Francis Creek Annual Suspended Sediment Yield

Turbidity Threshold Sampling Summary Report

Hydrologic Year 2012

Site FRC – 1099 Van Ness Avenue Ferndale, California

A collaborative project between

National Marine Fisheries Service

Humboldt County

Coastal Conservancy

Humboldt County Resource Conservation District

North Coast Regional Water Quality Control Board

For the

Salt River Ecosystem Restoration Project

By Clark Fenton
7-14-12

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1. Introduction

The Humboldt County Materials Testing Lab and Clark Fenton continue to maintain a Turbidity Threshold Sampling (TTS) Station on Francis Creek in Ferndale California with funding from the Humboldt County Resource Conservation District, 5 Counties Salmonid Conservation Program, City of Ferndale and the Road Fund of the Humboldt County Public Works Department. Hydrologic Year 2012 was the sixth year and fifth full year of TTS monitoring on Francis Creek. Sarah Wilson continues to analyze and report the annual suspended sediment yields and slide analysis.

The annual suspended sediment yield from the Francis Creek watershed above Site FRC for Hydrologic Year 2012 from July 19th 2011 to May 2nd 2012 was **65.8 million pounds** or **29.8 million kilograms** or **28,696 cubic yards** or **10,291 tons / square mile**.

The purpose of this TTS monitoring station is to provide guidance on how much suspended sediment can be expected to enter the Salt River dredge areas over time from the Francis Creek watershed. 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 will continue to be quantified to provide planning data for future dredging downstream.

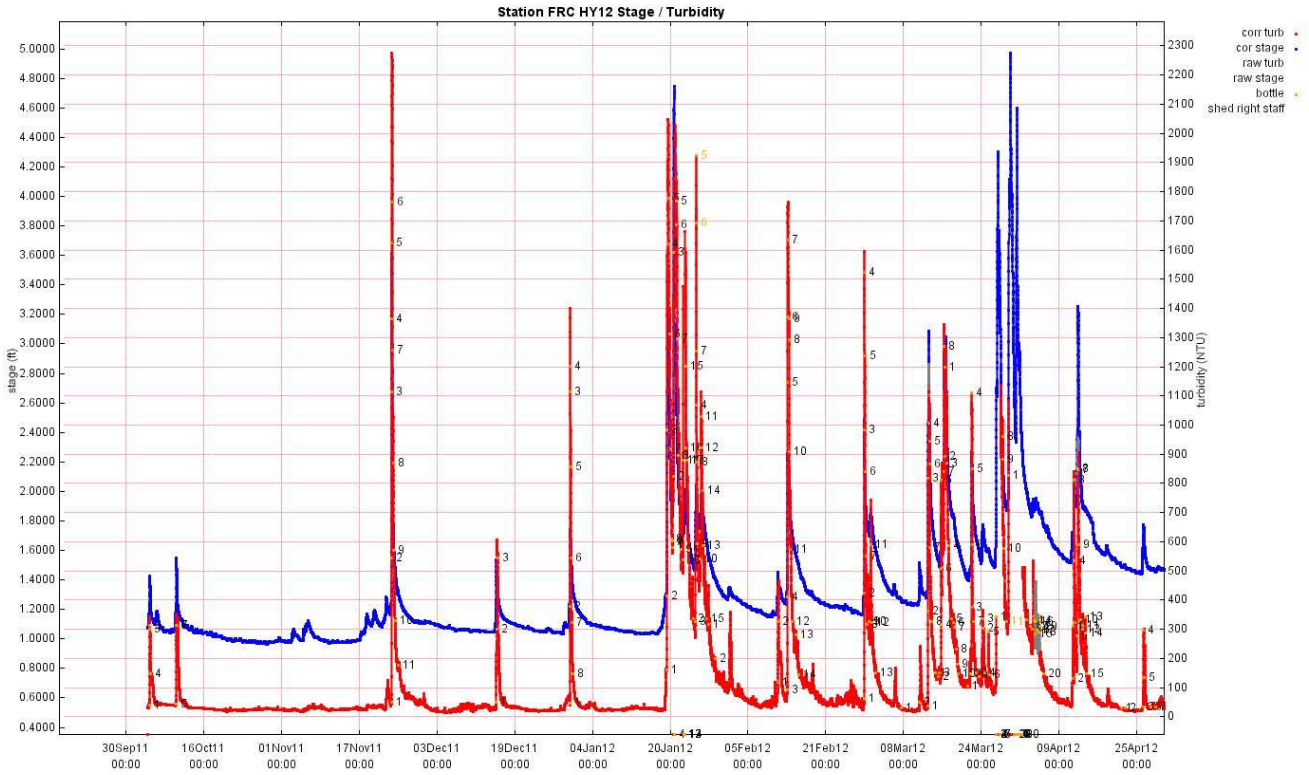
In March 2011 there was a large debris torrent in the last week of March in the upper Francis Creek Watershed. The Francis Creek Ranch Slide event contributed an estimated 11 million pounds of suspended sediment passing by Site FRC in HY 2011.This slide has altered the type and quantity of suspended sediment flowing down Francis Creek for HY 2012. See Section 2 for more details.

The Ferndale Enterprise reported on 6-28-12 that rainfall for Ferndale for "The weather year to date from 7-1-11 to 6-24-12 is **38.75** inches. Rainfall last year from 7-1-11 to 6-24-12 was 47.50 inches. The Weather Year average from 1971, July 1st to 6-24-12 is 40.44 inches rainfall." We had a dry winter and a wet spring.

The results from the last 5 water years are summarized below. The HY 2011 and HY 2012 totals include suspended sediment from the March 2011 Francis Creek Ranch Slide.

