of 2006, as data collection did not begin until January 2007.

Table 1. Summary of sediment load estimates for station VDC (Cummings Creek), water year 2007

Each estimate is given one of five grades: excellent, very good, good, fair and poor.
Grading is based on the quality within the following categories:

a) Number of sample bottles within the period and the coverage of bottles across the entire period.
b) The strength of the relationship between the surrogate variable (usually turbidity) and SSC of the samples, as measured by CV and r^2.
c) The complexity of the models used, and the number of objects that was necessary to calculate the estimate for the period.
d) The quality of the surrogate variable data (turbidity, flow, or sample bottle/time).

An estimate cannot receive a high grade if the quality of the underlying data is questionable.

Period	Dates and Times	Dump: Bottles	Sediment Load (kg)	Model(s)	CV %	r^2	Grade	% of Total Sediment Load
1	070124,1840,070207,0330	dd 1 bots 1-6 (not processed)	313	power	NA	0.866	fair / poor	0.03%
2	070207,0340,070208,1400	dd 2, 1-8	537	linear	12.69%	0.706	good	0.05%
3	070208,1410,070210,0140	dd 2: 9-24	4,354	power	3.95%	~0.965	good / very good	0.37%
4	070210,0150,070214,2300	dd 3: 3-17	131,258	power, logxy	4.50%	~0.96	fair / poor	11.30%
5	070214,2310,070220,1700	3: 18-24	5,556	logxy	6.01%	0.96	very good / good	0.48%
6	070220,1710,070224,1300	dd 5, bot 2	811,926	linear	6.37%	0.696	poor	69.90%
7	070224,1310,070227,0430	5: 3-20	99,513	time/bottle based	NA	NA	good	8.57%
8	070227,0440,070306,2300	6: 1-13	60,459	linear	6.85%	0.844	very good / good	5.20%
9	070306,2310,070319,2000	7: 5,18 and 22	3,810	square root	NA	0.949	good / fair	0.33%
10	070319,2010,070408,1000	7: 23-24, 8: 1-17	31,935	power	2.87%	0.978	good / fair	2.75%
11	070408,1010,070416,2200	9: 1-6	3,523	power	7.65%	~0.96	good	0.30%
12	070416,2210,070421,0700	9: 7-8	2,140	linear	24.20%	0.888	fair / poor	0.18%
13	070421,0710,070430,1200	10: 2,7 and 18	6,086	square root	NA	0.999	fair	0.52%
14	070430,1210,070617,1240	none	218	power	NA	0.998	fair / poor	0.02%

1,161,628	TOTAL LOAD (kg)
2,560,951	total lbs.
1,280	total tons (US)

Overall, the quality of data obtained from the TTS monitoring station was variable, and may reflect the difficulties encountered in trying to get the station constructed and equipment up and running in time for the 2007 hydrologic year. Part of the problem was the necessity to change from the OBS-3+ turbidimeter (on loan from Salmon forever) to the new DTS-12 turbidimeter during the most problematic period and storm event-prone time of the season. Problems with coding and programming of the turbidimeter may also have contributed to loss of information and data. The remoteness of the site makes it difficult to regularly check the condition of the equipment, and subsequently replace bottles if/when irregularities in conditions cause the inadvertent need for such replacement. The storm event in dump 6 (2/20/07 – 2/24/07) was the largest storm of the year. Unfortunately, this storm caused the pump sampler to use all of its bottles prematurely. A possible explanation is that the storm raised the stream to such a level of violence that large debris (e.g., log jam) may have displaced the turbidimeter boom causing the sensor to come out of the water for extended and erratic periods. This effect may also have occurred strictly as the result of the violence of the stream, the bottom of which is very rough and causes extreme wave action on the surface. This violence may have triggered the ISCO sampler to attempt to pump samples unnecessarily, thus depleting the supply of SSC bottles prematurely. Low turbidity readings as well as high readings by design, cause the pump sampler to be triggered, and to pump a sample. Ultimately, it may be impossible to completely avoid problems of this nature in this creek that is prone to such violence during large storm events.

Turbidity Grab Samples.

Precision of the turbidity samples was estimated from three replicate bottles (Hach cells) dipped into the stream simultaneously. Determination of the degree of precision was based on the calculation of the Coefficient of Variation (V), which is calculated as the Standard Deviation divided by the Mean. Using the mean in the equation eliminates the possibility of larger samples registering higher levels of variability (and thus, lower precision). Samples were considered to have adequate precision if V was less than 0.10, and less than adequate precision if V was greater than or equal to 0.10. The number of samples with V values < 0.10 was compared to those => 0.10 for each monitoring site over the sampling season (Table 1.). Data in Table 1. represent the number of sample events (e.g., trips to the monitoring site), each comprised of 3 replicates. Total number of replicates would equal Number of Records times 3. The precision of turbidity samples varied considerably between monitoring sites in the frequency of adequate V values, with some sites showing extremely good precision , as demonstrated by having a low proportion of V values => 0.10, and others showing substantially poorer precision with a much higher proportion of V => 0.10 (Table 1). Although the vast majority of values ranged between 0.00 and 0.10, a few samples collected early in the sampling program, were substantially higher. When viewed as a whole, these data suggest that precision may be unacceptably low when 20% or more of the samples exhibit V greater than 0.10.

Table 2. Use of the Coefficient of Variation (V) as an index of variability about the mean. Number of records equals the number of sample events, each with three replicates.

Variability Estimates			
Monitoring Site	Number of Records	**Coef. of Variation (V) => 0.10**	Percentage V => 0.10
Wolverton Gulch	64	3	4.69%
Yager Creek	66	6	9.09%
Wilson Creek	28	2	7.14%
Cummings Creek	120	17	14.17%
Fox Creek	73	2	2.74%
Mainstem Weare	77	9	11.69%
Flanigan Creek	17	3	17.65%
Hely Creek	94	15	15.96%
Grizzly Creek	38	7	18.42%
Rainbow Bridge	52	12	23.08%
Little Golden Gate	Not Shown due to Insufficient Samples		
Total	629	76	
Average	62.8	7.6	12.10%

High variability between the three replicate samples is not easily explained, as all three are taken from the same water at the same time. It was observed however, that at least in several cases, some of the bottles were older and visibly scratched, which could lead to an artificially high reading. It was also noticed than in several of the replicate samples, slightly different (differently marked) Hach cells were used, which lead to slightly, possibly significant, differences in the turbidity measurement. Finally, sampler error was undoubtedly a factor during this first year of sampling. Although instructors were extremely specific about the necessity to take "clean" uncontaminated samples, there is a likelihood that some may have been contaminated during the taking of the sample.

As of about November 20, 2006, a more streamlined process of reading turbidity was adopted, and most all samples were subsequently read within 24 to 48 hours after being collected. Although this change in procedure does not logically suggest that an improvement in precision would necessarily follow, it was also about this time that a flush of new bottles were added to the collection of Hach cells in use at that time, and this could have resulted in greater precision. Also, a greater awareness of the importance of precision may have developed within the community of volunteers collecting the samples. In any case, variability visibly dropped after that point, and precision proportionately increased. As there was no definitive reason to separate sample results before and after November 20, Table 1 only reflects totals and averages for the entire sampling season. Volunteers will be more experienced for the hydrologic year, and will be thoroughly versed at the next Community Monitoring Session, as to the importance of taking clean samples.

Grab sample turbidity-by-discharge-by-time, was plotted for all monitoring sites that recorded at least 25 samples per season (Figs. 3 – 11). In general, all streams showed similar as well as unique features.

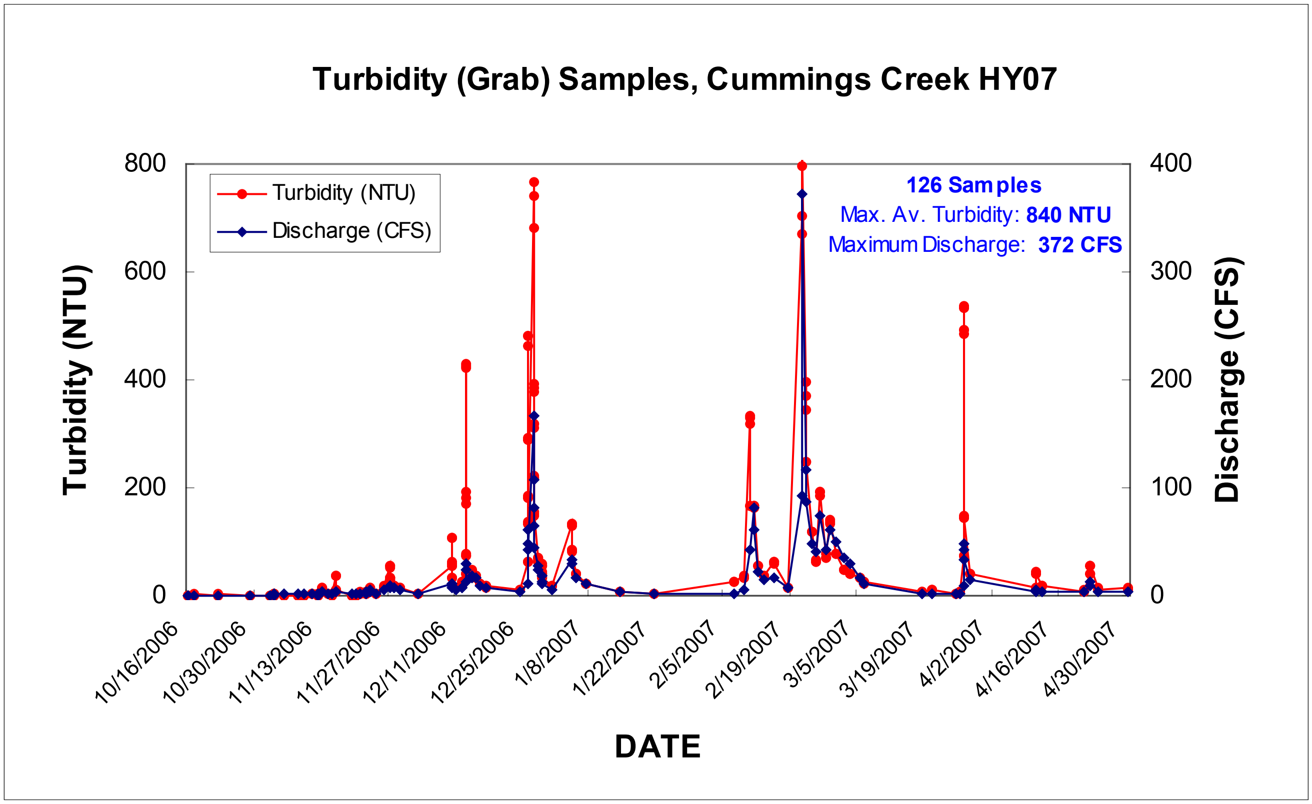

Fig. 3. Turbidity (NTU) in relation to discharge (CFS) at Cummings Creek, HY07.

Plotting turbidity and discharge over time produced figures that depicted nearly all of the same storm events at each monitoring site, and both turbidity and discharge exhibited relatively parallel behavior for all of the streams, when plotted versus time (i.e., Date).

