Francis Creek Suspended Sediment Yield

Turbidity Threshold Sampling

1-23-07 to 5-31-07

Site FRC – 1099 Van Ness Avenue Ferndale, California

A collaborative project between

Coastal Conservancy

Department of Fish & Game

Humboldt County

Humboldt County Resource Conservation District

National Marine Fisheries Service

North Coast Regional Water Quality Control Board

For the

Salt River Ecosystem Restoration Project

by Clark Fenton 7-8-07

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1. Introduction

In December 2006 the Humboldt County Materials Testing Lab and Clark Fenton were asked to construct and maintain a Turbidity Threshold Sampling (TTS) Station on Francis Creek in Ferndale, California.

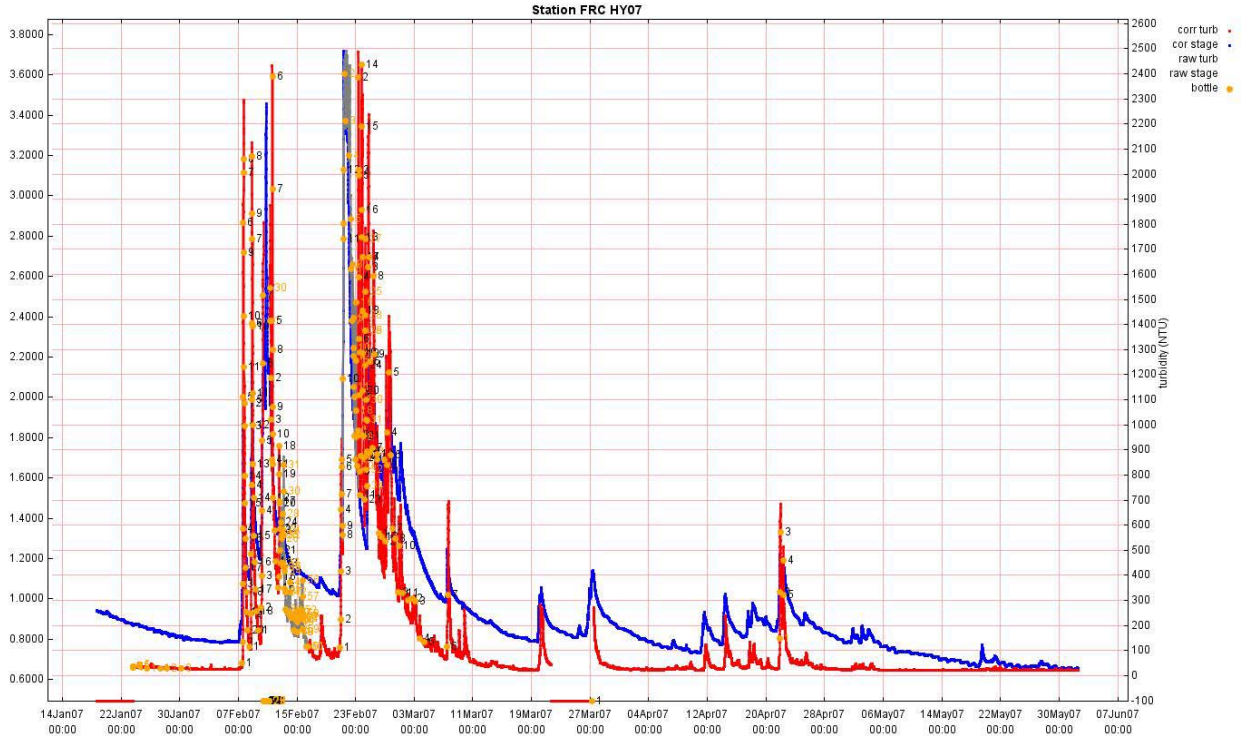
The Francis Creek TTS Station (Site FRC) is located at 1099 Van Ness Avenue in Ferndale, California. Francis Creek is the second largest tributary to the Salt River at 3.2 square miles (Buffleben, 2007). The Williams Creek watershed is the largest at 5.7 square miles. The Francis Creek TTS Station will be able to accurately measure suspended sediment loads originating upstream of the station. TTS Monitoring commenced at Site FRC on 1-23-07. The suspended sediment yield from Site FRC for 1-23-07 to 5-31-07 was **23,751,000 pounds** or **11,875 tons or 10,349 cubic yards**. See Section 2 for more details.

The Salt River Ecosystem Restoration Project is a joint effort by various agencies to improve riparian and fish habitat, reduce flooding, enhance sediment routing and lessen sewer plant impacts on Francis Creek and the Salt River. Suspended sediment yields from the Francis Creek watershed need to be quantified to provide planning data for future dredging downstream.