Hydrologic Year	Total Suspended Sediment Lb	Total Suspended Sediment Kg	Total Suspended Sediment Cubic Yards	Highest Single Storm Sediment Kg	Highest Single Storm Flow CFS	Annual Suspended Sediment Yield Tons/ Sq. Mile
2008	41,739,922	18,932,910	18,187	4,511,312	274	6,521
2009	12,578,664	5,705,593	5,480	1,351,049	135	1,965
2010	38,979,924	17,685,991	16,985	4,270,058	215	6,091
2011	70,342,760	31,915,953	30,650	17,045,608	268	10,991
2012	**65,859,288**	29,881,710	28,696	12,563,530	230	10,291

Table # 1 – Francis Creek Annual suspended sediment summaries



Plot # 1 Stage / turbidity plot of HY 2012 water year at Site FRC on Francis Creek.

Maximum storm stage was 4.9 feet / 230 cfs and maximum readable turbidity was 2200 ntu.

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)

The final certification for the Salt River Environmental Impact Report was in February 2011. Copies of the Final EIR are available for review at the Humboldt County Resource Conservation District, 5630 So. Broadway, Eureka. The EIR may also be reviewed on the HCRCD's web site (http://www.humboldtrcd.org, Salt River Restoration Project tab).

The first phase of the project, which involves wetland and upland restoration work on the 440-acre Riverside Ranch property and some channel excavation, was scheduled to begin late summer 2011 and continue into the next year. Phase 2, which includes channel excavation and restoration, would have begun in 2012.

Negotiations with property owners along the Salt River project have taken longer than expected and one property owner is left to sign on. The project is over $16 million now. Seven miles of channel are expected to be restored someday.

The flow data from this station may help operations at the new City of Ferndale sewage treatment plant downstream on Francis Creek that was opened this year.

