GARCIA RIVER TREND AND EFFECTIVENESS MONITORING: SPAWNING GRAVEL QUALITY AND WINTER WATER CLARITY IN WATER YEARS 2004 AND 2005, MENDOCINO COUNTY, CALIFORNIA

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Final Report to California Department of Forestry and Fire Protection

By Ridge to River
Teri Jo Barber
Anna Birkas

For Mendocino County Resource Conservation District

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EXECUTIVE SUMMARY

Have changes in land management resulted in changes in spawning gravel quality or winter water clarity in the Garcia River, the first on the northern California coast to receive a TMDL? To begin to answer this question, turbidity and spawning gravel quality (particle size distribution and permeability) were measured in four Garcia River watershed tributaries in water years 2004 and 2005.

Fine sediments filling spawning gravels are deleterious to salmon gravel redds because interstitial gravel spaces become filled with particles that clog the semi-permeable nest. As permeability is impaired, the flow of dissolved oxygen to incubating eggs is reduced. This can result in nest fouling, as metabolic waste products accumulate. In 1999 and 2004, four Garcia River tributaries were sampled for spawning gravel particle size distributions and permeability. Bulk spawnable gravels were collected in 6 gallon samples, repeated eight times per tributary, and sieved into particle size classes. From these samples, the relative accumulation or depletion of finer particles (0.85 mm, 6.5 mm, and 8.0 mm size classes, collectively referred to as fines) between 1999 and 2004 was determined. Permeability was measured directly in spawnable gravels with portable backpack water pumps. Permeability rates and particle size distributions were used to predict salmonids survival to emergence. Gravel redds were significantly more permeable at Pardaloe and Mill Creeks, and measurably (but not significantly) more permeable at Inman Creek and the South Fork Garcia River in 2004 verses 1999. Fewer fines in spawnable gravels were found at Pardaloe Creek and South Fork in 2004 than in 1999, but these improvements were not statistically significant. Further study with a larger sample size is necessary to determine whether these measurable differences are due to natural variation or to true improvements in spawning gravel quality.

Winter water clarity was tested with automated turbidity sensors every ten minutes in water years 2004 and 2005. Water clarity is occluded by sediments suspended in the water column during storms (peak turbidity) and to a lesser extent between storms (chronic turbidity). Chronic turbidity can impair sight and feeding of over-wintering salmonids and causes gill abrasion. Subwatershed South Fork experienced the lowest total number of hours with turbidities exceeding a threshold of 30 NTUs during WY 04 and 05. Mill Creek had the lowest total hours with turbidities exceeding 60 and 150 NTU thresholds in WY 2004 while Pardaloe and Mill shared these prizes in WY 2005. South Fork had the lowest storm-related peak turbidity, closely followed by Pardaloe. Pardaloe had the lowest timber harvest rate and road density of the five watersheds studied over a 17-year period. South Fork had relatively high road density but had recently experienced basinwide restoration. In general, the other streams had no restoration work and had moderate to high timber harvest intensities. Excepting Mill Creek, these basins exhibited greater peak and chronic turbidity. Road restoration work and past timber harvest intensity may explain these differences. But natural variation and the many factors in a watershed that affect stream and gravel quality may dominate. Further research must be conducted before conclusions can be definitively drawn. However in evaluating whether funding spent on watershed restoration erosion controls is effective in improving instream conditions, this news is encouraging.

ACKNOWLEDGEMENTS

The extension of recording turbidimeter and pumping water sampler technologies to an increasing list of watersheds, agencies, citizenry, and hydrologists have provided an exciting arena in which to observe water quality changes. This is possible through the technology transfer afforded by the staff of USFS Redwood Sciences Laboratory in Arcata, California. We benefited greatly from expertise provided by Rand Eads, Jack Lewis, and Liz Keppeler. Kevin Fauchet, employed by Campbell Timberland Management, supplied assistance in de-mystifying the ISCO pumping sampler. Ben Monmonier provided technical assistance maintaining our turbidity monitoring stations. Bill Trush, Geoff Hales, and Darren Mierrou provided expertise in the gravel monitoring component of the study as well as some guidance with our turbidity analysis. Hydrologist Randy Klein corrected our raw data and provided a finished data set on which to run our turbidity analysis. He also guided our analysis with his 2003 document *Duration of Turbidity and Suspended Sediment Transport in Salmon Bearing Streams in Northcoastal California*. Thorough editorial assistance on our first draft was provided from California Department of Forestry and Fire Protection's John Munn and Hydrologist Pete Cafferata, both with CDF's Monitoring Study Group who funded the purchase of our instrumentation. Funding for turbidity station maintenance and data analysis were provided by California's Water Resources Control Board through their Regional Water Quality Control Board whose helpful contributors include Dave Hope, Bob Tancredo, and Kathleen Daily – to name a few.