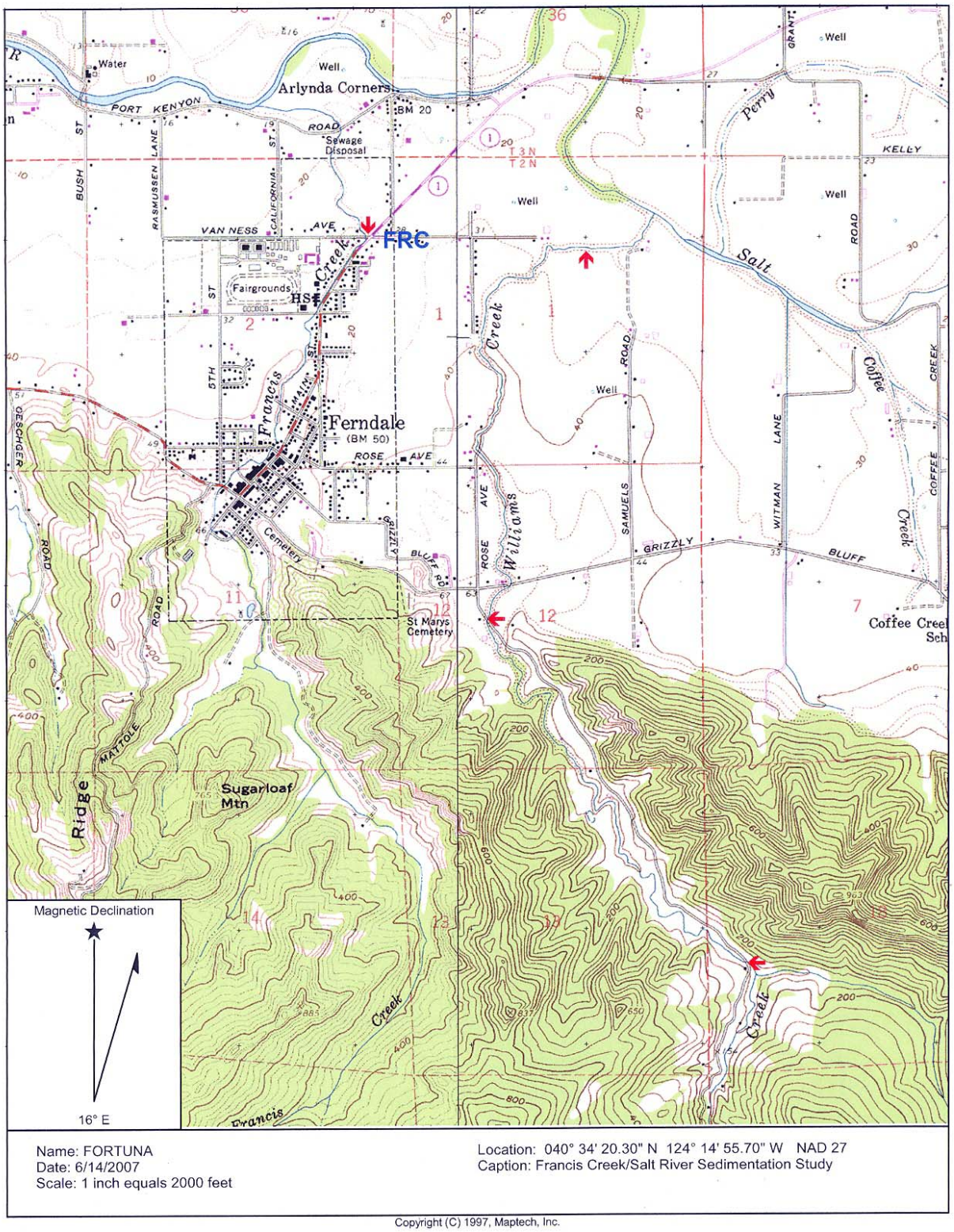
The Salt River is a tributary of the Eel River that heads in the Wildcat Mountains above Ferndale, flows across the Eel River Delta, and enters the Eel River within one mile of the Pacific Ocean. The watershed is part of the Franciscan Complex and mainly underlain by Quaternary mudstones, siltstones and sandstones of the Wildcat formation (McLaughlin, R.J. and others. 2000). Habitats and land uses that characterize the Salt / Eel River delta include the fourth largest estuary in California, salt-, brackish-, and freshwater marshes, riverine wetlands, riparian wetlands, agricultural lands dominated by dairy farms and irrigated pastures, and small communities (USDA, 1993).