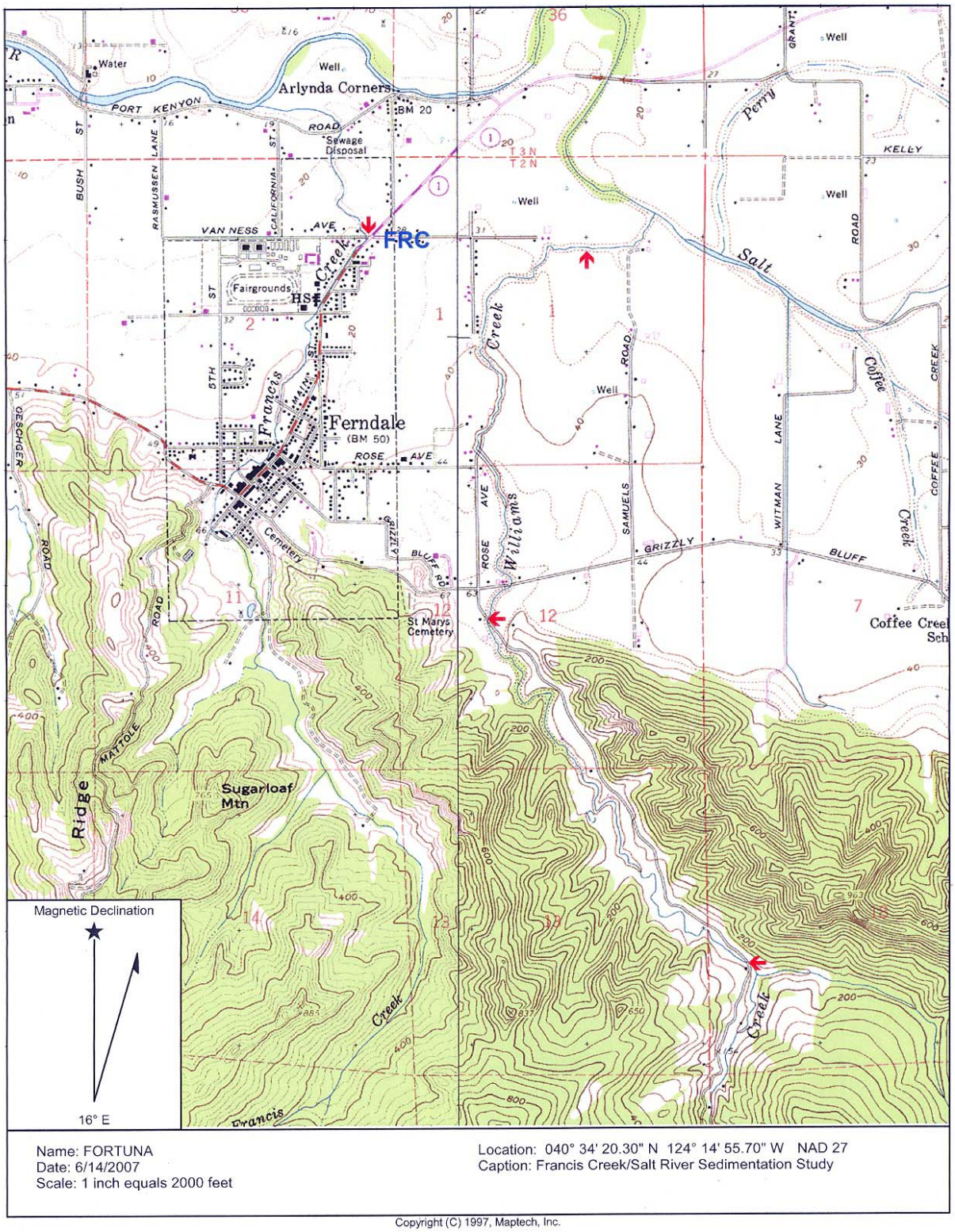


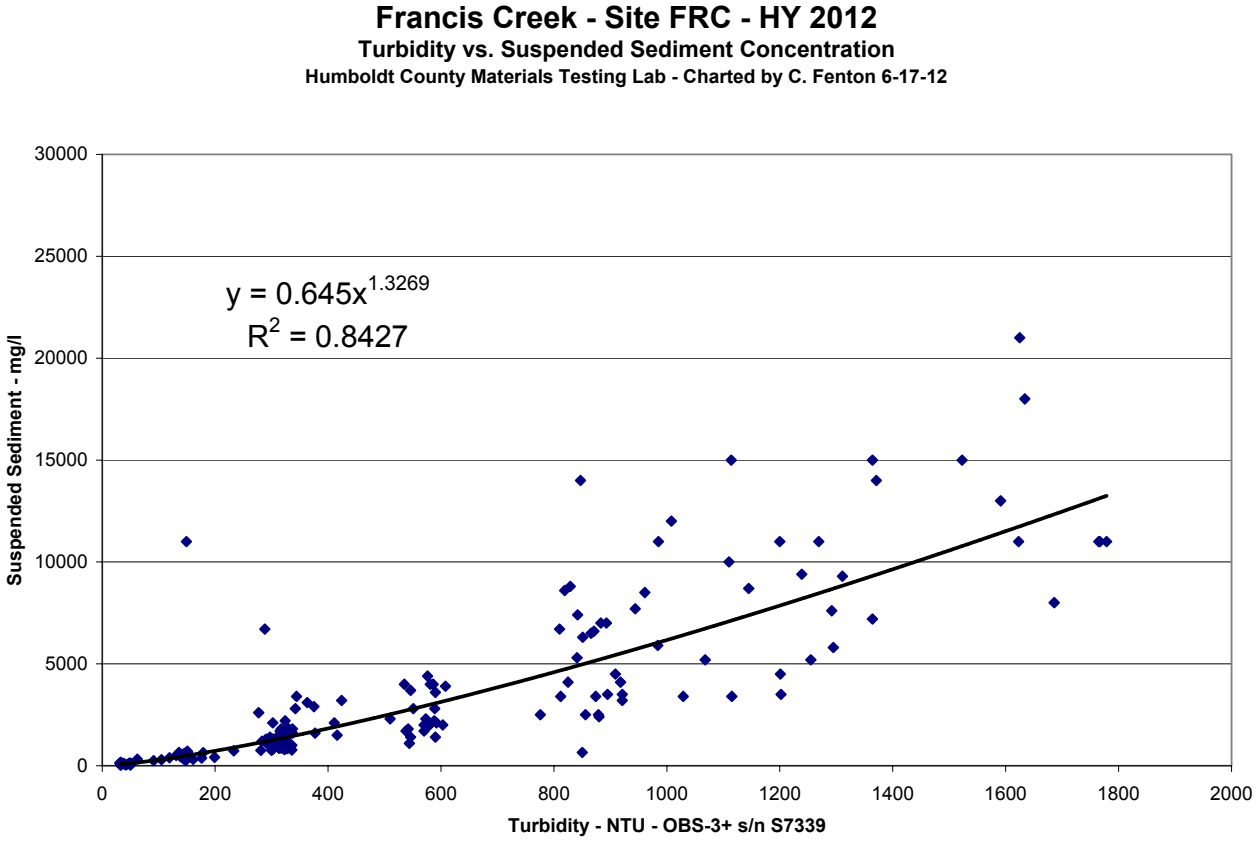
Figure # 1 Francis and Williams Creek monitoring locations

Turbidity Threshold Sampling (TTS)

Jack Lewis and Rand Eads at Redwood Sciences Lab developed turbidity Threshold Sampling over 10 years ago (Lewis, Eads, 2002). Redwood Sciences Lab is a research station for the USFS and deploys a network of these stations on Caspar Creek to monitor long-term sediment transport in the Jackson State Forest and other locations across Northern California. 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 using turbidity measurements every 10 minutes as a surrogate for suspended sediment measurements every 10 minutes. 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 rising and falling turbidity thresholds. The final 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 files for Site FRC 2007, 2008, 2009, 2010, 2011 and 2012 are included in Appendix 5. On-line real time plotting is available on the HSU website http://nrs-isa.humboldt.edu/rsl/tts_plot.html

Water samples continue to be taken to North Coast labs for suspended sediment concentration determination by subtracting filtering. A regression is developed for OBS-3+ turbidity versus suspended sediment concentration. The 10-minute turbidity data is converted to 10 minute calculated suspended sediment concentration. A discharge-rating curve is developed so flow is known for the every 10 min stage data. By multiplying flow / 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. 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.



Plot # 2 Turbidity vs. Suspended Sediment Concentration of Site FRC HY 2012 ISCO pump samples.

2. Francis Creek Ranch Slide – March 2011

During a set of 5 rainfall events starting 3-23-11 and ending 4-1-11 a large debris torrent occurred approximately 3.4 river miles upstream of the station. The forester of the upstream property, Chris Carroll, estimates the slide to be roughly 100,000 cubic yards in size.

The California Geological Survey visited the site on April 7, 2011. Details from their report by Don R. Braun dated April 18, 2011 include that a bridge was removed from it's abutments by the debris. At the slide site bedrock materials "consisted predominantly of soft to moderately dark gray siltstone with minor amounts of fine sub rounded gravel. Significant precipitation in the area during the month of March may have been the main contributor to the recent failure. The debris is estimated to consist of about 50% wood or logs and about 50% dark gray silt. Information supplied by Mr. Mark Distefano of TRC suggests that the destroyed former bridge over Francis Creek was approximately 15 to 20 feet above the channel and that the current debris in the channel is about 4 to 5 feet above the height of the old bridge suggesting that the debris thickness at this location may be about 19 to 25 feet. Francis Creek will likely remain turbid with suspended sediment during future rainy seasons until a stable channel and side slopes develop." (CGS, 2011)

Photo # 1 Francis Creek Ranch Slide

Using turbidity threshold sampling analysis for HY 11 Sarah Wilson estimated that 17 million kilograms / 37 million pounds / 16,000 cubic yards of suspended sediment flowed past Site FRC between March 23, 2011 and April 1, 2011. Approximately 6 million kilograms / 13 million pounds of suspended sediment would have flowed past during this storm event without a slide upstream. Approximately 11 million kilograms / 24 million pounds / 10,600 cubic yards of suspended sediment presumably came from the Francis Creek Ranch Slide during this period. The suspended sediment is mainly sand and silt and does not include bed load gravel.