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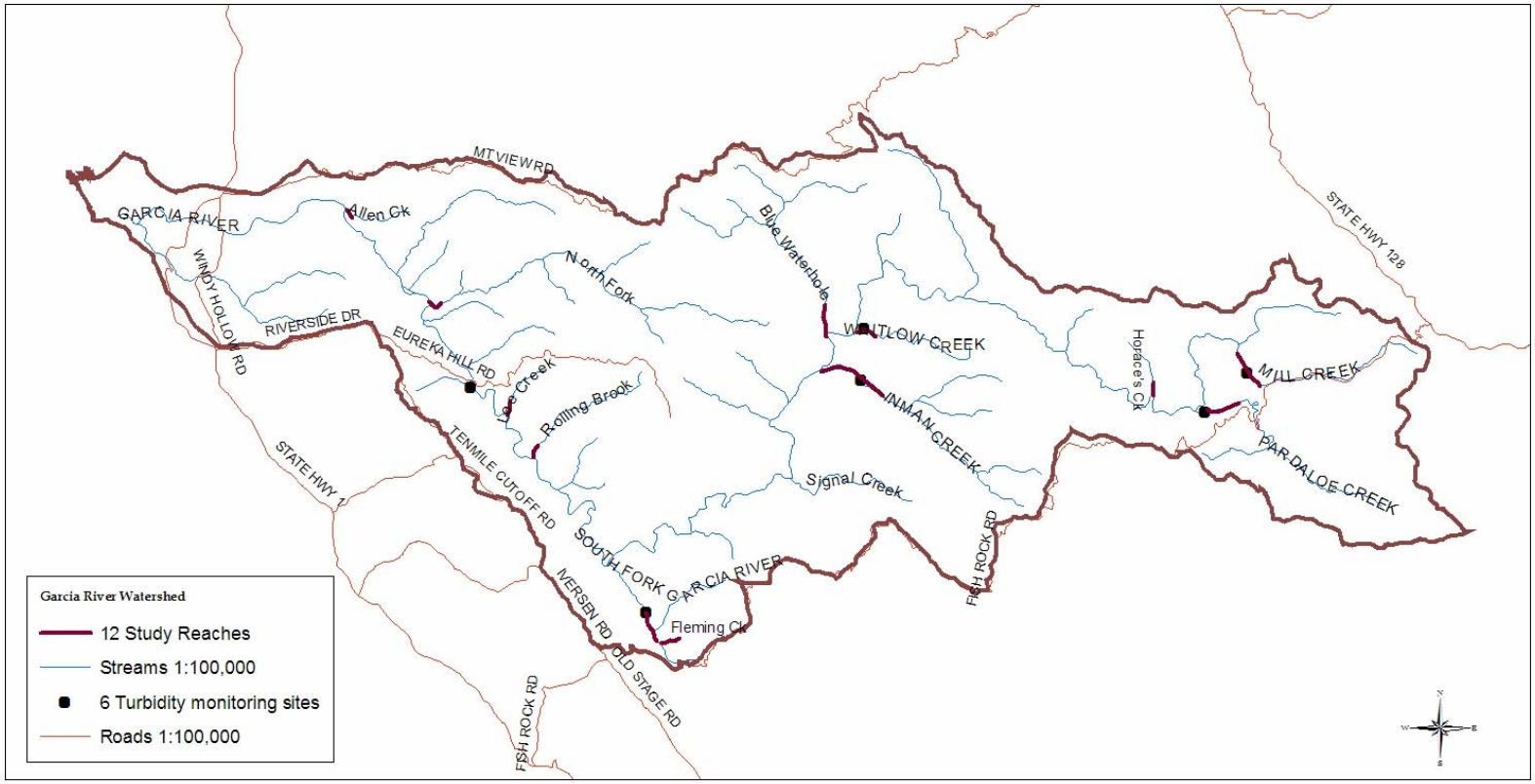

A project of:

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Figure 1. Map of Garcia River Watershed with 6 MCRCD Turbidity Monitoring Sites and 12 MCRCD Study Reaches