Sedimentation in the Salt River Channel has resulted in problems associated with flooding and drainage, including:

- Decreased agricultural production and land values;
- Degradation of the estuary and its habitats as excess nutrients are transported from flooded dairy lands downstream;
- Loss of a once navigable waterway; and
- Increased health hazards posed by water quality degradation (USDA, 1993).



Turbidity and Stage plot for Site FRC – Hydrologic Year 2007



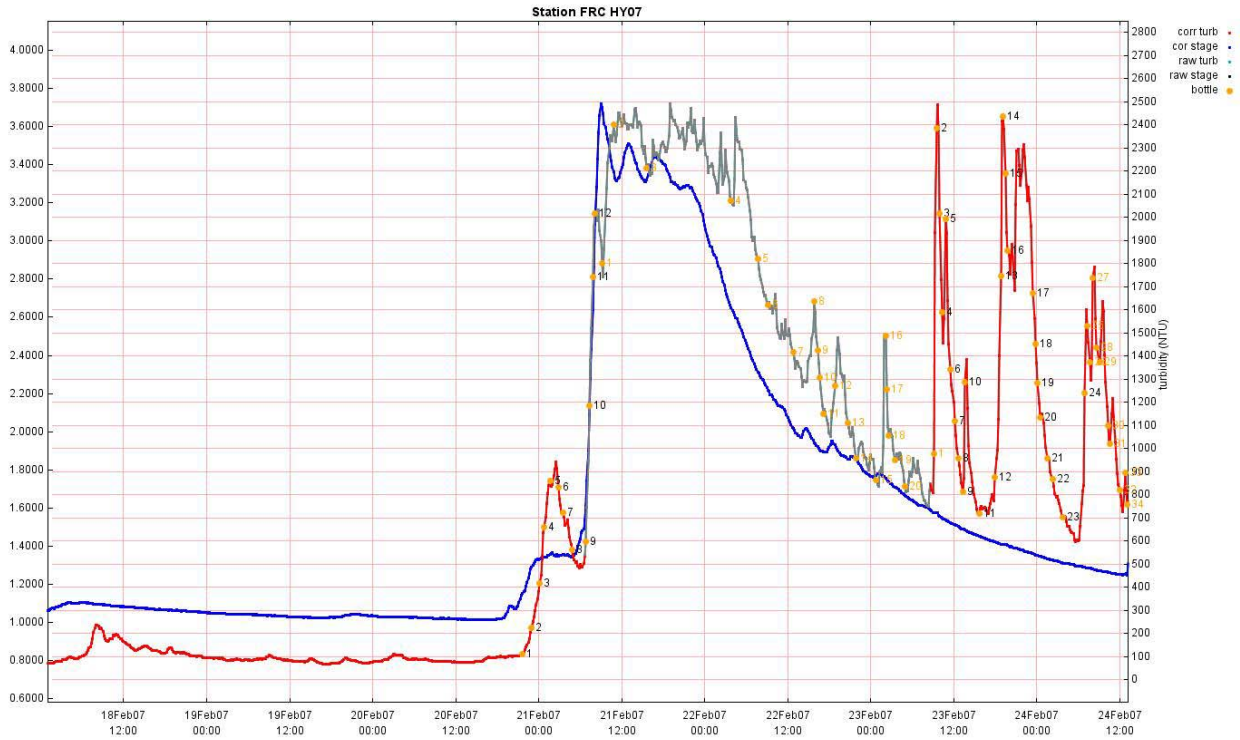
Francis and Williams Creek monitoring locations HY 2007

Turbidity Threshold Sampling (TTS)