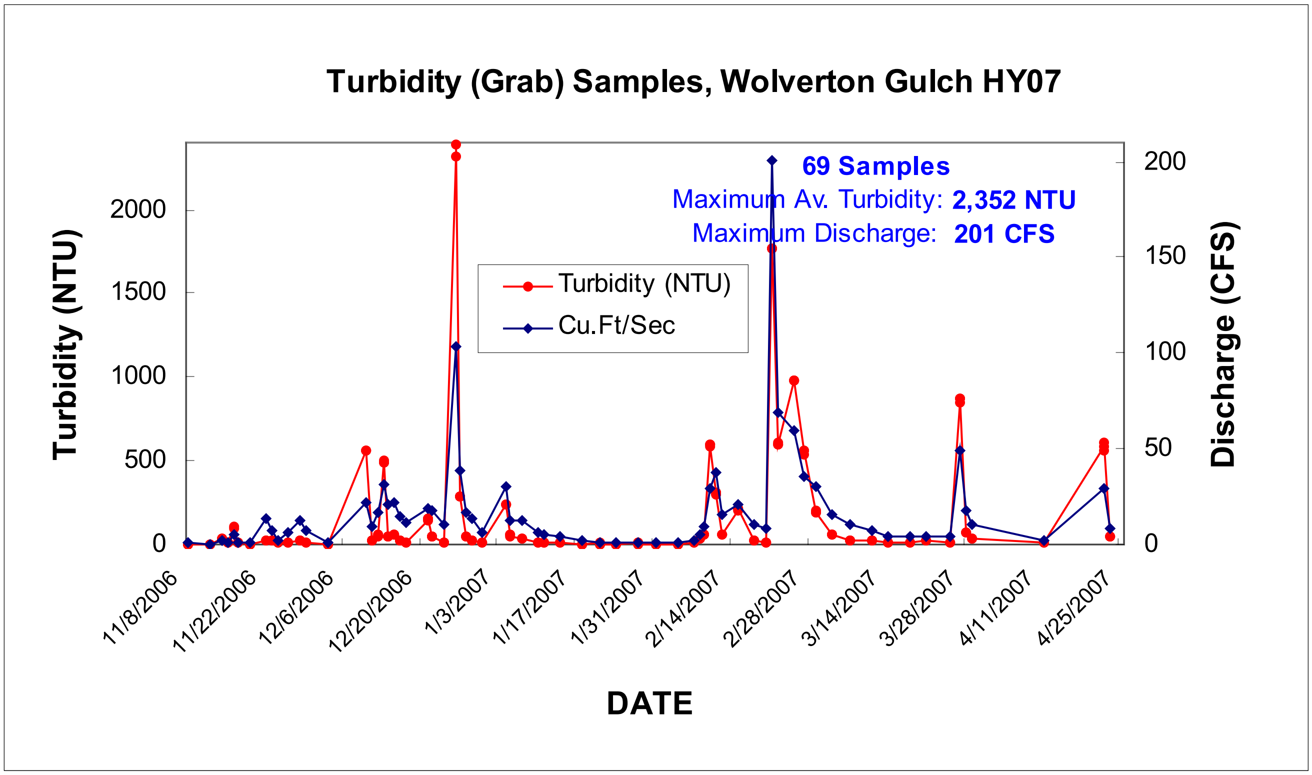

Fig. 4. Turbidity (NTU) in relation to discharge (CFS) at Wolverton Gulch, HY07.

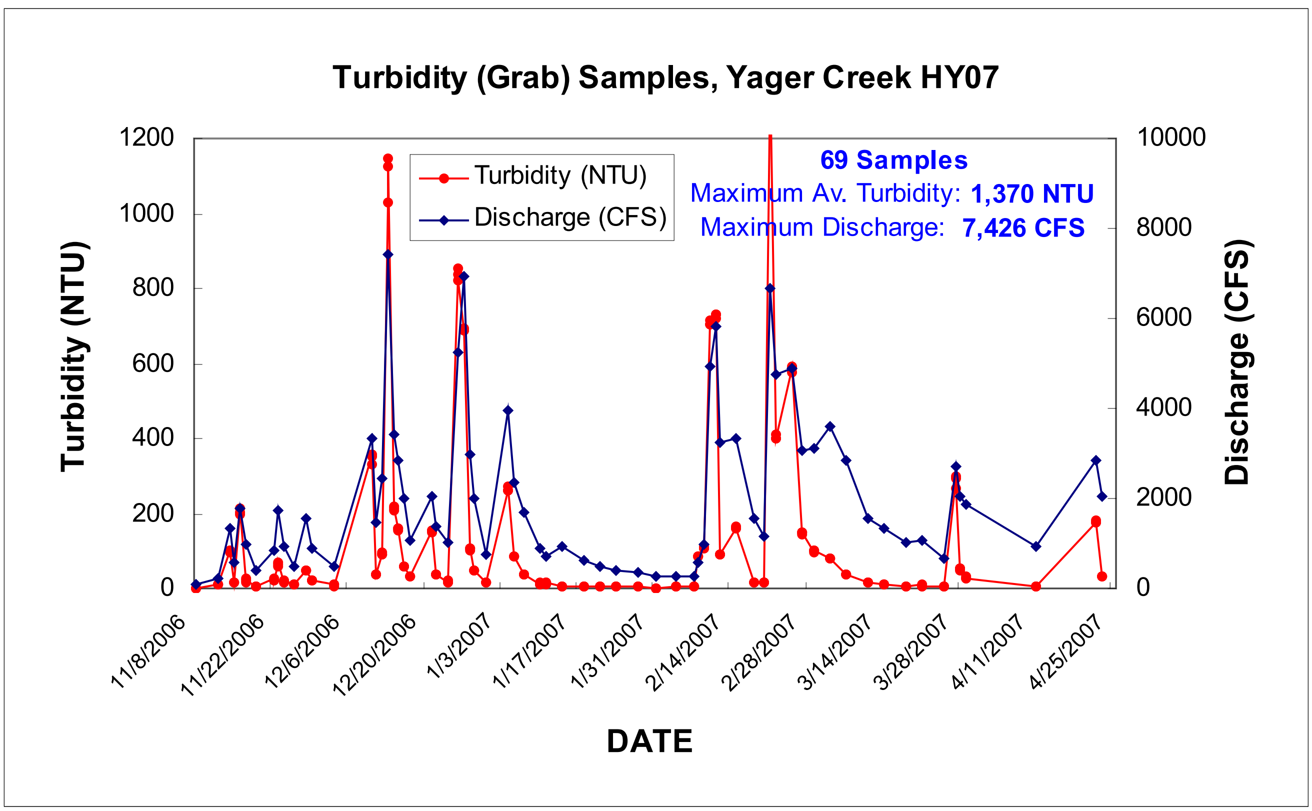

Fig. 5. Turbidity (NTU) in relation to discharge (CFS) at Yager Creek, HY07.

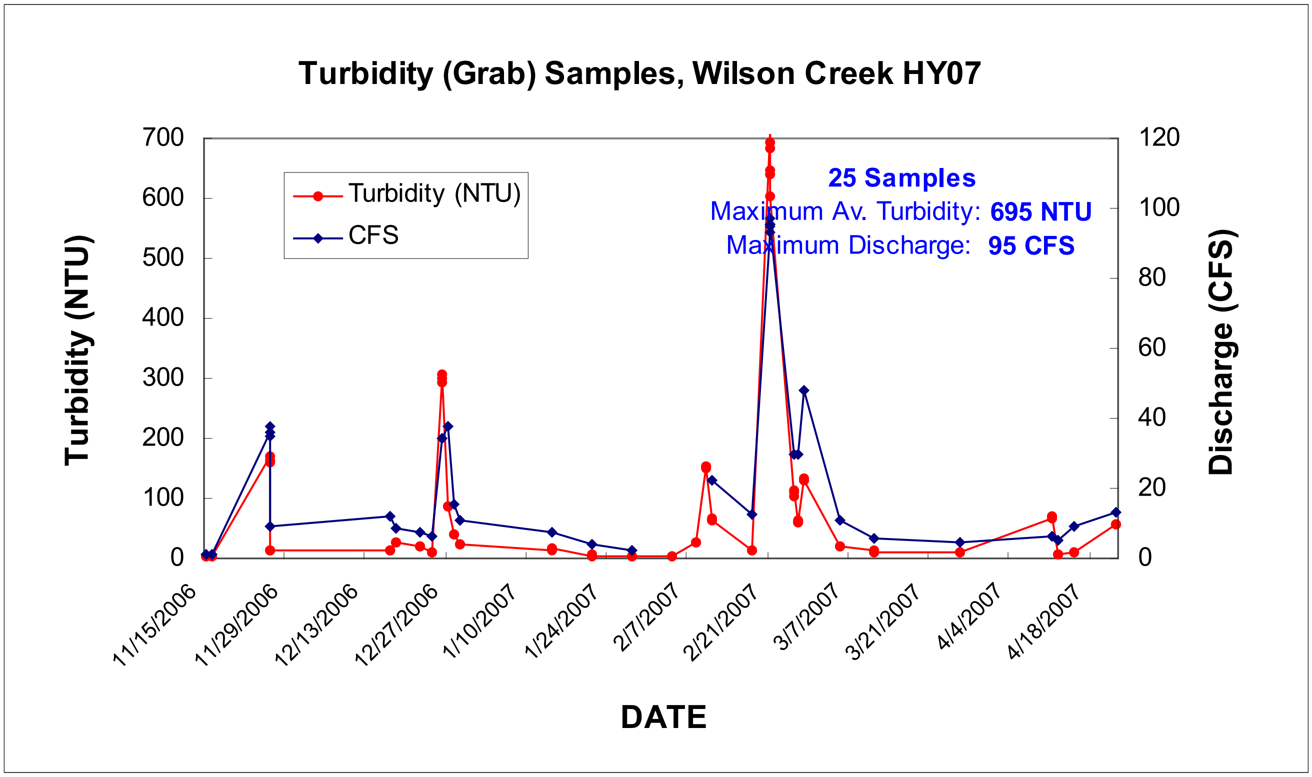

Fig. 6. Turbidity (NTU) in relation to discharge (CFS) at Wilson Creek, HY07.

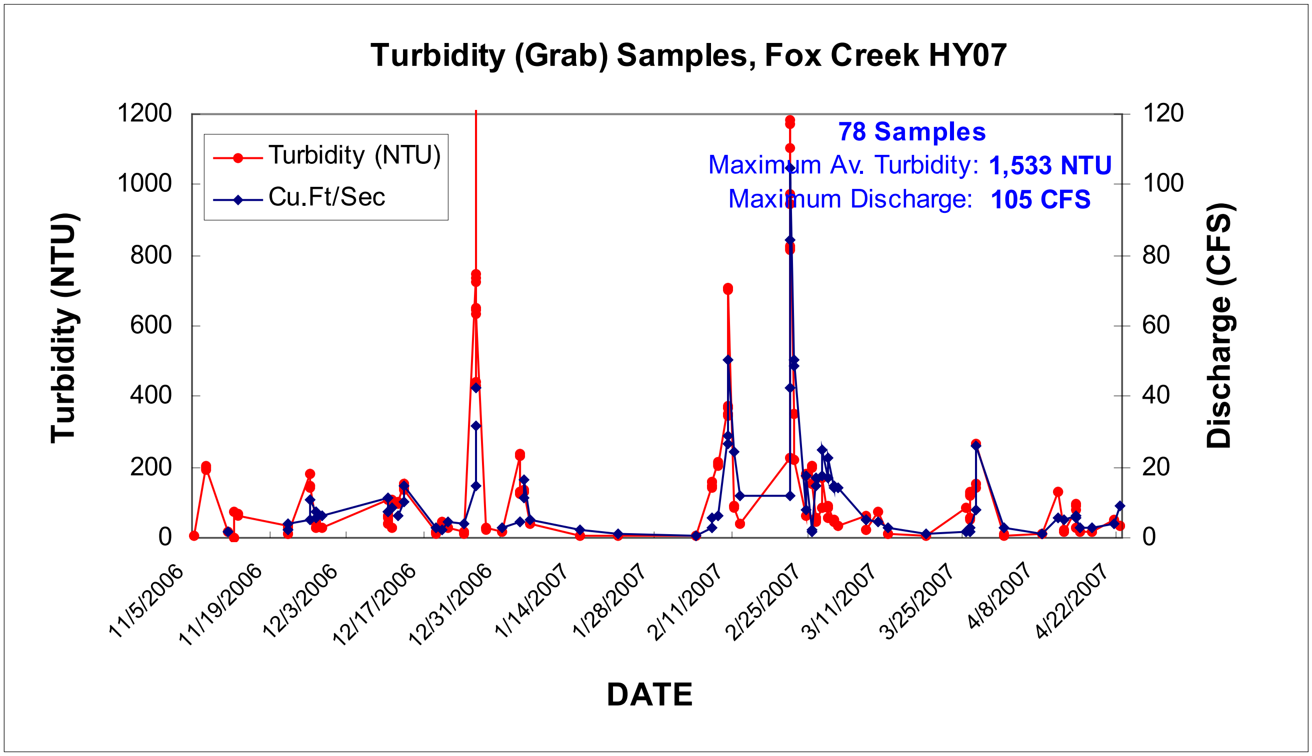

Fig. 7. Turbidity (NTU) in relation to discharge (CFS) at Fox Creek, HY07.