Water Years 2008 and 2010 total suspended sediment yield were each about 40 million pounds for the station on Francis Creek, and Water Year 2009 had 12.6 million pounds total. This event contributed in 6 days almost the same amount of suspended sediment yield as all of Water Year 2010. The slide itself sent twice the amount as all of Water Year 2009 suspended sediment yield downstream in HY 11.

During the slide event, the TTS station sucked over 40 water samples from Francis Creek, including 14 water samples over 35,000 milligrams/liter. Eight of those 14 bottles had over 65,000 mg/l, one bottle had 100,000 mg/l and one bottle had 180,000 mg/l.

Sarah Wilson produced the following charts showing the change in turbidity versus suspended sediment concentration pre and post slide.

frc10	frc11 pre-slide	frc12
$y = 0.3019x^{1.4017}$	$y = 0.2056x^{1.4586}$	$y = 0.645x^{1.3269}$

I have used these equations to compare the predicted suspended sediment concentrations at several levels of turbidity.

	estimated suspended sediment concentration (mg/l)		
turbidity	**frc10**	**frc11 pre-slide**	**frc12**
400	1340	1283	1829
800	3541	3528	4588
1000	4841	4885	6170
1200	6251	6373	7858

The predicted suspended sediment concentrations at turbidities from 400 to 1200 ntu are similar for HY10 and HY11 before the slide. The predicted suspended sediment concentrations for HY12 are substantially higher at each turbidity. This change in the relationship between turbidity and suspended sediment concentration may be an effect of the landslide which occurred in March 2011. (Sarah Wilson, 2012)

This slide continues to dominate the suspended sediment regime on Francis Creek for Hydrologic Year 2012. The relationship between suspended sediment and the OBS-3+ turbidimeter has changed. Higher suspended sediment concentrations are being measured against a corresponding turbidity than last year.

Several things may account for this including a change is the granular size of the sediment flowing downstream past the station. The slide debris may be finer or coarser than the previous mobile sediment in Francis Creek and the infrared turbidimeter may read those sediments differently. The OBS-3+ turbidimeter is calibrated the same each year and has not exhibited any unusual symptoms this year. This does not affect the accuracy of the TTS sampling analysis.

For each **HY 2011 period** after the landslide, sediment load without any slide materials was estimated using the relationship between discharge ("flow") and suspended sediment concentration ("ssc") immediately prior to the slide.

Period	Best Estimate of Sediment Load During Each Period (kg)	Flow-Based Estimate of Sediment Load Without Slide (kg)	Estimated Slide Contribution (kg)	Percent of Estimated Sediment Load Contributed by Slide
16	17,045,608	6,363,652	10,681,956	63%
17	49,714	13,289	36,425	73%
18	24,502	1,372	23,130	94%
19	12,735	656	12,079	95%
20	15,247	939	14,308	94%
21	992,140	357,446	634,694	64%
22	274,633	91,396	183,237	67%
23	43,012	25,062	17,950	42%
24	8,624	NA	NA	NA

Any large rainfall events from now on will probably remobilize slide sediment at the slide site and in the upper reaches of Francis Creek and wash it downstream. This event is not a positive thing for infrastructure and habitat restoration efforts downstream.

This spring 2012 a set of survey points were set across the slide to monitor movement.

The slide's contribution to the annual suspended sediment yield for Francis Creek seems to be slowly diminishing with time as the slide debris settles in and the easily mobilized sediments are used up. A large year storm event may be needed to cause this slide to remobilize.

Even so, the Francis Creek watershed can expect to have annual suspended sediment yields in the future approximately twice of what they were before the Francis Creek Ranch Slide.

3. Hydrologic Year 2012 Suspended Sediment Yield

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 watershed at 3.2 square miles (Buffleben, 2007). The Williams Creek watershed is the largest at 5.7 square miles. TTS Monitoring commenced at Site FRC on Francis Creek on 1-23-07.

Sarah Wilson continues to do suspended sediment analysis with Redwood Sciences Lab analysis software. Sarah Wilson received her Bachelors of Science in Biology from San Jose State University and a Masters of Science in Watershed Management from Humboldt State University. Her husband is an active duty member of the US Coast Guard. They have a son and a daughter and are currently stationed in the Los Angeles area.