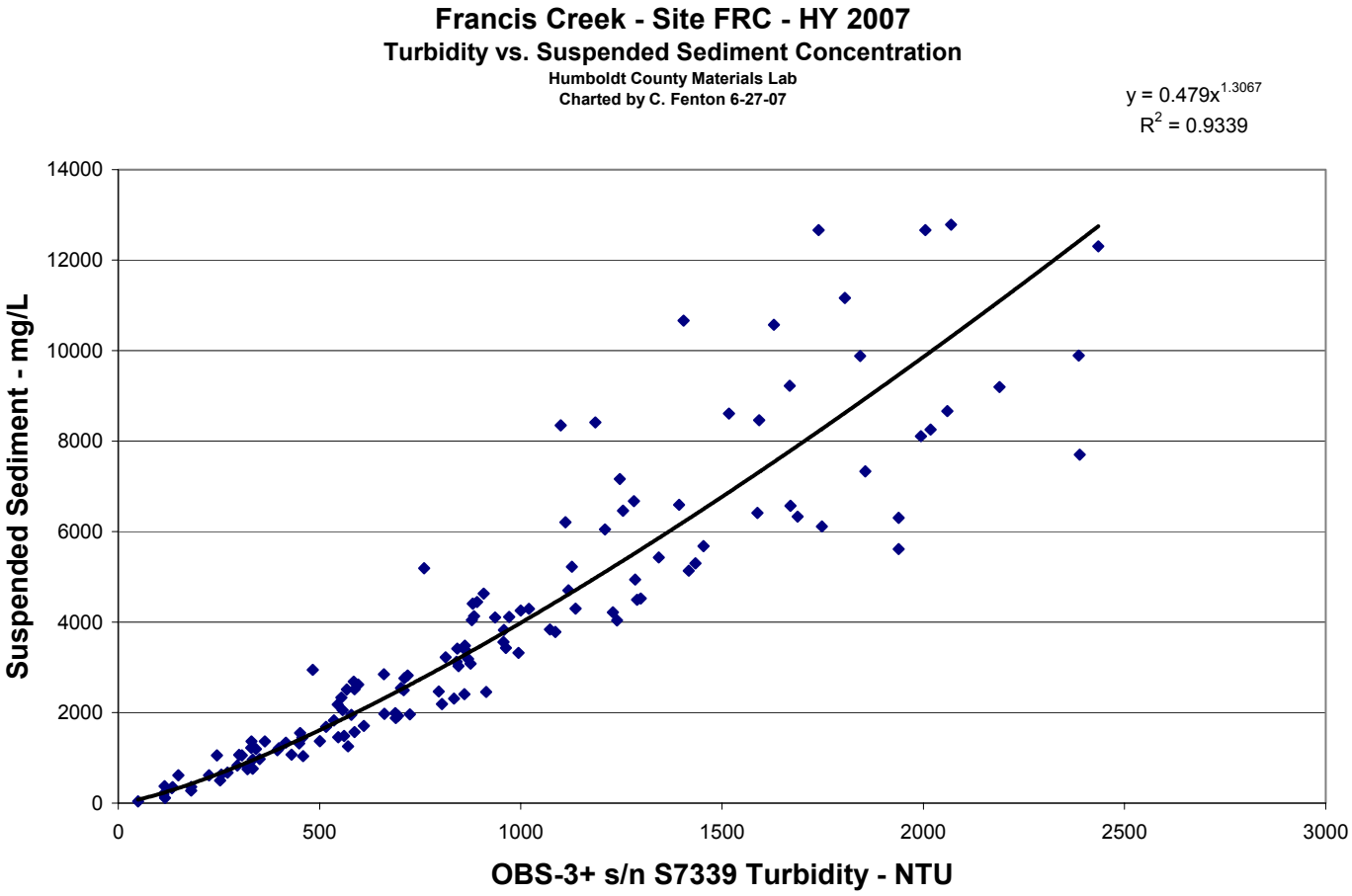
Jack Lewis and Rand Eads at Redwood Sciences Lab developed turbidity Threshold Sampling (TTS) over 10 years ago (Lewis, Eads, 2002). Redwood Sciences Lab is a research station for the USFS and has an extensive network of these stations on Caspar Creek to monitor sediment in the Jackson State Forest in 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 OBS-3+ Turbidimeter are 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. 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. The flo file for Site FRC 2007 is included in Appendix 5.

Water samples were taken to North Coast Laboratories (Arcata, California) for suspended sediment concentration determination. A regression is developed for OBS-3+ turbidity versus suspended sediment concentration. Using this regression, the 10-minute turbidity data is converted to 10 minute calculated suspended sediment concentration. A discharge rating curve is developed so flow rate is known for every 10 min stage data. By multiplying flow rate / cfs and suspended sediment concentration, pounds of sediment passing by the station are calculated. TTS Adjuster software is used to do data correction and R Sed 2.2.0 software is used to calculate suspended sediment loads (Appendix 1). 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.



Storm plot showing stage, turbidity and ISCO bottles for a single storm at Site FRC on 2-21-07
This storm contributed 11 million pounds or 46% of suspended sediment for the Francis Creek 07 study period.



Turbidity vs. Suspended Sediment regression of Site FRC HY 2007 ISCO pump samples.

2. Suspended Sediment Yield

The suspended sediment yield for the Francis Creek watershed above Site FRC totals over **23,750,904 million pounds** for the period 1-23-07 to 5-31-07. This translates to **11,875 tons or 10,349 cubic yards or 3,708 tons per square mile** of suspended sediment. A bulk density of 85 lbs per cubic foot (1.36 g/cc) was used to calculate cubic yards of fresh flood deposit sediment (USDA, 93).