0 1,650 3,300 6,600 9,900 13,200 Meters

0 4,850 9,700 19,400 29,100 38,800 Feet

1 inch equals 9,333 feet

This project funded by the State Water Resources Control Board and the CA Department of Forestry and Fire Protection

GARCIA RIVER TREND AND EFFECTIVENESS MONITORING: SPAWNING GRAVEL QUALITY AND WINTER WATER CLARITY IN WATER YEARS 2004 AND 2005, MENDOCINO COUNTY, CALIFORNIA *Ridge to River 5-15-2006*

INTRODUCTION

STATEMENT OF PURPOSE

Sediment delivery in the Garcia River has resulted in a loss of quantity and quality of salmonids habitat. Both California Department of Forestry and Fire Protection (CDF) and the North Coast Regional Water Quality Control Board (NCRWQCB) have responded to the degradation of North Coast watersheds. The NCRWQCB (1998) established a Total Maximum Daily Load (TMDL) for the Garcia River of 552 tons per square mile per year. This represents a 60% reduction in the estimated average annual sediment load of 1380 tons per square mile per year delivered to the Garcia River Watershed. The Garcia River was the first watershed in California to receive a TMDL allocation for excessive sedimentation. CDF responded by funding instream and upslope monitoring projects to determine whether implementation of current Forest Practice Rules are controlling observable erosion delivery to Class I fish-bearing streams. The primary goal of the Board of Forestry and Fire Protection's Monitoring Program is to assess the effectiveness of the Forest Practice Program in protecting water quality. The Monitoring Study Group, an advisory committee of the Board of Forestry and Fire Protection, concluded that instream monitoring should be used to assess current conditions and long- term channel trends. The Monitoring Study Group made the Garcia River watershed its first cooperative instream monitoring project in 1997.

Sediment delivery from roads to fish bearing streams is perhaps the single most important problem for salmon bearing watersheds for which there is a probable solution. In 1999, Trout Unlimited was awarded a California Department of Fish and Game (DFG) SB 271 grant to treat 8.75 miles of road for drainage improvements and erosion controls in the South Fork Garcia River watershed. Work was conducted on Mendocino Redwood Company (MRC) property with the goal of preventing over 28,000 cubic yards of sediment delivery to stream channels. Ten instream habitat sites were also funded for implementation in South Fork Garcia. This work was implemented in 2000 and 2001 (Craig Bell, Point Arena, personal communication, 2005). The purpose of upslope road-based erosion control is to minimize sediment delivery to fish-bearing streams. The time period between 2001 and 2003 provided two years following watershed restoration work to allow erosional adjustments at the sites undergoing drainage improvements and erosion control. Beginning in 2004, conditions in the stream channel were documented following the restorative treatments. This study will illuminate whether and to what extent channel conditions have changed following restorative treatments in the South Fork.

Both CDF and the NCRWQCB have contributed financially to the Garcia Monitoring Project. CDF's Hillslope Monitoring Program final report recommended that CDF support further instream monitoring studies to answer questions about the effectiveness of the Forest Practice Rules and to determine if current practices are complying with

Regional Water Quality Control Board Basin Plan standards designed to protect salmon spawning and rearing habitat (Cafferata and Munn, 2002).

This project will assist the NCRWQCB and CDF, as well as landowners in the Garcia River Watershed, to answer the following question: How and to what extent are sediment- related instream conditions improving for anadromous salmonids in the Garcia River? Gravel quality and instream water clarity are parameters known to be sensitive to watershed restoration. Other protocols previously measured in Garcia River tributaries in 1998-1999 are: channel cross-sections, longitudinal thalweg profiles, large wood loading, spawning surveys, summer water temperatures, and canopy closure (Maahs and Barber 2001). Spawning gravel particle size composition and permeability were also measured in 1999, and remeasured in 2004-2005. Instream winter turbidity monitoring coupled with summer gravel sampling were selected as indexes of whether conditions are improving toward numeric TMDL targets and whether watershed restoration is facilitating recovery in the Garcia River basin.

SCOPE OF PROJECT

The focus of this Garcia River Monitoring Project is Trend and Effectiveness Monitoring for both Garcia River Spawning Gravel Quality and Winter Water Clarity (Task 7). The other tasks in the contracted Scope of Work support Task 7, including administration, quality assurance plan, outreach, compilation of a GIS monitoring database for the Garcia River Watershed, and Bluewaterhole Sediment Control Treatments (cost-share under a separate contract in 2003).