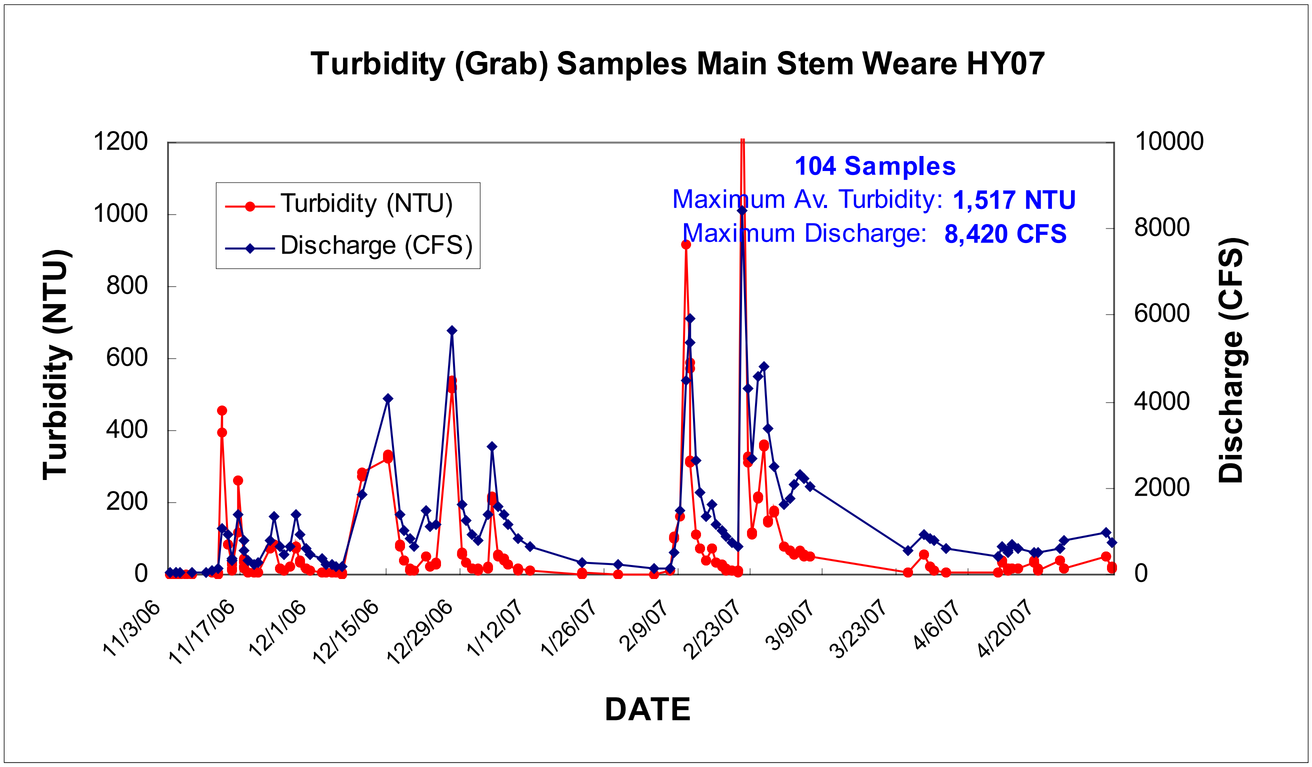

Fig. 8. Turbidity (NTU) in relation to discharge (CFS) at Main Stem Weares, HY07.

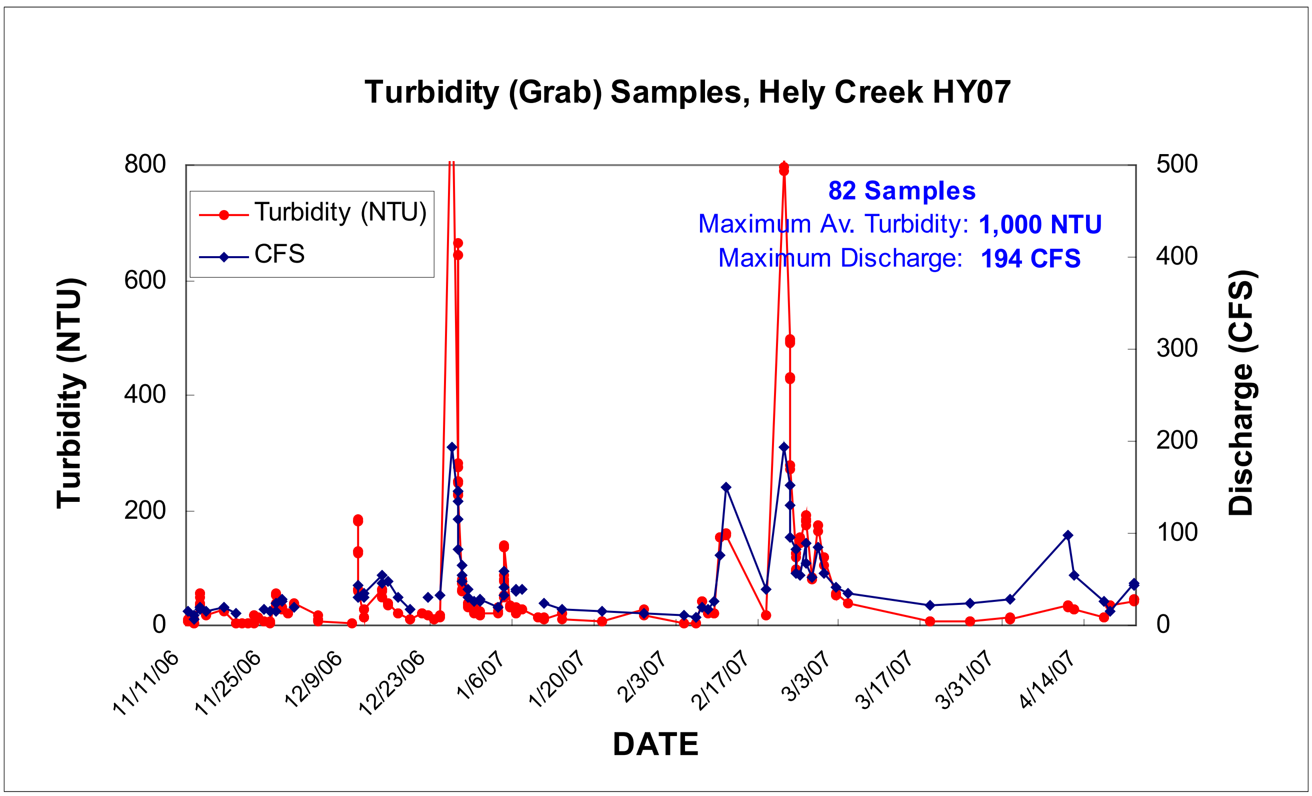

Fig. 9. Turbidity (NTU) in relation to discharge (CFS) at Hely Creek, HY07.

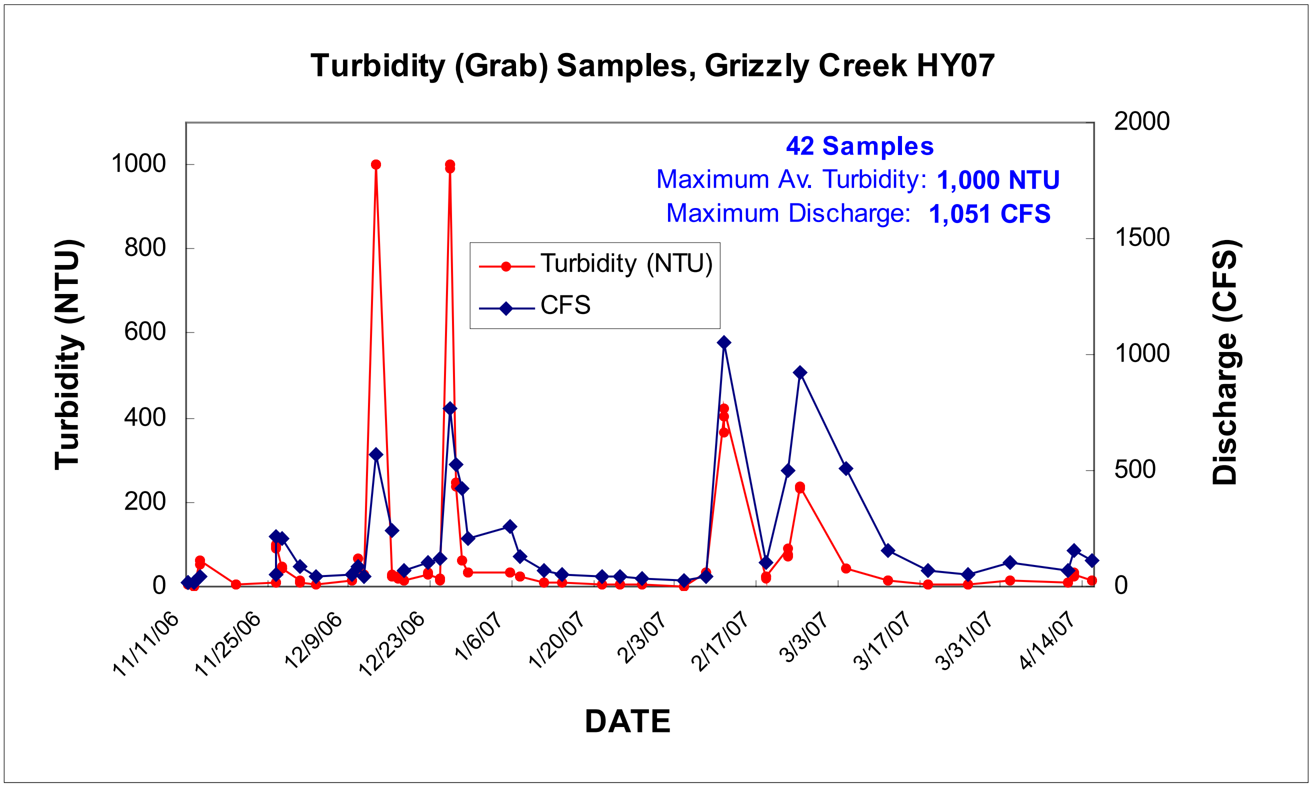

Fig. 10. Turbidity (NTU) in relation to discharge (CFS) at Grizzly Creek, HY07.