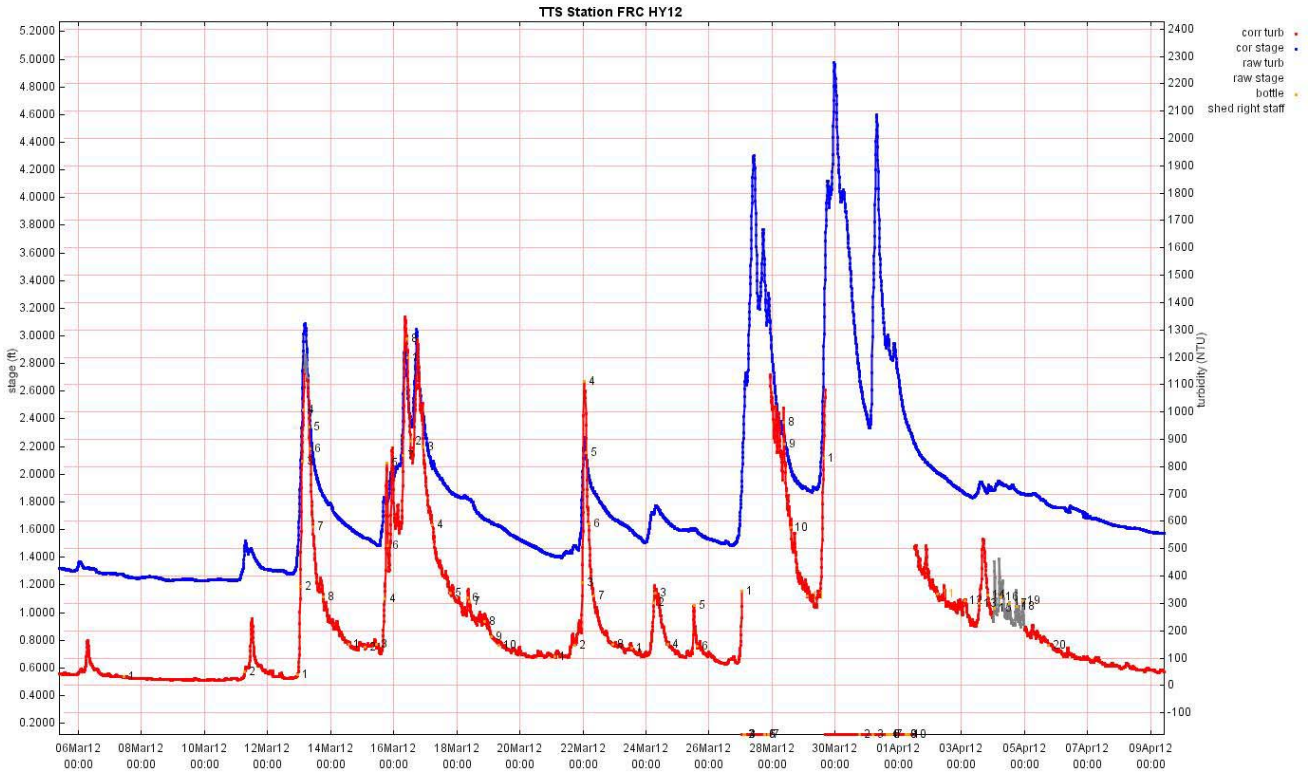
The annual suspended sediment yield from the Francis Creek watershed above Site FRC for Hydrologic Year 2012 from July 19th 2011 to May 2nd 2012 was 65.8 million pounds or 29,881,710 kilograms or 28,696 cubic yards or **10,291 tons / square mile**. A bulk specific gravity of 85 lbs per cubic foot was used to calculate cubic yards of fresh flood deposit sediment. (USDA, 93)

The largest suspended sediment estimation period of HY12 was storm period 16 from March 29 to April 11, 2012. The total estimated load for period 16 was 12.6 million kg, 42% of the total estimated load for HY12. The two next largest estimation periods were storm period 15 (3-26 to 3-29 2012) with 17% of the total and storm period 17 - 4-11-12 to 4-17-12 with 7% of the total. Half of the total came in Late March and mid April.

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 mi/yr** for Qss. (Klein, R. 2007, Personal Communication.)

Francis Creek continues to exceed the annual suspended sediment yield in tons per square mile of most local watersheds and even the El River.



Plot # 4. Francis Creek from March 8th 2012 to April 8th 2012 showing a series of storms in a 3 week period mobilizing 44 million pounds or 67% of the HY 12's total suspended sediment yield.

The plot shows water depth as blue peaking at 4.9 feet / 230 cfs and turbidity in red.

The table below is from the Sarah Wilson suspended sediment report for FRC **HY 2012**. Her complete report is in Appendix 1. The hydrologic year was broken up into storm-by-storm time periods and the suspended sediment load was calculated for each period. Ms. Wilson has done this same analysis for Redwood Sciences Lab.

Summary of sediment load estimates for station FRC, water year 2012

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 sample ssc, as measured by CV and r2.

The complexity and number of models and object used to calculate the estimate for each period.
The quality of the surrogate variable data (usually turbidity).

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

Discharge rating equation: at stage < 1.7799 discharge is 0.5889*stage^5.7592 and at stage > 1.7799 discharge is 2.9197*stage^2 + 44.278*stage - 64.555

Period	Dates and Times	Dump: Bottles	Sediment Load (kg)	% of Total Load	Grade
1	111004,1330,111110,0900	3:1-7	5,111	0.02%	good
2	111110,0910,111201,0000	4:1-11	1,069,633	3.58%	good
3	111201,0010,111229,0600	5:1-3	10,265	0.03%	fair
4	111229,0610,120118,1800	6:1-8	22,596	0.08%	good
5	120118,1810,120120,1230	7:1-9, 8:1	1,471,506	4.92%	very good
6	120120,1240,120122,0920	8:2-9	3,180,569	10.64%	very good
7	120122,0930,120125,0150	8:10-17, 9:1-2	259,013	0.87%	good
8	120125,0200,120129,1200	9:3-15, 10:1-2	363,726	1.22%	very good
9	120129,1210,120212,2300	11: 1-2	16,086	0.05%	fair/poor
10	120212,2310,120228,1600	11:3-14	638,106	2.14%	good
11	120228,1610,120312,2000	12:1-13, 14:1-2	480,035	1.61%	very good
12	120312,2010,120315,1330	15:1-8, 16:1-3	793,506	2.66%	very good
13	120315,1340,120321,0000	16:4-8, 17:1-10	1,555,357	5.21%	very good
14	120321,0010,120326,2200	18:1-8, 19:1-6	254,440	0.85%	very good
15	120326,2210,120329,1000	20:1-10	5,089,771	17.03%	good
16	120329,1010,120411,1100	21:1-20	12,563,530	42.04%	fair
17	120411,1110,120418,1000	22:1-15	2,071,149	6.93%	fair/poor
18	120418,1010,120502,0800	23:1-7	37,311	0.12%	fair/poor

Total Load (kg)	29,881,710

65,859,288 pounds

Table # 2 – HY 2012 Storm Period Suspended Sediment yields

4. Field Operations HY 2012

The station on Francis Creek – Site FRC – was made possible by funding from the Humboldt County Resource Conservation District, 5 Counties Salmonid Conservation Program, City of Ferndale and the Road Fund of the Humboldt County Public Works Department**.** The City of Ferndale Public Works constructed the Site FRC Equipment Enclosure Shed, and the equipment was installed in January of 2007.