The total annual suspended sediment yield for Site FRC for (Hydrologic Year) 2007 can't be calculated because of the 1-23-07 starting date of the TTS Station. The Francis Creek HY 2007 annual suspended sediment yield can be expected to at least **triple** if the major storms earlier in the year are added in. If an approximated hydrograph can be developed then a flow based suspended sediment load can be calculated.

The biggest storm on 2-20-07 contributed 46% of the study period's sediment. The highest flow and suspended sediment yield for this period came during the 2-20-07 storm with a peak turbidity of 2500, a peak discharge of 200 cfs and a peak 10 min load of approximately **84,000** pounds. The major turbidity events peaked at about 2500 ntu in February and March. Suspended Sediment Yield data sets and spreadsheets are in Appendix 1.

For comparison of the 3,708 tons / sq mi that Francis Creek produced in less than 2 months:

The **Eel River at Scotia** carries an almost incredible **4,330 tons of sediment every year from every square mile** of its drainage basin. On average, 4 to 8 inches of soil is washing is washing off the slopes every hundred years. That is the highest regional rate of erosion ever measured in the United States, more than 13 times the national average. Most of that phenomenal load goes down the river in about 6 days of the largest discharges during the winter floods (Roadside Geology of Northern and Central California – D. Alt / D. Hyndman – 2000).

The average annual suspended load for the **Mad River** is about 1,751,500 tons, or about **3,600 tons /sq. mile / yr** (Randy Klein).

The average suspended sediment yield from the **Elk River** watershed is about **500 tons / sq. mile / year** (Jeff Barrett / Pacific Lumber, Humboldt Bay Symposium, 2005).

The Francis Creek watershed has a very energetic and long lasting elevated turbidity response compared to other North Coast watersheds. Sediment is mobilized fast and available longer after the peak of a storm event.

The ability to track turbidity and suspended sediment loads on a storm by storm basis can be vital in revealing discrete watershed events such as landslides when they occur. Landslide delivery events can be tracked and delivery volumes can be verified.

TTS sampling provides an accurate and robust dataset to use in planning projects in the Francis Creek watershed. Francis Creek suspended sediment yields can be expected to rival most other watersheds on the North Coast of California.

The Table below is from the Sarah Wilson suspended sediment report for FRC HY 2007. The monitoring period was broken up into periods and the suspended sediment load was calculated for each period.

Summary of sediment load estimates for station FRC, 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:

Number of sample bottles within the period and the coverage of bottles across the entire period.

The strength of the relationship between the surrogate variable (usually turbidity) and ssc of the samples, as measured by CV and r^2.

The complexity of the models used, and the number of objects which were necessary to calculate the estimate for the period.

The quality of the surrogate variable data (usually turbidity).

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

Period	Dates and Times	Dump: Bottles	Sediment Load (kg)	Model(s)	CV %	r^2	Grade	% of Total Sedimen Load
1	070118,1600,070207,0320	dumps 1, 2, 3	**1,363**	lineartime, power	NA	NA	poor	0.01%
2	070207,0330,070208,1650	4: 1-20, 5: 1	**169,763**	power	~0.8%	~0.999	good to very good	1.58%
3	070208,1700,070210,0030	5: 2-18, 6: 1	**282,835**	linear, power	~2.2%	~0.995	very good	2.63%
4	070210,0040,070212,1100	6: 2-24, 7: 1-15	**3,147,346**	power, linear, lineartime, logxy	~3.7%	~0.89	good to fair	29.21%
5	070212,1110,070218,0050	7: 16-24	**133,432**	linear	3.45	0.994	very good to good	1.24%
6	070218,0100,070224,1300	8: 1-12, 10: 1-24	**4,979,896**	logxy, lineartime, power	~2%	~0.96	good to fair	46.22%
7	070224,1310,070227,0140	11: 2-13, 12: 2	**1,258,204**	linear	2.94%	0.996	excellent	11.68%
8	070227,0150,070307,0820	12: 3-11, 13: 1-5	**722,255**	power	3.88%	0.971	excellent to very good	6.70%
9	070307,0830,070319,1930	13: 6-7	**26,387**	power	9.97%	0.971	fair	0.24%
10	070319,1940,070325,0630	none	**6,281**	power, lineartime	~11%	~0.971	fair	0.06%
11	070325,0640,070410,2000	14: 1	**12,514**	power, lineartime, power	NA	~0.96	poor	0.12%
12	070410,2010,070421,0620	none	**6,342**	power	16.10%	0.971	fair to poor	0.06%
13	070421,0630,070601,1520	16: 1-5	**25,507**	power	9.59%	0.947	good	0.24%

Total Load (kg)	**10,773,242**

3. Field Operations HY 2007

The new station on Francis Creek – Site FRC – was made possible through grant from the State Coastal Conservancy and Department of Fish provided to the Humboldt County Resource Conservation District. Spencer Engineering and Alice Berg provided assistance with purchasing of equipment. The City of Ferndale Public Works constructed the FRC Equipment Enclosure Shed, Clark Fenton installed the equipment and Jesse Noell of Salmon Forever, fabricated the instream turbidimeter boom and discharge bridge board in January of 2007.