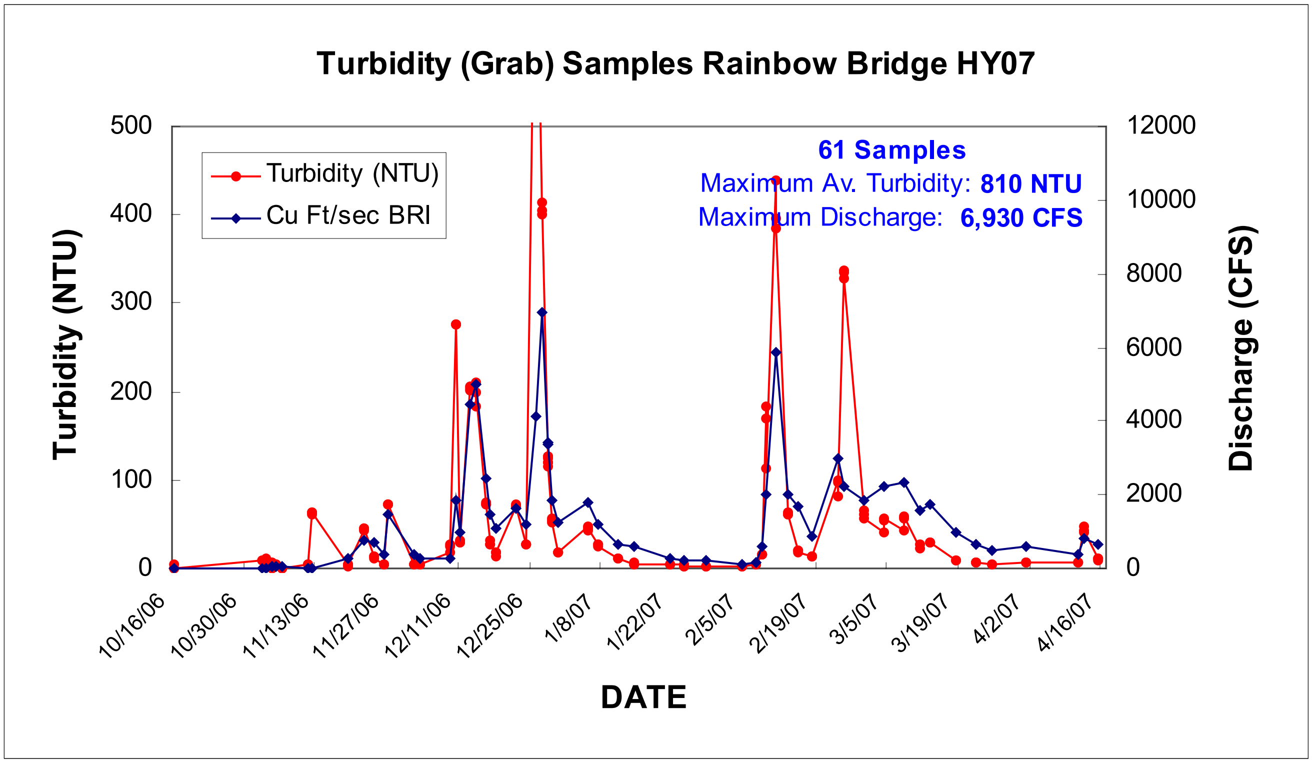

Fig. 11. Turbidity (NTU) in relation to discharge (CFS) at Main Stem Rainbow Bridge, HY07.

Plotting turbidity from grab samples, versus discharge, allowed functions to be developed specific to each stream with R^2 values ranging from 0.55 to 0.92. Some of these relationships are illustrated below (Figs. 12 – 16).

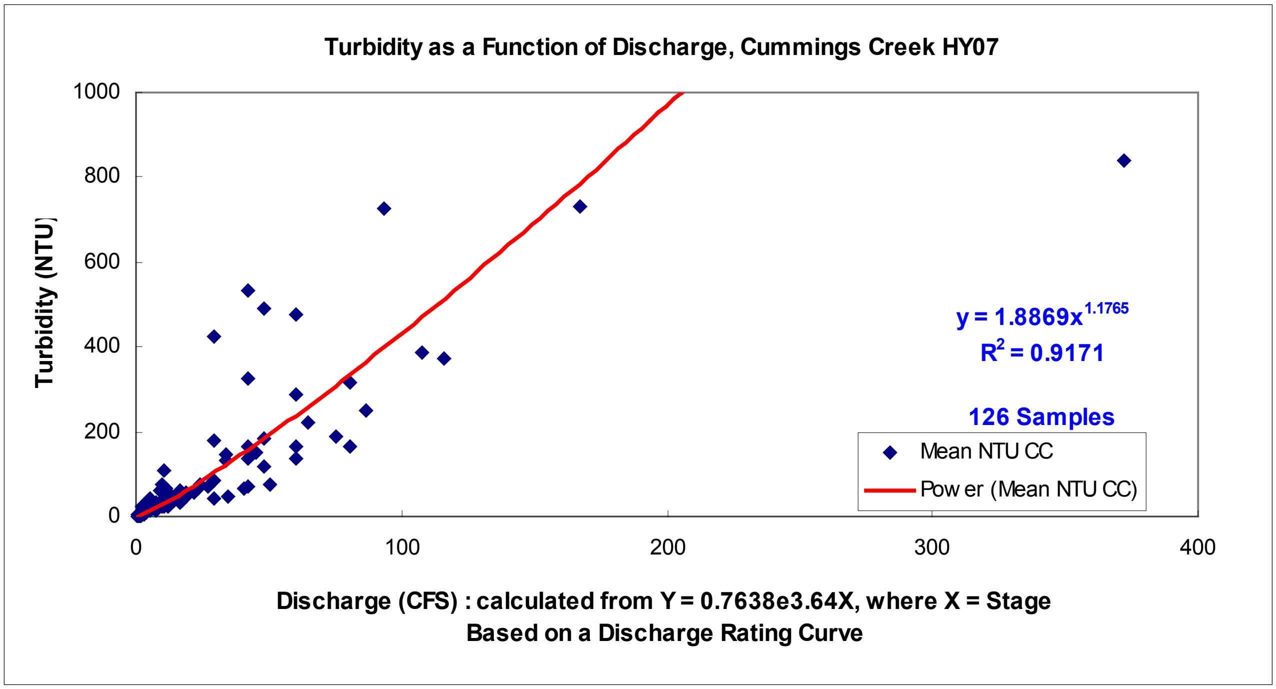

Fig. 12. Grab sample turbidity-discharge relationship for Cummings Creek, using a power function.

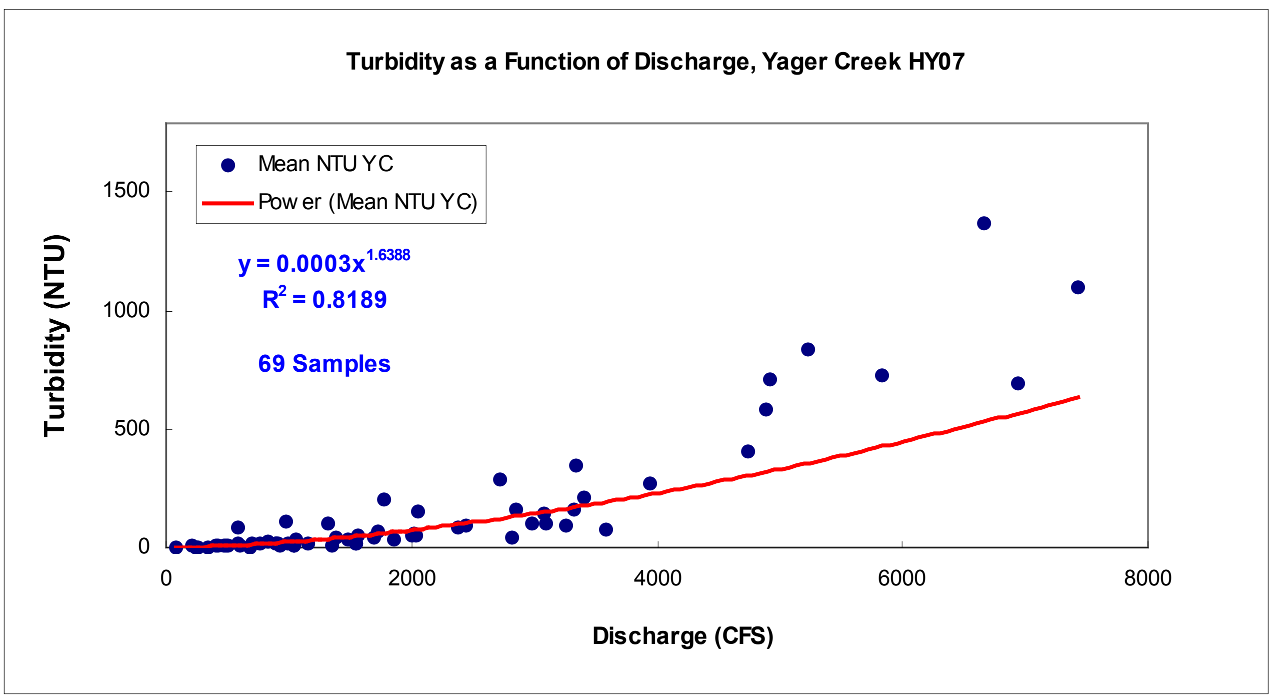

Fig. 13. Grab sample turbidity-discharge relationship for Yager Creek, using a power function.

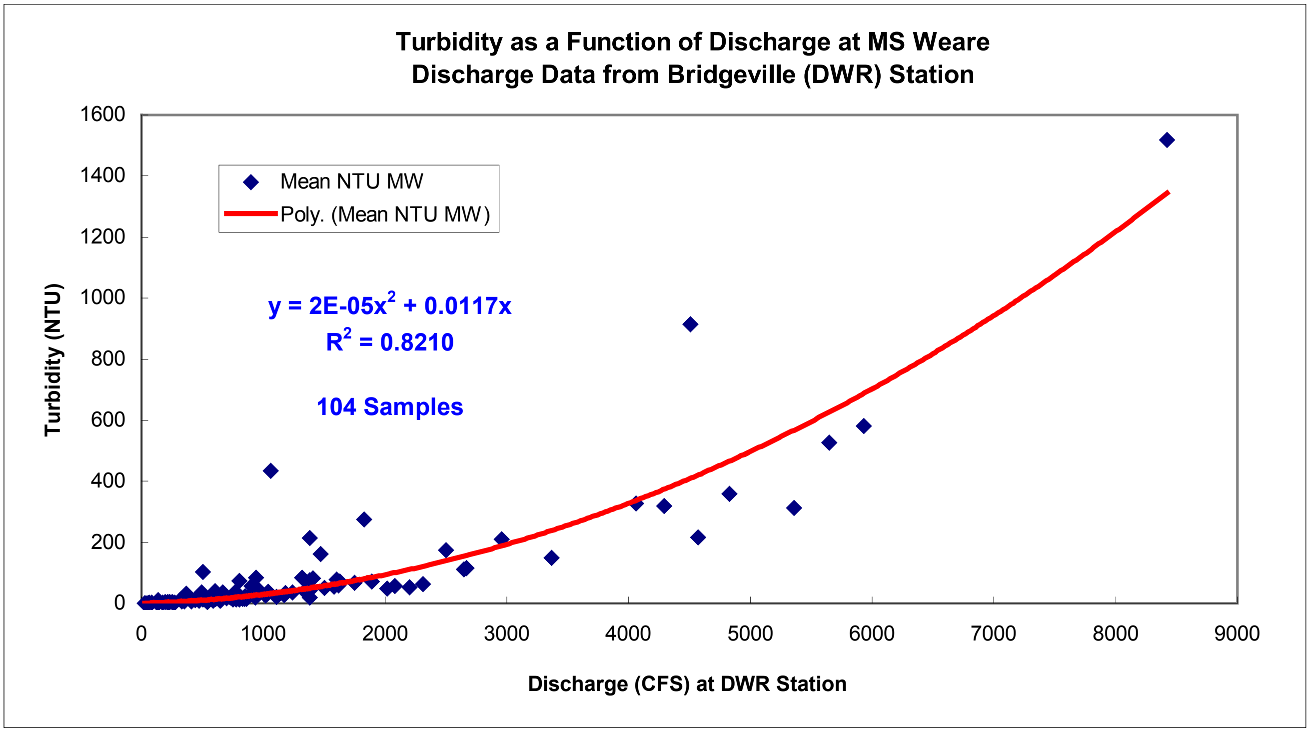

Fig. 14. Grab sample turbidity-discharge relationship for Mainstem Weares, using a power function.