Photo # 2 - 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 data logger and pressure transducer were up and running on 1-18-07. The OBS-3+ in-stream turbidimeter hangs from a boom off the ceiling of the culvert and has been operational since 1-23-07. The equipment has been mostly trouble free and the turbidimeter will be sent in for calibration each summer.

Field Operations still include upgrading TTS station equipment, taking discharge measurements, making TTS Station FRC data dumps / sample 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. This real time on-line data plotting has been available since the beginning of HY 2008 and will continue. This plotting can be accessed at http://nrs-isa.humboldt.edu/rsl/tts_plot.html.

Streambed aggradation has covered over the end of the pressure transducer housing pipe with gravel during large storm events and has caused minor intermittent shifts in water depths measured. These are corrected in the final data analysis.

Turbidity:

Turbidity is a number derived from the amount of light suspended sediment blocks from passing through water. Turbidity caused by rising water flow transporting increasing levels of suspended sediment. Chronic turbidity is the tendency for streams to remain at elevated levels of turbid water for long periods. Causes of chronic turbidity can include landslides into a stream bleeding sediment for long periods to several storms in a row hitting a watershed in close intervals and keeping flow and turbidity and suspended sediment concentrations elevated. Land use in a watershed can contribute to chronic turbidity. Elevated levels of turbidity can cause harm to aquatic species.

This 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. Anomalous turbidity spiking may be management activities or discrete bank failures or some sediment delivery mechanism that keeps turbidity levels elevated.

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. Flow based suspended sediment loads will be used for turbidities above the range of the OBS-3+ Turbidimeter or where debris has pushed the turbidimeter instrument boom out of the water.

Discharge Measurements HY 2012:

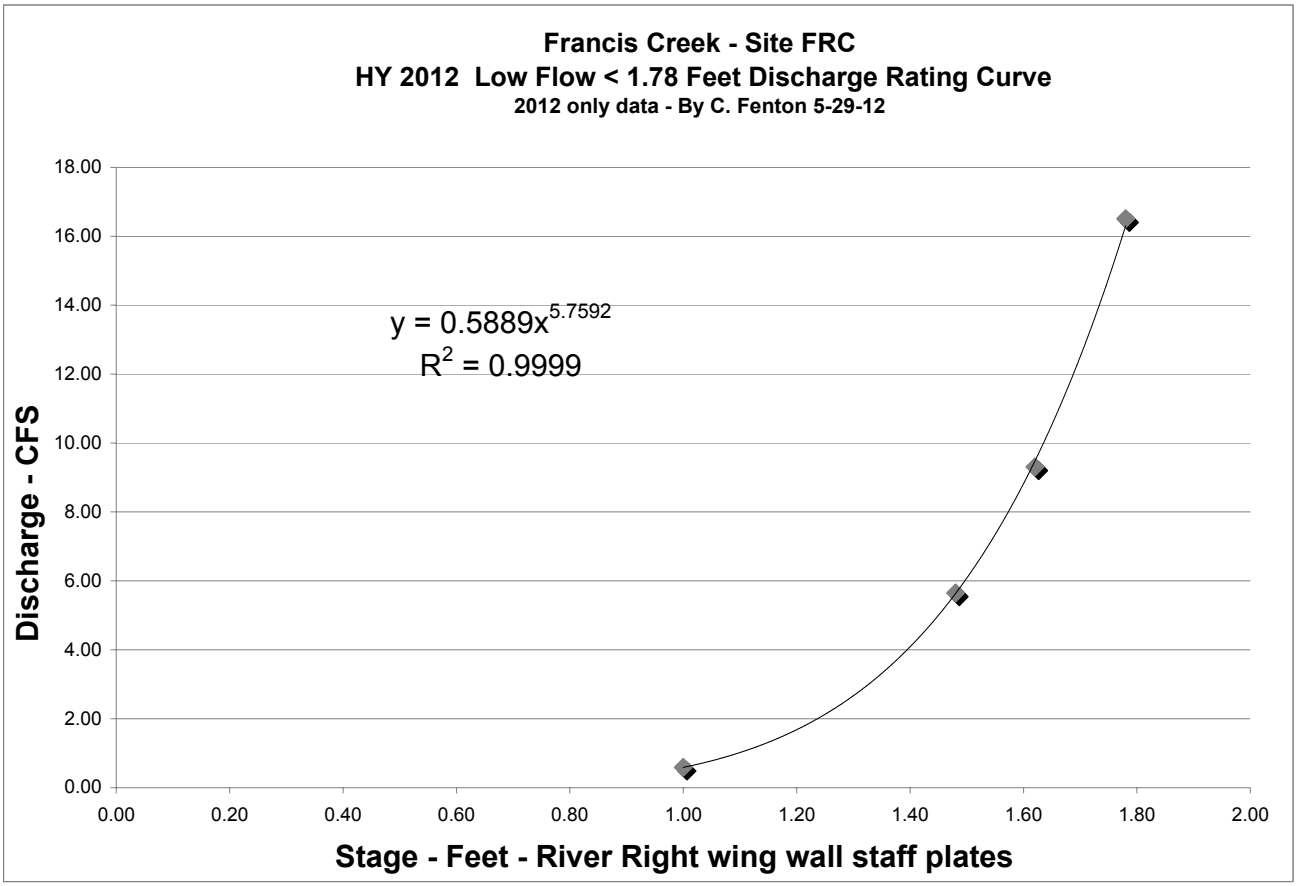
Obtaining high flow discharge measurements is proving to be elusive. Our highest discharge measurement at this site is still 252 cfs at a 5.2-foot stage taken January 31st 2008. Despite Clark Fenton buying his own set up, more high flow measurements are still needed. The high stage for this year was **4.9 feet / 230 cfs**. Clark managed to measure flow for a 4.2 foot stage.