Site FRC at 1099 Van Ness Avenue

The TTS station uses an ISCO Model 6700 automatic pump sampler, a Campbell CR101X data logger, Druck 1830 pressure transducer, and an OBS-3+ turbidity probe. The shed was installed on 1-12-07. The datalogger and pressure transducer were up and running on 1-18-07. The OBS-3+ in-stream turbidimeter was operational on 1-23-07.

The OBS-3+ Turbidmeter was chosen for this application because of the expected very high turbidities. The OBS-3+ sensor consists of a high intensity infrared emitting diode, which shines out into the water flow and a detector to measure light bounced back from suspended sediment. The more infrared light bounced back the higher the turbidity. The OBS-3+ has a stated range of 4000 ntu but has a practical high range of 2600 ntu for Francis Creek Sediments, which is the highest available for an in-stream turbidimeter. Unfortunately from grab samples taken before the TTS Station was installed we can expect ntu's of over 10,000 during high loading events. When turbidities exceed the range of the in-stream turbidimeter, the TTS sampling software triggers timed interval sampling and uses those grab samples to measure suspended sediment loads.

Field Operations include upgrading TTS station equipment, taking discharge measurements on Francis and Williams Creeks, making TTS Station FRC data dumps / bottle swaps, repairing storm damage to equipment and removing sediment and debris covering the pressure transducer pipe tip and/or hanging on the turbidmeter boom.

A data logger modem was also purchased so that real time stage (water level) and turbidity data could be posted on the Redwood Sciences Lab website, which could function as part of an early warning network for flooding. Unfortunately funds were not available this year to start up phone service.

12-26-06 Francis Creek Storm – Grab Sampling

Francis Creek grab sampling was conducted by Clark Fenton during the 12-26-06 storm. Stage at FRC was about 5 feet. Very high turbidities were measured and a grab sample was sent to D&A to calibrate the OBS-3+ Turbidimeter. D&A reported 29,000 mg/l for the 12-26-06 15:30 grab sample. The in-stream turbidity was easily over 10,000 ntu for an OBS-3+ turbidimeter. This was probably not at the peak of the storm either. No hydrograph of Francis Creek for this storm is currently available, so accurate suspended sediment loads are difficult to report. No subsequent storm in HY 2007 came close to this one.

Clark Fenton measured water depth at the time of the grab samples and using the new discharge rating curve extrapolated 391 cfs at the time of the 29,000 mg/L suspended sediment concentration garb sample. He took a sample earlier at 638 cfs at 12-26-07 13:10 but no suspended sediment concentration was run on that sample. Using that single suspended sediment sample, loads at the height of this storm might easily **approach 700,000 pounds per 10 minutes or over 20 million pounds of suspended sediment in 5 hours**. **Using a flood deposit unit weight of 85 lbs. / cubic foot (USDA 93) that storm would deposit 8,700 cubic yards in 5 hours**. Unfortunately the TTS Station was not installed until 1-23-07 so this storm was not fully documented. The total suspended sediment load for this storm could easily be 4 or 5 times 8700 cubic yards. A surrogate hydrograph for Francis Creek should be developed for December and January of HY 2007 and a flow based suspended sediment yield developed. See Appendix 2 for details on that storm.