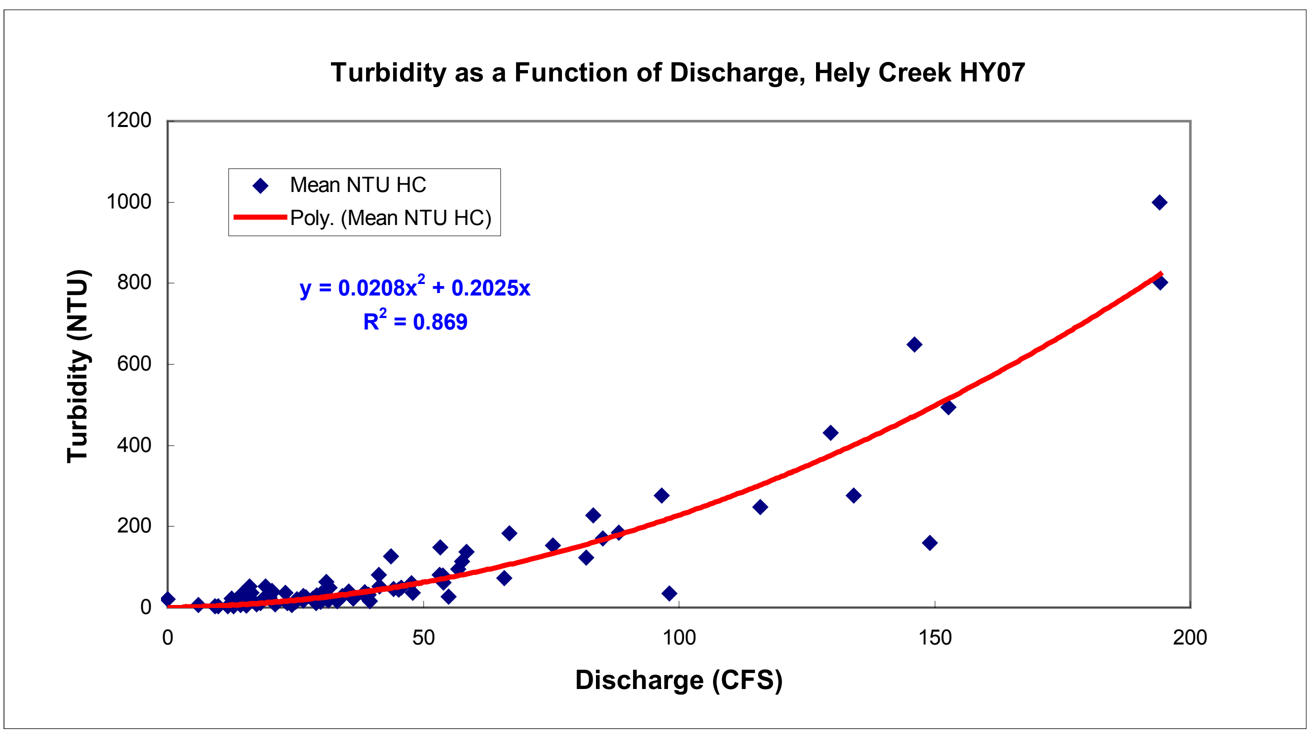

Fig. 15. Grab sample turbidity-discharge relationship for Hely Creek, using a power function.

In general, most streams exhibited a moderate to tight correlation between turbidity and discharge (Table 3), suggesting a reasonable likelihood of developing a satisfactory algorithm to estimate suspended sediment given sufficient samples taken in HY08.

Table 3. Average turbidity (NTU) as a function of discharge (CFS) within the Lower Van Duzen Watershed Project Area during Hydrologic Year 2007 (HY07).

Monitoring Site	Number of Samples	Turbidity-Discharge Function	R^2 (Coefficient of Correlation)
Wolverton Gulch	69	$y = 3.4559x^{1.138}$	0.79
Fox Creek	78	$y = 11.759x$	0.55
Mainstem Weare	104	$y = 2E–5x^2 + 0.0115x$	0.82
Yager Creek	69	$y = 0.0003x^{1.6388}$	0.82
Flanigan Creek[1]	25	$y = 0.731e^{16.136}$	0.62
Hely Creek	82	$y = 0.0208x^2 + 0.2025x$	0.87
Grizzly Creek	42	$y = 0.0744x^{1.2241}$	0.74
Cummings Creek	126	$y = 1.8869x^{1.1765}$	0.92
Rainbow Bridge	61	$y = 4E\text{-}6x^2 + 0.0414x$	0.55
Wilson Creek	25	$y = 1.0205x^{1.3381}$	0.82
Total	675		
Average	67.5		0.75

[1] Flanigan Creek was not adequately sampled for velocity to allow calculation of discharge. Therefore, the equation shown represents turbidity versus stage.

Using the maximum average turbidity recorded throughout HY07, all streams sampled can be ranked according to relative health, or the converse, relative impairment (turbidity) (Table 4). During HY07, of all the tributaries, Wolverton Gulch registered the highest average turbidity levels and also the highest single reading (2,352 NTU) of any other stream. Fox Creek registered the second highest value (1,533 NTU), and Yager Creek the third highest (1,370 NTU). Highest turbidity levels on the mainstem were moderately high relative to the tributaries.

Table 4. Maximum average turbidity (NTU) recorded for all monitoring sites within the Lower Van Duzen Watershed Project Area during Hydrologic Year 2007 (HY07).

Monitoring Site	Number of Samples	Maximum Average Turbidity (NTU)	Severity Ranking : Percent of Highest Recorded Value
Wolverton Gulch	69	2, 352	1
Fox Creek	78	1, 533	2 : 65%
Yager Creek	69	1, 370	3 : 58%
Flanigan Creek	25	1, 191	4 : 51%
Hely Creek	82	1, 000	5 : 43%
Grizzly Creek	42	1, 000	5 : 43%
Cummings Creek	126	840	7 : 36%
Wilson Creek	25	695	8 : 30%
Average for Creeks	64.5	1,248	
VDR at Rainbow Bridge	61	810	34%
Mainstem Weare	104	1, 517	64%
Average for Mainstem		1,164	
Average of Total	67.5	1, 231	

This ranking changes, if we use the amount of suspended sediment per unit time (Table 5). During HY07, insufficient SSC grab samples were taken to allow conversion of turbidity NTUs to suspended sediment. However, a proxy statistic (NTU_CFS) can be calculated, and used instead to assess and quantify the amount of sediment carried by each stream. This metric is the product of turbidity (NTU) by discharge (CFS), which translates into cubic feet of turbid material transported per second. Because of its size, volume of water, and catchment area, Yager Creek was observed to carry more sediment than any other stream, which was an order of magnitude greater than the second highest, Grizzly Creek (10 million NTU_CFS to 1 million NTU_CFS). Wolverton Gulch, ranked third, still very high for such a small stream. The amount of turbid material carried in Yager Creek was surpassed only by that amount recorded for the main stem Van Duzen River at MS Weare. It is interesting that Grizzly Creek carried more material per second than the main stem Van Duzen River at Rainbow Bridge.

However, ultimately the most critical variable to assess stream impairment will be the amount of suspended sediment being transported per unit time per unit catchment area. If that becomes the metric of greatest importance, it can also be indirectly estimated based on the above data. Assuming that the volume of water transported by a given stream is proportional to its catchment area, then we can estimate the amount of material being transported per unit time per unit area by removing CFS from the NTU_CFS variable, which once again highlights the data in Table 3. Therefore, once again, Wolverton Gulch was by far the most impaired stream of all those monitored during HY07, with a maximum value of 2,352 turbid units of material per unit time per unit catchment area, followed by Fox Creek and then Yager Creek.

Table 5. Turbidity (NTU) and Discharge (CFS) for all monitoring sites recorded within the Lower Van Duzen Watershed Project Area during Hydrologic Year 2007 (HY07).

Monitoring Site	No. of Samples	Maximum Av Turbidity (NTU)	Maximum Recorded Discharge (CFS)	NTU_CFS	Severity Ranking	Percent of Highest
Wolverton Gulch	69	2,352	201	472,752	3	4.6
Fox Creek	78	1,533	105	160,965	6	1.5
Yager Creek	69	1,370	7,426	10,173,620	1	
Flanigan Creek	25	1,191	- - -	- - -	- - -	- - -
Hely Creek	82	1,000	194	194,000	5	1.9
Grizzly Creek	42	1,000	1,051	1,051,000	2	10.3
Cummings Creek	126	840	372	312,480	4	2.4
Wilson Creek	25	695	95	66,025	7	0.6
Average for Creeks	64.5	1,248	1,349	1,775,835		
Rainbow Bridge	61	810	8,420	6,820,200	3+	67.0
Mainstem Weare	104	1,517	8,420	12,773,140	1+	1.26
Average for Total	67.5	1, 231	2,920	3,558,242		

In general lower sampling frequency during the year resulted in much lower levels of correlation between turbidity and discharge (or stage). Future monitoring efforts should be focused on the need for greater sampling frequency (at least 80 to 100 samples per year) to better describe the hydrologic behavior of these streams. With additional analysis, the next phase will be to quantify the relationship between turbidity and suspended sediment concentration (SSC), and ultimately a comparison of streams based on SSC per unit time and catchment area.

Several generalizations can be made with regard to turbidity grab sampling.
1. Grab samples can provide valuable information with respect to water quality conditions in streams. In general, data provided a good description of turbidity throughout the hydrologic year, as well as the relationship between turbidity and discharge over time. The turbidity-discharge relationship closely resembled the turbidity-stage relationship (May, 2007 Monitoring Report), and in some cases (i.e., Hely Creek) produced a better fit than the turbidity-stage relationship when plotted over time. During HY08, grab samples for suspended sediment will also be collected at all of the monitoring sites, thus allowing for a rigorous comparison of all of the streams based on suspended sediment per unit time (e.g., per year) and per catchment area (per square mile).

Although the data showed a range in the precision in which samples reflected actual turbidity levels, this metric should improve in hydrologic year 2008, as volunteers gain more experience and confidence in their ability to take samples. Some of the samples exhibited extremely good precision, and next year should fully demonstrate an improvement in the overall precision of the process.

Instructors and advisors are now more clearly aware of the necessity to stress the importance of a) clean samples, b) timing of samples, and c) frequency of samples.

2. High sampling frequency provides more information and in more detail on the individual behavior of turbidity in streams, and results in better estimates of stream conditions, than low sampling frequency. This effect is exemplified in Fig. 1. Cummings Creek had dramatically more samples taken over the hydrologic season than at any other monitoring site. This higher frequency of samples is reflected in a curve that is smoother than those from other sites, and shows greater detail with respect to the timing and therefore, the dynamics of turbidity in the stream with respect to stage. Data similar to that from Cummings Creek should more accurately reflect true suspended sediment loads per unit area and time than other less detailed data.

3. Different streams show similar as well as unique responses to storm events. Results showed that all streams (creeks and the main stem Van Duzen River) responded similarly to storm events, and plots of stage and turbidity versus date provide a reasonably good estimate of the number and timing of storm events that occurred in the lower basin during the 2007 hydrologic year. However, the levels of turbidity in response to the storm events varied and were unique to each stream. Wolverton Creek produced some of the highest turbidity levels of the season, with a maximum of 2,320 NTU. These data are interesting, as Wolverton Gulch is the smallest catchment area for any of the monitoring sites within the project study area. Further monitoring data and GIS analyses may shed additional information as to why this site produced such high turbidity values.

4. Dynamics of turbidity closely mimic the dynamics of stage and/or water level, as observed in all of the figures (Figs. 3 – 11). However, it is apparent that this relationship varies from stream to stream. Regression analyses add additional information as to the dynamics of this relationship, on a stream by stream basis. Further analyses will also include correlations and regression analyses between turbidity, discharge, suspended sediment, and upslope conditions.

Macro Invertebrates (excerpt from Jon Lee, aquatic macro invertebrate biologist).

Benthic macro invertebrates (BMIs) were collected and rated according to the California Stream Bioassessment Procedure (CDFG 2003), a modification of the Rapid Bioassessment Protocol (Barbour et al. 1999). At each site three riffles, along a 300 foot reach, were randomly selected for sampling. At each selected riffle a transect was randomly selected across the riffle for BMI sample collection.

Three one ft^2 areas of substrate were sampled along each transect using a D-framed aquatic net with a 0.5 mm mesh size. A consistent collecting effort was maintained at each sample area. The three collections along each transect were combined to make one “composite” sample. Each sample was preserved in 95% ethanol. This procedure was repeated at each selected riffle resulting in 3 (three ft^2) samples collected at each site.