It was decided to use a 2-part discharge-rating curve for HY 2012 again. See the charts below for the 2 discharge rating curves used. Accurate determination of flows at high stage levels is more important for suspended sediment yields than at low flows. Though very little sediment is transported at these low flows a lot of volume of water is accumulating and that volume data may need to be accurately defined so a low flow curve and a high flow curve were used.

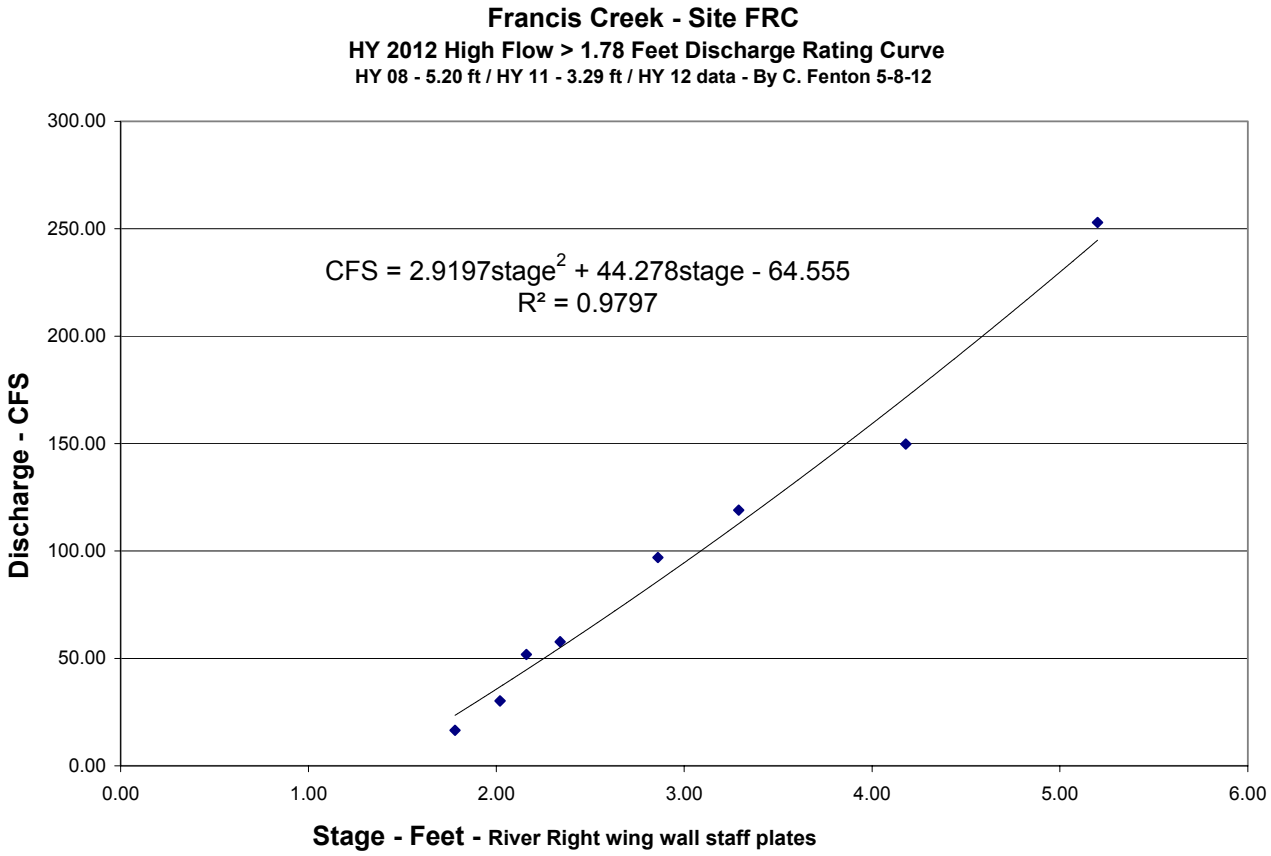
USFS / USGS methods were used for obtaining flow measurements. (Harrelson 1994, USGS). Low flows were measured with a Wading Rod using either a Pygmy current meter or a Price AA current meter. For higher flows an A-55 Reel, 30 lb. Columbus Weight, Price AA current meter and a bridgeboard were used. An accurate estimate of stream discharge is vital to accurate suspended sediment load calculations. See Appendix 3 for discharge sheets and rating curves.

Aggradation or rising of the streambed around the staff plates is still being observed. The streambed is mobile gravels and annual discharges are needed in this location to ensure representative discharge measurements.

9 discharge (cubic feet per second) water measurements were taken on Francis Creek at the FRC site in HY 2012 ranging from 5.65 cfs at a 1.48-foot stage up to 150 cfs at 4.18-foot stage.



Plot # 4 – Low Flow Discharge Rating Curve HY 2012



Plot # 5 – High Flow Discharge Rating Curve HY 2012

5. Lab Operations 2012

Clark Fenton continues to visit the station periodically to switch out sample bottles as they are filled. North Coast Labs is responsible for processing the ISCO Pump sampler bottles for suspended sediment concentration. The North Coast Lab contact is Bob Stuart at 707-822-4649.

The Francis Creek TTS sampling software triggered 202 ISCO pump samples at rising and descending turbidity thresholds at Site FRC from 10-4-11 to 4-26-12. 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. See the FRC 2012 turbidity / suspended sediment concentration chart in Section 1.