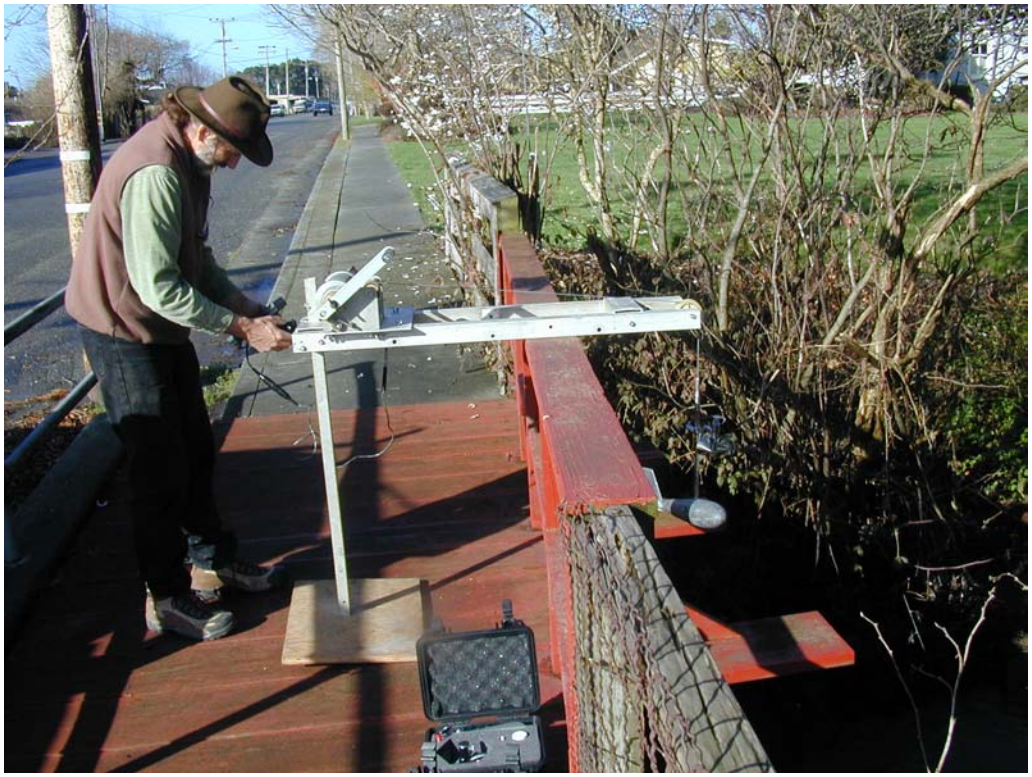
Site FRC at 12-26-07 at 14:11

Discharge Measurements HY 2007:

Six discharge (cubic feet per second) water measurements were taken on Francis Creek at the FRC site in HY 2007 ranging from 1 to 167 cfs. USFS / USGS methods were used for obtaining flow measurements (Harrelson 1994, USGS). Lower flows were measured with a Wading Rod using either a Pygmy current meter or a Price AA current meter. For higher flows an A-55 Reel, 30 lb. Columbus Weight, Price AA current meter and a bridgeboard were used from the Van Ness Avenue culvert. An accurate estimate of stream discharge is vital to accurate suspended sediment load calculations. See Appendix 3 for discharge sheets and rating curves.

Choosing a final discharge rating equation for a site using Excel can be problematic. Several different ways are available to apply a rating equation to a data set. A single equation can be fitted to the data set, or multiple equations can be fitted to separate portions of the data. Based on the number of measurements, a single discharge rating curve equation is being used to calculate cubic feet per second for all stages at FRC for the study period. With more data points several different stage / discharge equations could be used for low flow, medium flow, or combinations thereof at a site.

The problem with using a single equation is that fitting a curve to a set of data using Excel can cause the stage discharge equation to underestimate or overestimate flow at certain stages. Low flows may be underestimated using the above equation. This is not vital to calculating suspended sediment loads at high flows. A zero flow stage of 0.81 feet was used for sediment yield calculations. This stage/flow relationship can be improved with more flow measurements.



A-55 Reel and bridge board and AA current meter and 30-lb Columbus weight at Site FRC.

Williams Creek Discharge Measurements

Williams Creek discharged to the Salt River prior to diversion. This Williams Creek flow needs to be quantified to help plan for future stream work in Francis Creek and Salt River.

Staff plates were installed on the upstream bridge abutment on Williams Creek Road at PM 1.67 (Site WMC) on 3-19-07 and a discharge-rating curve created using 3 discharge measurements from 4 to 33 cfs. Discharges were also measured at 1 site lower down just above Grizzly Bluff road at PM 0.13 (Site WMB) and one in the pastures where Williams Creek is diverted (Site LWMC).

A comparison was tried between flows on Francis Creek and Williams Creek. The lack of major storms in the months of March and April hindered measurement of high flows. Williams Creek seems to provide twice the flow that Francis Creek does at low stage levels. This correlates with the Williams Creek watershed Area OF 5.7 square miles versus Francis Creek's 3.2 square miles. See Appendix 3 for discharge comparisons.

On 4-20-07 staff plates measurements were taken at Site WMC and then a discharge measurement was taken at the lower end of Williams Creek to determine how much flow is added from the top of the watershed to the bottom. Flow was doubled from the upper Williams Creek site (WMC) to the lower site (LWMC) in the pastures.