In the laboratory the three samples from each site were combined and evenly distributed in a gridded tray. Grids were randomly selected and all BMIs were picked from each selected grid until a total of 500 specimens were removed from the sample. BMIs were identified to a targeted level of taxonomic determination, in this case Taxonomic Level 1: most BMIs to the genus taxonomic level (Richards and Rogers 2006). Various metrics (biological measures) were calculated for each site in order to evaluate the sites.

The BMIs collected are generally in line with what would be expected from the stream sizes at the collection sites in the north coast region. Although none of the streams would be categorized as very good or outstanding based on the BMI samples, none would be categorized as poor, either. The BMI data does not suggest poor water quality within the watershed. Although relative abundance of BMIs was not extremely low at the sample sites, a higher relative abundance could be expected. A moderate to high level of embeddedness exists at the sites sampled, reducing the available habitat compared to a non-embedded stream site.

1. Brief notes on streams sampled in late June 2007.

The mainstem Van Duzen River BMI samples displayed a high number of EPT taxa (25 and 28), a positive attribute. Some spring emergers remained in the river with the developing summer taxa at the time of sampling, contributing to the high EPT taxa richness.

Grizzly, Hely and Cummins Creeks displayed somewhat similar taxa, with Grizzly Creek having more of an affinity to the mainstem than did Hely or Cummins Creeks. Cummins Creek had the highest number of taxa typical of a high quality, cool, mid-sized stream, among all the sites sampled.

Yager Creek had a relatively high number of EPT taxa (23) but also had the highest number of the relatively tolerant midge family Chironomidae and the ubiquitous and tolerant mayfly *Baetis* (Baetidae) of the sample sites. These two groups made up over 60% of the individual BMIs collected at Yager Creek, contributing to the lowest diversity index score among the sites and suggesting an imbalance.

Wolverton Gulch had the lowest taxa and EPT taxa richness of the sample sites. This can be expected from a small, low order creek. However, a higher number of intolerant taxa would be expected than were found in the Wolverton Gulch samples. A deviation from similarly sized, high quality creeks on the north coast is suggested. If this is not an artifact of the watershed, the BMI sample suggests that this is an impaired system.

2. North Coastal Index of Biological Diversity.

The California Department of Fish and Game has produced a draft version of an index of biological diversity for northern coastal California (Rehn et al. 2005). Several metrics were evaluated to determine if they could discriminate between minimally disturbed reference sites and sites that had experienced known stressors. Eight metrics (Table 6) were chosen for use in the IBI. Though it is emphasized this is a draft, it should be informative as a measure for comparing streams. The following table shows the scoring used in this IBI applied to the Van Duzen Watershed BMI samples. The metric scoring range is 0 (very poor) to 10 (very good).

Table 6. Use of the IB Index (IBI) to distinguish macro invertebrate populations at seven monitoring sites within the Lower Van Duzen River Basin.

	Mainstem Rainbow	Grizzly Creek	Hely Creek	Mainstem Weare	Cummings Creek	Yager Creek	Wolverton Gulch
EPT Taxa	9	7	8	10	10	9	6
Coleoptera Taxa	5	10	7	7	10	9	5
Diptera Taxa	7	10	7	7	6	7	8
% Intolerant*	7	6	7	6	8	3	4
% Scraper	4	9	8	5	3	3	8
% Predator	8	10	9	6	10	6	7
% Shredder	2	4	4	3	6	4	4
% Non-Insect	8	8	8	8	8	9	9
Total (x 1.25) **	62.5	80	72.5	65	76.25	62.5	63.75

* % Intolerant should be corrected for watershed size.
** Multiplied by 1.25 to fit a 100-point scoring system.

0-20: very poor
21-40: poor
41-60: fair
61-80: good
81-100: very good

Grizzly and Cummings Creeks scored near the upper end of the "good" category. Hely Creek fell in the middle of the "good" category, while the remaining samples fell in the lower range of the "good" category (End Excerpt).

Other Indices of Water Quality.
Temperature, pH and dissolved oxygen appeared to be within acceptable levels for salmonid species during the winter months (Figs. 16-18). Conductivity values (Fig. 19) were similar at all monitored sites except Wolverton Gulch, where values were excessively high. The water of this creek is also characterized by a brownish tint year round, all of which when combined with turbidity grab sample results, suggests a high degree of impairment. At several sites (Yager Creek, and both sites on the mainstem VDR) during summer months, temperatures approached unacceptable levels (Fig. 16). These consistent differences in temperature can also be observed in the HOBO temperature data presented for Cummings Creek (Fig. 20), versus Yager Creek (Fig. 21) and the mainstem Van Duzen at Rainbow Bridge (Fig. 22). Whereas temperatures in tributaries like Cummings, Hely, and Grizzly Creeks ran relatively cool during summer months, temperatures surpassed stress levels, and in some cases, lethal levels in the mainstem Van Duzen River (U.S. Environmental Protection Agency 2007). Data from the Mainstem Weares site were similar to those at Mainstem Rainbow Bridge.

Additional measurements were taken on discharge, suspended sediment, turbidity, and stage. These data, in general, support results from grab samples (Table 7). Based on CA Department of Fish & Game standards that set 40 NTU as an upper limit for acceptable chronic turbidity, turbidity and suspended sediment measurements registered unacceptable levels for all streams sampled during storm events (Table 7). However, duration of chronic turbidity, an important index of impairment, cannot be estimated from these data. Duration of chronic turbidity will be estimated from grab and continuous sampling efforts, that will be quantified and described in subsequent monitoring reports.

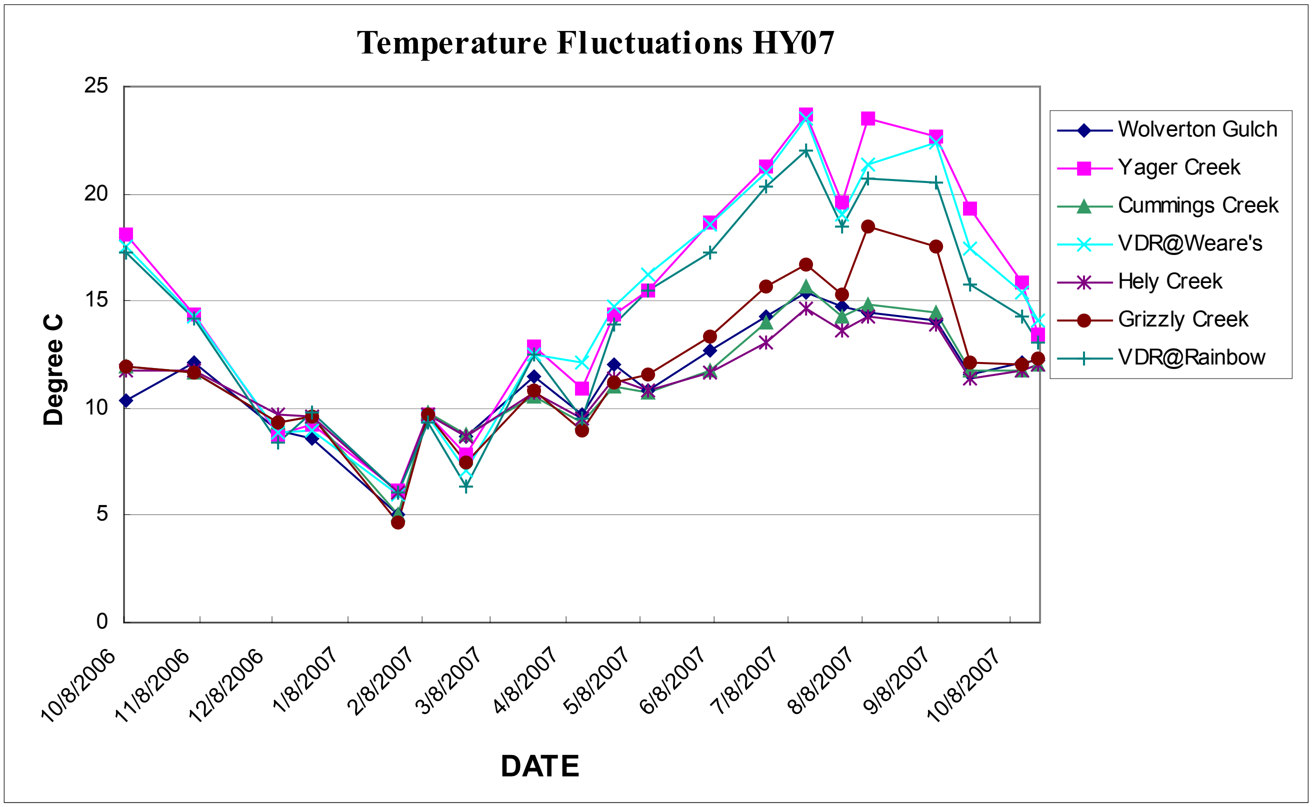

Fig. 16. Temperature (^{o}C) measurements for seven monitoring sites during HY07.

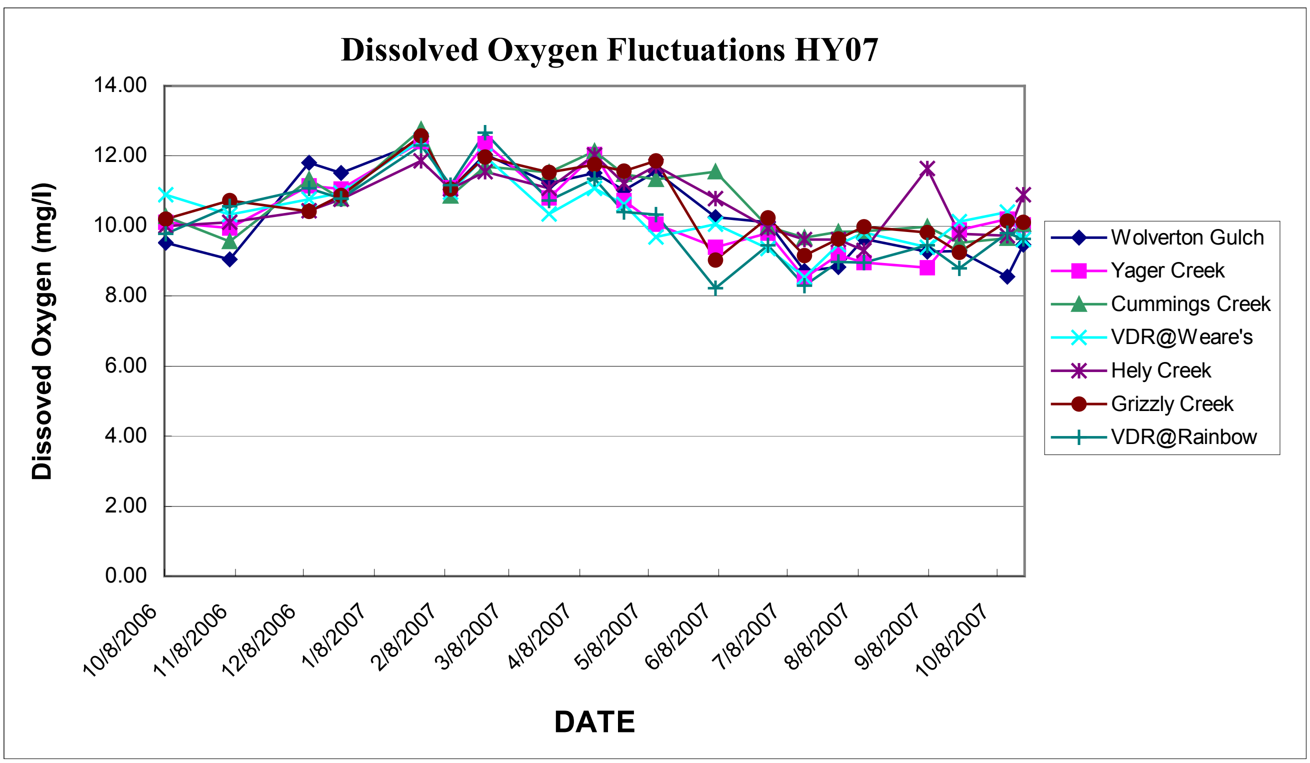

Fig. 17. Dissolved oxygen (mg/l) measurements for seven monitoring sites over time.