North Coast Labs has purchased equipment to allow large filters to be used to avoid a separate TDS determination for measuring suspended sediment concentrations of ISCO pump samples

Test Methods consist 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.

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

6. Closing Summary:

The Francis Creek TTS station continues to provide data on the amounts of suspended sediment routing through the Francis Creek Watershed. Suspended sediment yields from the Francis Creek watershed will be quantified to provide planning data for future dredging downstream. The biggest challenge has been to keep the turbidimeter instrument boom from being pushed up out of the water by the ever present debris in Francis Creek during storm events and to measure discharge at those large storm events.

The HY 12 Depth-Integrated sampling program documents a very uniform and homogeneous mixing of suspended sediment concentration the width and depth of flow in the Van Ness Avenue Culvert. It shows a strong correlation of the boom sampling to the entire stream flow. No DI adjustments were used for HY12.

The slide's contribution to the annual suspended sediment yield for Francis Creek seems to be slowly diminishing with time as the slide debris settles in and the easily mobilized sediments are used up. A large storm event may be needed to cause this slide to remobilize.

Even so, the Francis Creek Ranch Slide will be adding large amounts of suspended sediment to the system for years to come. The Francis Creek watershed can expect to have annual suspended sediment yields in the future approximately twice of what they were before the Francis Creek Ranch Slide.

Thanks to Hank Seeman for supporting this program.

7. References / Bibliography

Alt, D. D., Hyndman, W. D. (2000). *Roadside Geology of Northern and Central California*, 2nd Ed., Mountain Press, Missoula, Montana.

California Integrated Seismic Network. (2010). "Earthquake Details." *USGS Earthquake Hazards Program*, <http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/nc71338066/> (Jun. 23, 2010).

Focused Engineering Geologic Evaluation Recent Landslide Within Francis Creek Ranch, Upper Francis Creek Watershed, Ferndale California, Apri18, 2011, Don R. Braun, California Geological Survey, Eureka Ca. CGS (2011)

Harrellson, C. C., Rawlins, C. L., Potyondy, J. P. (1994). "Stream Channel Reference Sites: An Illustrated Guide to Field Technique*." General Technical Report RM-245,* United States Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Lewis, E., Lewis, R., & Lewis, J. (2002). *ContinuousTurbidity Monitoring in Streams of Northwestern California. In: Turbidity and Other Sediment Surrogates Workshop* (ed. Glysson, G.D. & Gray, J.R.), 30 April – 02 May 2002, Reno, Nevada. 3 p.

Lewis, J. (2002). *Estimation of Suspended Sediment Flux in Streams Using Continuous Turbidity and Flow Data Coupled with Laboratory Concentrations. In: Turbidity and Other Sediment Surrogates Workshop* (ed. Glysson, G.D. & Gray, J.R.), 30 April – 02 May 2002, Reno, Nevada. 3 p.

McLaughlin, R.J., Ellen, S.D., Blake, M.C., Jr., Jayko, A.S., Irwin, W.P., Aalto, K.R., Carver, G.A., Clark, S.H. Jr. (2000). "Geology of the Cape Mendocino, Eureka, Garberville, and Southwestern part of the Hayfork 30 x 60 Quadrangles and Adjacent Offshore Area, Northern California." *USGS,* <http://pubs.usgs.gov/mf/2000/2336/> (Jun. 23, 2010).

(Salt River Watershed – Local Implementation Plan – Humboldt County Ca – USDA Soil Conservation Service 1993)

United States Department of Agriculture, Soil Conservation Service, Water Resources Planning. (1993). "Salt River Watershed, Local Implementation Plan." *Volume 1 & Maps*, Library Documents Natural Resources Division, Department of Public Works, Humboldt County, California.

United States Department of Agriculture, Soil Conservation Service, Water Resources Planning. (1993). "Salt River Watershed, Local Implementation Plan." *Appendix A: Water Quality Report*. 1-26, Public Library Humboldt Room, Eureka, California.

Standard Methods and Test Guides

ASTM Standard D 3977, 1997 (2002), "Determining Sediment Concentration in Water Samples," ASTM International, West Conshohocken, PA, 2002, DOI: 10.1520/D3977-97R02, www.astm.org.

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.

AWWA Standard 2540 B, (1990), "Standard Methods for the Examination of Water and Wastewater: Total Solids."

Standard 2540 D, (1998), "Standard Methods for the Examination of water and Waste Water: Suspended Solids," 20th Edition.

United States Environmental Protection Agency:

EPA 841D 95001, Volunteer Stream Monitoring: A Methods Manual (April, 1995).

United States Environmental Protection Agency, Washington D. C., Office of Environmental Information:

EPA QA/G-4, Guidance for the Data Quality Objectives Process (Feb., 2006).

EPA QA/G-5, Guidance for Quality Assurance Project Plans (Dec., 2002).

EPA QA/G-6, Guidance for the Preparation of Standard Operating Procedures (Apr., 2007).

EPA QA/R-5, EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations (Mar., 2001).

United States Geological Survey

Techniques of Water-Resources Investigations of the USGS, Washington:

Buchanan, T. J., Somers, W. P. (1968). "Stage Measurements at Gaging Stations," Book 3, Chapter A7-A8.

Guy, H. P. (1969). "Laboratory Theory and Methods for Sediment Analysis," Book 5, Chapter C1.

Guy, H. P., Norman, V.W.(1970). "Field Methods for Measurement of Fluvial Sediment," Book 3, Chapter C2.

Surface Water Techniques:

Carter, R. W., Davidian, J. (1965). "Discharge Ratings at Gaging Stations," Book 1, Chapter 12.

Unpublished Sources

(Buffleben, 2007) Personal Communication Mon, 7 May 2007 13:23:53 -0700
10-m DEM and calculated the upland area to be 82,955 cells which translates to:
8,295,500 square meters or 2,050 acres or 3.2029 square miles.

Klein, R. 2007, Personal Communication.