Task 7.1: Measure bulk instream gravel composition, embeddedness, and permeability at 4 tributaries for one summer season (South Fork, Mill Creek, Pardaloe and Whitlow creeks). Bluewaterhole Creek has been a monitored sub basin for several years and it has benefited from watershed restoration efforts. Bluewaterhole Creek was thus initially included in the list of tributaries to be monitored. However landowner Stuart Bewley would not allow any further monitoring on his Bluewaterhole Creek property due to existing conflicts he has with NCRWQCB on another property. In the absence of another eligible stream with a cooperative landowner, we felt that examining mainstem turbidities would provide an opportunity to view tributary turbidity in the context of mainstem turbidity. We found a cooperative landowner on the mainstem Garcia, Hugh Brady, and set up a monitoring station there near Eureka Hill bridge instead of at Bluewaterhole Creek. However the streambank at Garcia mainstem underwent undermining lateral erosion toward our station and we felt a second winter risked our instrumentation. We found another cooperative landowner, The Conservation Fund, at Inman Creek tributary. We were compelled to record turbidity conditions there because Inman is targeted for watershed restoration in 2006-2007. In fall 2005 we removed the sampling boom from mainstem Garcia and recycled it into a turbidity monitoring station at Inman Creek. Whitlow Creek could not be monitored for permeability as it was dry on sampling. So instead we sampled permeability at Inman Creek where there was still adequate streamflow in late summer, 2004.

The objectives of task 7.1 were to:
a. Compare with baseline conditions measured in 1999
b. Predict survival-to-emergence based on gravel particle size composition and permeability
c. Correlate gravel particle size composition and embeddedness if possible
d. Have road-related sediment prevention measures improved spawning gravel?
- determine whether percent of in-gravel fines have been reduced to date
- determine whether gravel permeability has increased to date

The body of this report includes an entire section excerpted from the McBain and Trush report entitled "Assessing Salmonid Spawning Gravel Suitability Using Bulk Sediment and Permeability Sampling in the Garcia River Watershed, California." The appendix of our report includes the raw data files and the entire McBain and Trush report from 2005.

Task 7.2: Continuously monitor instream turbidity with recording turbidimeters at the above listed tributaries.

The objectives of task 7.2 were originally to:
a. Locate sediment sources by viewing spikes in turbidimeter readings to determine potential future treatments
b. Observe cause and effect relationships between hillslope activities, hydrologic triggers, and instream conditions by observing turbidity spikes and making cursory channel/hillslope inspections to determine the source of turbidity
c. Determine the total and consecutive days turbidity was sustained over 60 ntus as well as other biologically related turbidity thresholds

It was determined at our first meeting that Tasks 7.2a and 7.2b were unsupported by landowners and land managers in the tributaries of the Garcia River Watershed. Landowners were uncomfortable authorizing unlimited access across their lands to locate sediment sources and would not sign landowner access agreements under those conditions. Therefore, task 7.2a was omitted and task 7.2b was adjusted to replace *site specific* scale channel and hillslope inspections with a *remote* investigation of land management activities (a GIS based review of sub-basins in terms of timber harvest history and road density).

APPROACH

Two approaches were adopted for data analysis. The first approach was to interpret the gravel and instream water clarity data as it relates to salmonid habitat preferences based on criteria used by agencies and found in the literature (Tasks 7.1b and 7.2c). The second approach was to utilize the Garcia River mainstem water clarity (turbidity) data from water year 2003-2004 and gravel particle size distribution and permeability measured in 1999 as background conditions from which to determine:

(1) whether any measurable changes have been recorded.
(2) whether any of these measurable changes might be attributed to land management disturbances or restoration work.

Improvements in water clarity would be indicated where

- chronic exposures to threshold turbidities (hours greater than 30, 60, 150 ntu) were found to be smaller in restored basins or
- in basins having only low levels of timber harvest.

Improvement in gravel quality for anadromous salmonids would be indicated where

- the percent of spawning gravels in the finer categories were smaller in restored basins or in basins having only low levels of timber harvest, or
- if permeability of spawning gravels was more rapid in basins having had restoration or experienced only low levels of timber harvest.

Lack of pre-treatment turbidity data in watersheds with road improvement work prevents conclusions to be drawn directly regarding the effects of roadwork on observed changes. However any measurable improvements found in watersheds having restorative treatments was to be noted.

METHODS

Sampling Locations are Representative of the Garcia River Watershed

The Garcia River Instream Monitoring Plan identified optimal, representative monitoring tributaries of the 2nd and 3rd Strahler stream order (Euphrat et al. 1997). In 1998 this list was refined prior to sampling and based on obtaining written landowner agreements allowing access to the contractors completing the work. Our 2003-05 project utilized a subset of these monitoring study reaches.