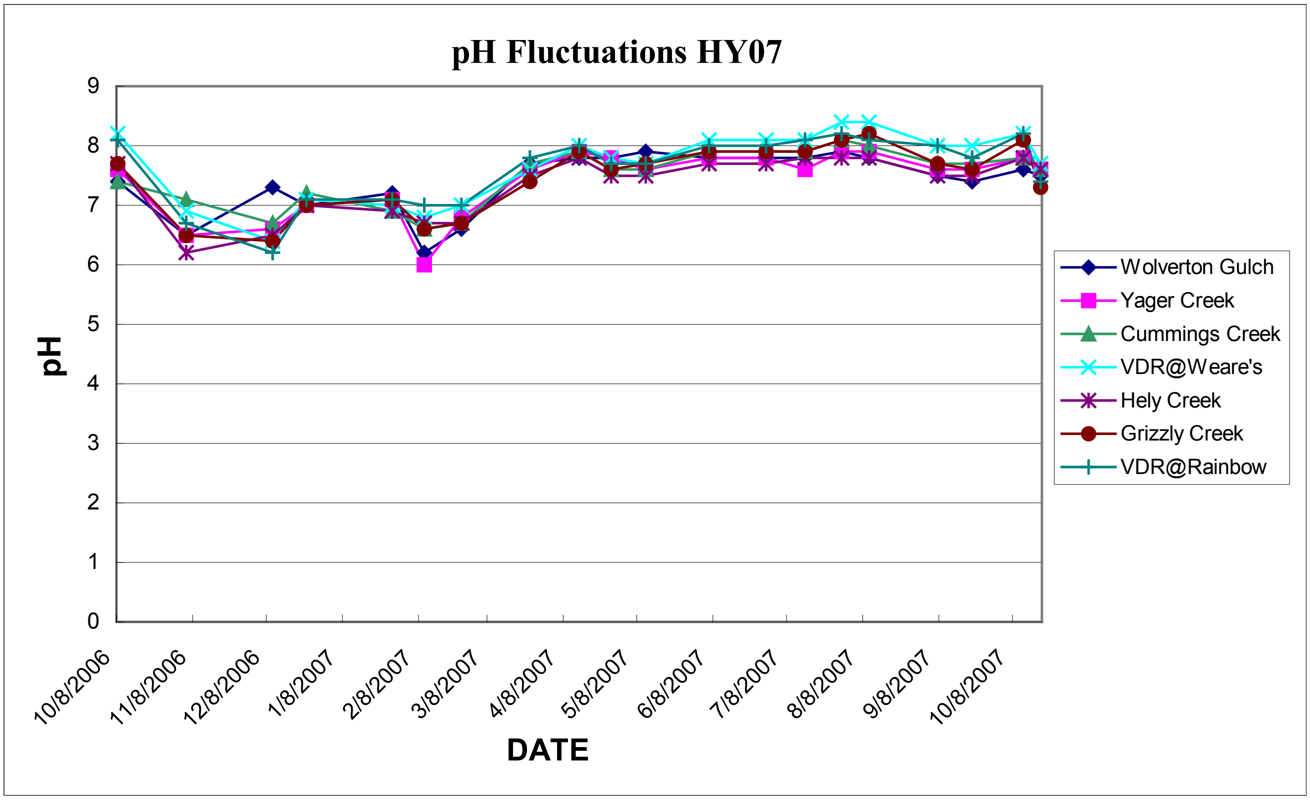

Fig. 18. pH measurements for seven monitoring sites over time.

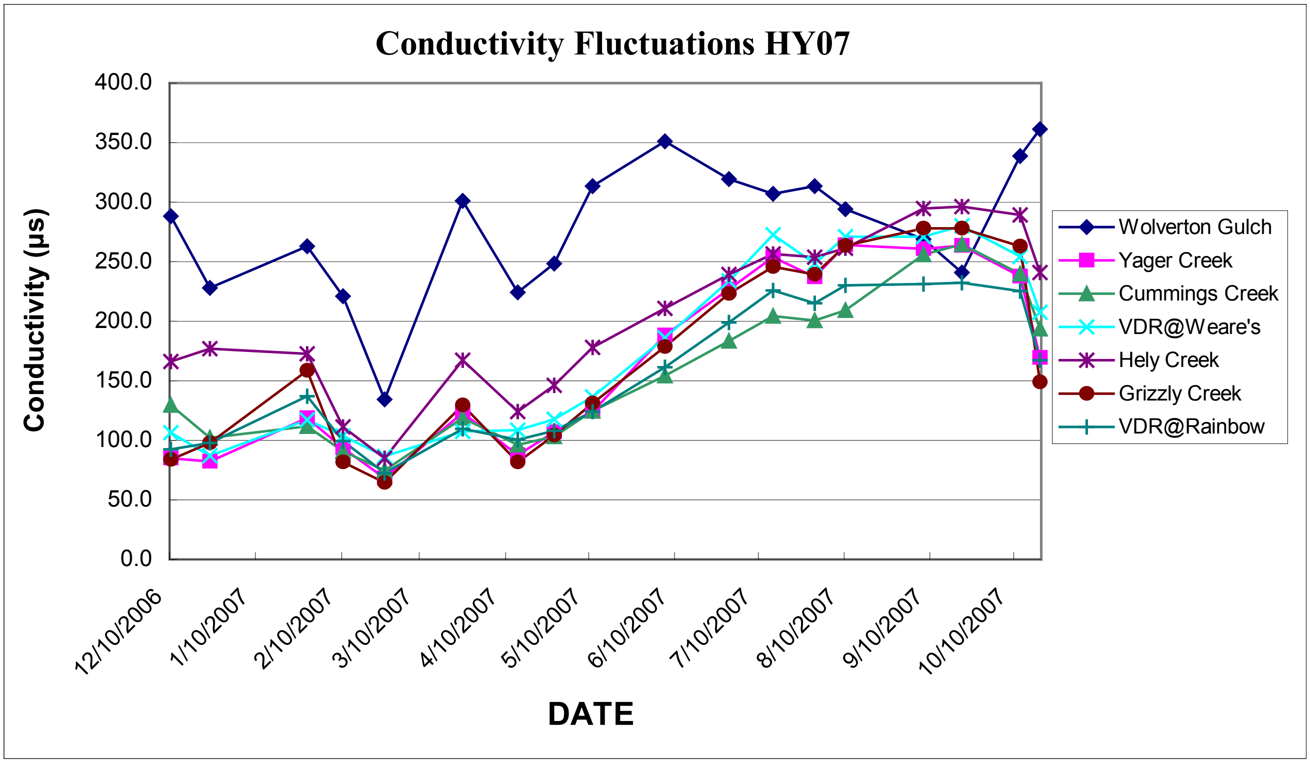

Fig. 19. Conductivity (µs) measurements for seven monitoring sites over time.

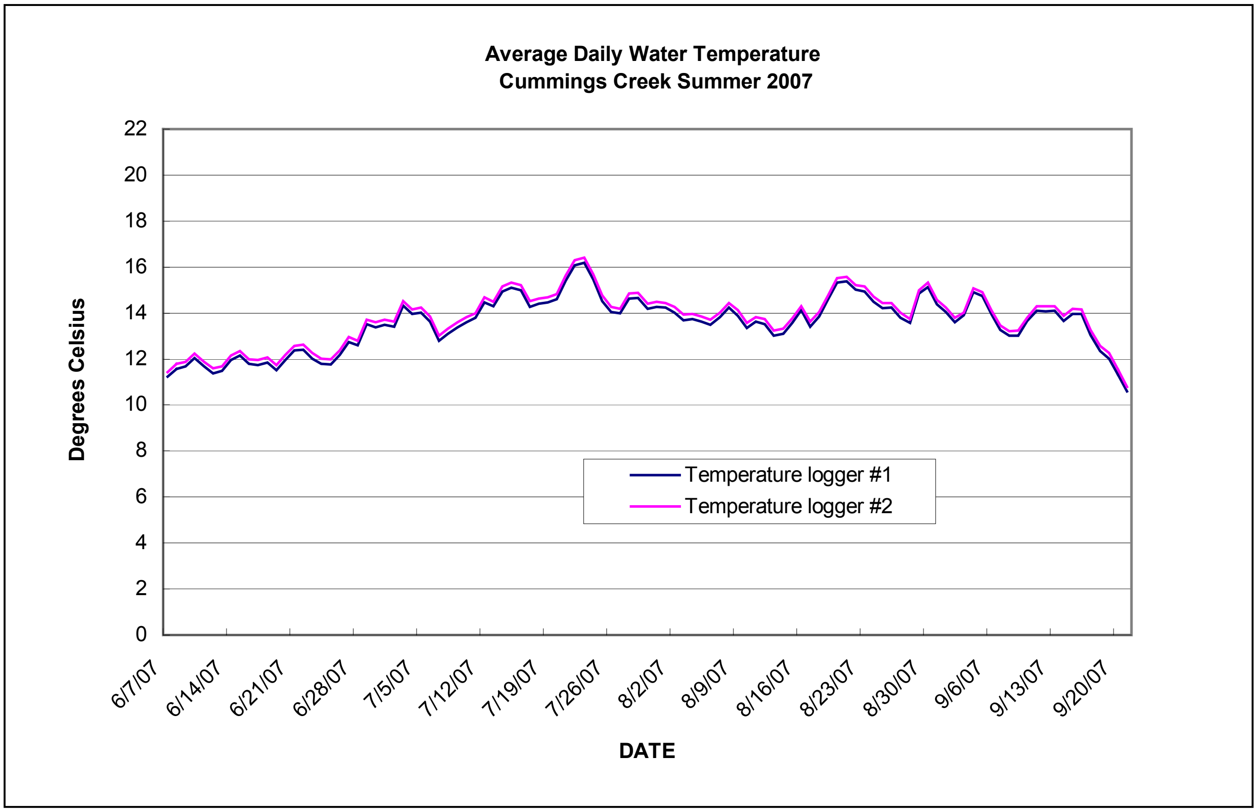

Fig. 20. Average daily water temperature for Cummings Creek, Summer 2007.

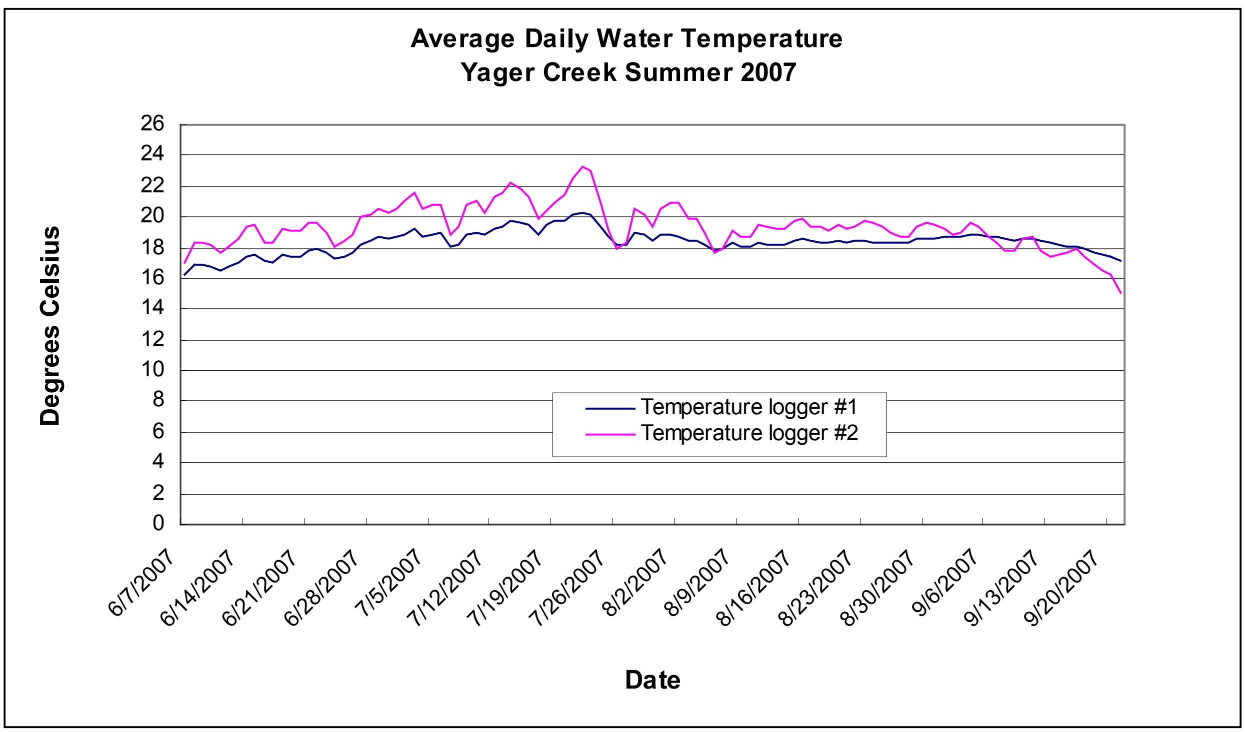

Fig. 21. Average daily water temperature for Yager Creek, Summer 2007.