Total Dissolved Solids in Williams Creek is similar to Francis Creek's with 270 mg/L of dissolved solids.

Comparisons of flow and sediment concentrations between Francis Creek and Williams Creek need to be done at a range of flows for a proper comparison.

No water depth continuous recording equipment has been installed on Williams Creek and none is planned.

4. Lab Operations 2007

Clark Fenton visited the station periodically to switch out sample bottles as bottles were filled. Clark Fenton would then take the bottles to North Coast Labs. North Coast Labs was responsible for processing the ISCO Pump sampler bottles for suspended sediment concentration. The North Coast Lab contact was Bob Stuart at 822-4649.

Francis Creek yielded 161 ISCO pump samples from Site FRC from 1-31-07 to 5-31-07. As discussed in section 1, the suspended sediment concentration of each bottle is compared to the corresponding OBS-3+ Turbidity and a regression is developed for each storm period and for the entire year.

Total dissolved solids were measured approximately every 20th bottle. Total Solids were determined and Total Dissolved Solids were subtracted form Total Solids to yield Suspended Sediment Concentration in mg/L. North Coast Labs measured to 2 significant figures. The Francis Creek dissolved solids were about 270 mg/l.

Test Methods consisted of:

ASTM D 3977 (2002) Standard Test Methods for Determining Sediment Concentration in Water Samples. ASTM D 3977 (2002) was used for Total Solids and suspended sediment concentration.

ASTM D3977 (2002) Test Method A – Evaporation of the sample in a crucible was used because of large suspended sediment concentrations. Usually 47 mm - 1 micron glass fiber filters are used to filter sediment but sediment levels in Francis Creek samples at high flows would overwhelm the filters.

Standard Method 2540 D Total Suspended Solids Dried at 103 – 105 ^{0}C was used to refine the evaporation method. Standard Methods, 20th Edition 1998.

North Coast Labs reports are on file at the Humboldt County Materials Lab.

5. Closing Summary and Observations:

Large amounts of suspended sediment are passing by the FRC TTS Station. Annual tons/ sq mile yields are much more than Freshwater Creek and Elk River and are similar to the Eel River and Mad River.

TTS sampling is an important tool in planning for restoring beneficial uses of Francis Creek. It is hoped that turbidity and suspended sediment data collected by Site FRC can be used to determine long term trends in chronic turbidity, annual suspended sediment yields and turbidity discharge relationships in the Francis Creek Watershed. As time allows data from preceding years will be used towards those endeavors. Eventually comparisons with other watersheds will be possible also. Long term trends in land use and sediment levels can be investigated and documented with the TTS sampling methodology used in this report

Turbidities are expected to be very high during large storm events. When turbidities exceed the range of the in-stream OBS-3+ turbidimeter, the TTS sampling software will trigger timed interval sampling and uses those grab samples to measure suspended sediment loads. Turbidity sampling thresholds were adjusted in March to reduce duplicative and for suspended sediment concentration.

More sand fraction samples need to be taken to quantify the proportions of sand to silt and clay in Francis Creek flows.

On-line real-time stage and turbidity needed – This should provide man-hour and cost savings. Field crews are able to see conditions without visiting site. Field crews can tell how many bottles have been pumped and if more empty bottles are needed soon. Stage and discharge can be seen without visiting the site and plans made to measure needed discharge levels for discharge rating curves. City of Ferndale Public Works can see current water levels to anticipate sewage plant conditions and flooding actions.

More Discharge measurements needed –The existing discharge rating curve only goes up to 3 foot +. Discharge measurements are needed at the 4 foot, 5 foot and 6 foot water depths. These are hard to catch and real time on-line monitoring would increase success of measuring these high flows.

Clark Fenton would like to thank Curtis Ihle of the Humboldt County Resource Conservation District and Scott Kelly of Spencer Engineering for their support of this monitoring program. I would like to thank Jesse Noell of Salmon Forever for grabbing the high flow discharge measurement. I would like to thank Margaret Tauzer of the National Marine Fisheries Service for her support and her loan of Fish and Wildlife Service discharge equipment for Francis and William Creek monitoring. I would like to thank Alice Berg for buying staff plates for the Williams Creek site.

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10-m DEM and calculated the upland area to be 82,955 cells which translates to:
8,295,500 square meters 2,050 acres 3.2029 square miles

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EPA QA/G-5 Guidance for Quality Assurance Project Plans
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- Discharge Measurements at Gaging Stations Book 3 Chapter A8
- Laboratory Theory and Methods for Sediment Analysis Chapter C1 Book 5
- Field Methods for Measurement of Fluvial Sediment Chapter C2 Book 3

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