Sampling Methods

Spawning gravel quality methods used in this study are well-described in McBain and Trush (1999). Sampling locations were selected using the 1999 procedures, which specified using 8 pool tail crests within the monitoring study reach of each tributary. There was no attempt to relocate the same pool tail crests used in the 1999 study, but the same protocols were followed. Permeability was sampled at 3-5 positions within the pool tail, including the location where bulk gravel was extracted. Gravel was sampled from spawnable (but unspawned upon) pool tail crests located in the monitoring study reaches within Mill, Pardaloe, South Fork, and Whitlow Creek. Gravel was extracted using a toothed cylinder which was pushed into the substrate. All gravel and sediment materials were then removed from the cylinder and transferred into 5-gallon buckets, which were transported to Graham Mathews and Associates' laboratory in Arcata, California for drying and particle size analysis.

Teri Jo Barber measuring permeability in a Garcia River tributary pool tail

Permeability of streambed materials was measured onsite with a backpack sampling apparatus developed by McBain and Trush. This included a notched standpipe driven into the gravel substrate. A long, flexible tube was then inserted into the standpipe and attached to a 12-volt pump. Stream water was pumped from the spawnable gravel (at approximately the 6-8" depth) into a graduated cylinder, where the rate of flow was measured and recorded in centimeters of water pumped in a given time period. Monitoring study reaches are displayed in Figure 1. Bulk spawning gravel was sampled for particle size distribution, permeability, and embeddedness in August and September, 2003.

Winter Water Clarity

The automated turbidity monitoring program is best described at the Redwood Sciences Laboratory website, www.fs.fed.us/psw/topics/water/tts or in the QAPP, written by Teri Jo Barber (see Appendix). The staff at Redwood Sciences Laboratory, particularly Liz Keppeler, Jack Lewis, and Rand Eads, provided technical assistance with installation of the monitoring stations. Kevin Fauchet, Campbell Timberland Management, helped with setting up the ISCO pumping sampler for deployment in the field.

USFS Redwood Sciences Laboratory Turbidity Threshold Sampling (TTS) software enabled a suite of instruments to record turbidity, stage height, water temperature, day #, and time at each "wake-up" scheduled at 10 minute intervals. At the Mill Creek station,

this software also prompted the ISCO pumping sampler to read the turbidity and stage height recorded at the last wakeup to determine whether to pump a water sample from the creek.

The equipment used in the Garcia River watershed is similar to that used at the Caspar Creek experimental watershed operated by USFS-PSW and CDF. All five stations had pressure transducers used to monitor stream stage and a DTS-12 digital turbidity sensor with a lens wiper (similar to a windshield wiper used to clear the lens prior to a reading), both of which were wired to a Campbell Scientific CR510 datalogger. We accessed the dataloggers approximately every three weeks with a portable laptop computer, downloaded the data, and performed a variety of troubleshooting and maintenance operations when necessary. This provided automated, constant (every 10 minutes) turbidity records for two water years, 2003-04 and 2004-05 from approximately October through the early summer of each year. However, unlike the Caspar Creek Study, discharge was not determined, so estimates of storm and annual sediment loads were not possible, and there was only one ISCO 6712 automatic pumping sampler, which was placed at the Mill Creek station in early 2005.

LIST OF TASK PRODUCTS SUBMITTED

1.2 Progress Reports
1.5 Contract Summary Form
1.6 MBE/WBE Documentation
1.8 Project Survey Form
2.2 Permits
3.1 Monitoring Plan with Map of Sites
3.2 QAPP
4.1 Updated Landowner Contact List, notification letters
4.2 Pre-project Meeting Minutes
4.3 Copies of Landowner Access Agreements
4.4 MCRCD newsletter articles
4.5 Minutes of Post-project Meeting
5.1 CD with complete database
7.1 Summary of Instream Gravel Composition, embeddedness, and permeability
7.2 Summary of Instream Turbidity
8.2 Draft Final Report
8.3 Project Final Report

Ben Monmonier pulling bulk gravel sample from the streambed with steel toothed sampling cylinder in pool tail near permeability standpipe driven into same pool tail.