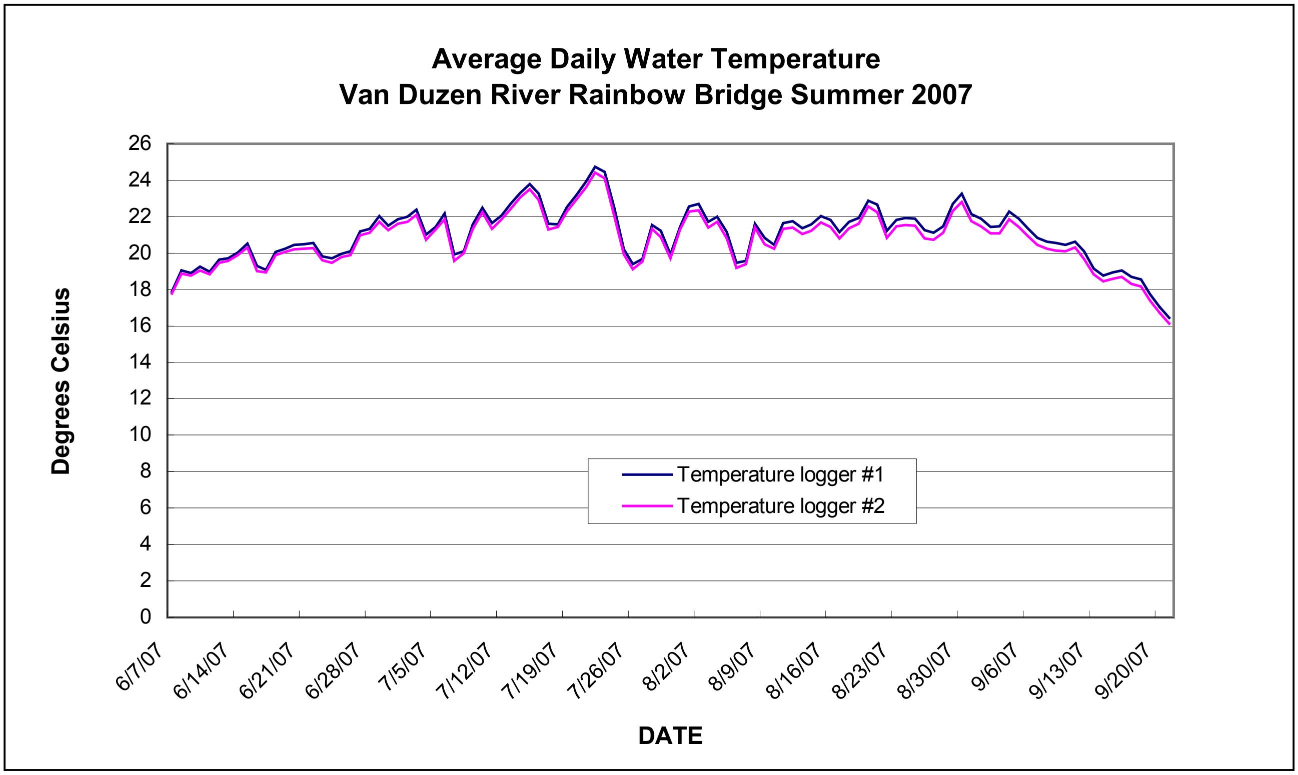

Fig. 22. Average daily water temperature for the VDR at Rainbow Bridge, Summer 2007.

Table 7. Results of bi-monthly monitoring streams for turbidity and suspended sediment (SSC) conditions within the Van Duzen River Basin.

VDWP Monitoring Data (* Discharge measurements determined with Flow Probe, except at
HY 2007 Rainbow Bridge, the site of the USGS gauging station #11478500)

Date	Location	Discharge (cfs)*	SSC (mg/l)	Turbidity (NTU)	Staff Plate (ft)
10/08/06	Wolverton Gulch	1.0			
	Yager Creek	12.0			
	Cummings Creek	1.2			
	VDR @ Weare's	28.0			
	Hely Creek	3.0			
	Grizzly Creek	3.5			
	VDR @ Rainbow	12.0			
11/05/06	Wolverton Gulch	1.0	50.0		
	Yager Creek	21.0	50.0		
	Cummings Creek	1.4	0.0		
	VDR @ Weare's	63.0	50.0		
	Hely Creek	4.1	0.0		
	Grizzly Creek	4.8	0.0		
	VDR @ Rainbow	50.0	50.0		

Date	Location	Discharge (cfs)*	SSC (mg/l)	Turbidity (NTU)	Staff Plate (ft)
12/10/06	Wolverton Gulch	8	600.0	397.0	
	Yager Creek	NA	700.0	345.0	
	Cummings Creek	23	100.0	148.0	
	VDR @ Weare's	NA	300.0	252.0	
	Hely Creek	14	100.0	130.0	
	Grizzly Creek	NA	100.0	138.0	
	VDR @ Rainbow	1790	200.0	184.0	
12/24/06	Wolverton Gulch	4	0.0	13.7	
	Yager Creek	NA	0.0	14.3	
	Cummings Creek	17	0.0	10.2	
	VDR @ Weare's	NA	40.0	30.3	
	Hely Creek	15	0.0	12.5	
	Grizzly Creek	68	0.0	17.5	
	VDR @ Rainbow	1220	40.0	28.5	
01/28/07	Wolverton Gulch	2		5.40	
	Yager Creek	NA		1.80	
	Cummings Creek	5		1.90	
	VDR @ Weare's	NA		1.40	
	Hely Creek	6		4.50	
	Grizzly Creek	18		2.10	
	VDR @ Rainbow	205		1.50	
02/10/07	Wolverton Gulch	NA	750.0	403.0	
	Yager Creek	NA	700.0	308.0	
	Cummings Creek	NA	572.0	284.0	
	VDR @ Weare's	NA	300.0	254.0	
	Hely Creek	NA	900.0	440.0	
	Grizzly Creek	NA	550.0	403.0	
	VDR @ Rainbow	3230	600.0	314.0	
02/25/07	Wolverton Gulch	NA	500.0	416.0	0.85
	Yager Creek	NA	346.0	427.0	NA
	Cummings Creek	NA	250.0	227.0	1.30
	VDR @ Weare's	NA	440.0	386.0	8.40
	Hely Creek	NA	300.0	241.0	0.60
	Grizzly Creek	NA	200.0	198.0	2.80
	VDR @ Rainbow	5480	320.0	274.0	5.80
03/25/07	Wolverton Gulch	3		7.3	0.36
	Yager Creek	NA		7.2	1.22
	Cummings Creek	8		6.5	0.29
	VDR @ Weare's	NA		6.7	
	Hely Creek	8		8.4	NA
	Grizzly Creek	96		5.2	0.46
	VDR @ Rainbow	512		6.3	NA

Date	Location	Discharge (cfs)*	SSC (mg/l)	Turbidity (NTU)	Staff Plate (ft)
04/14/07	Wolverton Gulch	11	200.0	262.3	0.49
	Yager Creek	NA	36.0	52.3	2.99
	Cummings Creek	NA	18.0	41.3	0.58
	VDR @ Weare's	NA	18.0	20.3	NA
	Hely Creek	26	80.0	90.3	NA
	Grizzly Creek	NA	276.0	101.4	1.37
	VDR @ Rainbow	624	145.0	77.2	2.2
04/27/07	Wolverton Gulch	2		11.5	0.34
	Yager Creek	NA		9.3	1.81
	Cummings Creek	14		9.3	0.46
	VDR @ Weare's	NA		7.7	2.50
	Hely Creek	12		12.6	0.68
	Grizzly Creek	47		9.3	0.79
	VDR @ Rainbow	541		7.1	2.07
05/11/07	Wolverton Gulch	2.0	0.29	9.4	80.0
	Yager Creek	NA	1.09	3.4	40.0
	Cummings Creek	8.0	0.22	4.5	40.0
	VDR @ Weare's	NA	1.75	3.1	37.7
	Hely Creek	10.0	0.55	6.5	37.7
	Grizzly Creek	35.0	0.45	4.3	54.5
	VDR @ Rainbow	319.0	NA	3.4	36.4
06/06/07	Wolverton Gulch	1.5	0.27		
	Yager Creek	48.0	0.53		
	Cummings Creek	5.0	0.10		
	VDR @ Weare's	NA	0.89		
	Hely Creek	8.0	-0.27		
	Grizzly Creek	26.0	0.18		
	VDR @ Rainbow	106.0	NA		
06/29/07	Wolverton Gulch	1.5	0.26	2.4	
	Yager Creek	30.0	0.23	0.7	
	Cummings Creek	4.0	0.04	0.9	
	VDR @ Weare's	NA	NA	1.1	
	Hely Creek	7.0	-0.60	1.5	
	Grizzly Creek	18.0	0.08	0.7	
	VDR @ Rainbow	34.0	0.70	0.8	
07/15/07	Wolverton Gulch	NA	0.18		
	Yager Creek	NA	0.06		
	Cummings Creek	NA	0.03		
	VDR @ Weare's	NA	NA		
	Hely Creek	NA	NA		
	Grizzly Creek	NA	0.00		
	VDR @ Rainbow	19.0	0.60		

Date	Location	Discharge (cfs)*	SSC (mg/l)	Turbidity (NTU)	Staff Plate (ft)
07/30/07	Wolverton Gulch	NA	0.20		
	Yager Creek	NA	0.06		
	Cummings Creek	NA	0.03		
	VDR @ Weare's	NA	NA		
	Hely Creek	NA	NA		
	Grizzly Creek	NA	-0.20		
	VDR @ Rainbow	17.0	0.56		
08/10/07	Wolverton Gulch	1.0	0.18		
	Yager Creek	11.0	0.15		
	Cummings Creek	2.5	0.02		
	VDR @ Weare's	15.0	NA		
	Hely Creek	4.0	-0.32		
	Grizzly Creek	6.0	-0.42		
	VDR @ Rainbow	12.0	0.50		
09/07/07	Wolverton Gulch	1.0	0.15		
	Yager Creek	7.0	-0.15		
	Cummings Creek	1.0	-0.05		
	VDR @ Weare's	8.0	NA		
	Hely Creek	3.0	-0.03		
	Grizzly Creek	3.5	-0.11		
	VDR @ Rainbow	7.0	0.44		
09/21/07	Wolverton Gulch	1.0	0.02		
	Yager Creek	6.0	NA		
	Cummings Creek	1.0	-0.06		
	VDR @ Weare's	7.0	NA		
	Hely Creek	2.0	-0.04		
	Grizzly Creek	3.0	-0.10		
	VDR @ Rainbow	7.0	0.42		

NA = Not Available

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