Table 1. Tributary Codes Utilized in this and Preceding Garcia River Monitoring

Tributary code	***Tributary name***
Tributary-1	Whitlow Creek
Tributary-4	Mill Creek
Tributary-5	Pardaloe Creek
Tributary-8	Inman Creek
Tributary-9	South Fork Garcia River

Copyright note: *The following section pertaining to instream gravel quality was reproduced with permission, from McBain and Trush's 2005 Assessing Salmonid Spawning Gravel Suitability Using Bulk Sediment and Permeability Sampling in the Garcia River Watershed, CA and contains numerous references to their previous 2001 report entitled Spawning Gravel Composition and Permeability within the Garcia River Watershed, CA of 1999 baseline gravel sampling available online at the CDF webpage: http://www.bof.fire.ca.gov/board/msg_supportedreports.html . Bulk gravel extraction from the streambed, embeddedness observations, and instream gravel permeability were measured in the field by Ben Monmonier and Teri Jo Barber of Ridge to River. Bulk gravel samples were dried and sieved into particle size classes by Graham Mathews and Associates, Arcata, California.*

2004 sampling results and comparison with 1999 samples

Particle Sizes

Table 2. Comparison between 1999 and 2004 bulk sediment sampling results for fractions finer than 0.85 mm and 8.0 mm. (McBain and Trush's Table 4).

	1999 Bulk Sample				2004 Bulk Sample			
Tributary	0.85 mm mean	0.85 mm standard deviation	8.0 mm mean	8.0 mm standard deviation	0.85 mm mean	0.85 mm standard deviation	8.0 mm mean	8.0 mm standard deviation
Tributary-1	9.7%	0.018	31.0%	0.074	11.2%	0.017	28.9%	0.049
Tributary-4	8.8%	0.021	35.2%	0.085	10.7%	0.051	37.0%	0.137
Tributary-5	8.4%	0.025	37.9%	0.068	7.5%	0.026	36.5%	0.123
Tributary-9	10.1%	0.019	29.8%	0.106	7.8%	0.020	34.5%	0.081

Analysis of the 1999 data focused on the 8.0 mm and 0.85 mm sizes (cumulative percent finer) as indices to characterize the variability of substrate composition within a single tributary. The intent of the 2004 analysis was to use the 1999 results as a basis to detect changes within a tributary over time, and to detect significant differences between tributaries (if they exist). The 1999 results generally showed a large variability of fine sediment percentages for both the 0.85 mm and 8.0 mm fractions within the tributary reaches sampled. The 2001 Report concluded that although certain samples showed similar results, few discernable overall patterns emerged from the data analysis (see the *Analysis of variation in particle size distribution* section in the 2001 Report).

The 2004 sampling collected 8 bulk samples per tributary, approximately the same as the number of samples analyzed in the 2001 Report. For the 2004 bulk sample statistical analysis, Dr. Baker compared the 2004 results to the 1999 results using parametric (two-tailed t-test) and nonparametric statistical testing (order-based statistics). These statistical tests compare the equality of sample means; that is, the null hypothesis is that the two sets of data were drawn from the same distribution. If test results show significance, the null hypothesis is rejected and sample means are not considered equal (the sample means between 1999 and 2004 have changed). Conversely, if significance is not determined, the null hypothesis is accepted and sample means are considered equal (the sample means between 1999 and 2004 for Tributary "X" have not changed). Both tests were performed on the cumulative fractions finer than 0.85 mm and 8.0 mm

The results of the t-test shows significance only for Tributary-1, fraction finer than 0.85 mm - that is, statistically, a change has occurred between means from the 2004 vs. 1999 samples. Therefore the remaining samples can be treated as if no change in their sample means has occurred. But does the lack of significance reflect a real absence of change? Considering the statistics, and acknowledging potential sample biases (e.g., size-distribution variability of individual samples within each tributary; sample mass collected based on Church et al. (1987) criteria; total number of samples collected on each tributary to reduce variability), it is still worth comparing these data to see if an overall trend of the 0.85 mm and 8.0 mm fractions is present? Table 2 presents 1999 and 2004 cumulative percentages finer than both 0.85 mm and 8.0 mm fractions, and summary statistics for each tributary. These results show that overall, some tributaries showed slight decreases in fine sediment (coarsening) where others showed slight increases in fine sediment (fining).

Permeability

2004 permeability data are summarized in Table 3, and includes the log-transformed 1999 permeability results used for comparison.

Table 3. 2004 and 1999 permeabilities and summary statistics from each tributary sample site. (McBain and Trush's Table 5)

2004 permeability

Tributary	Pool-tail site (geometric mean of replicate measurement median permeabilities) (cm/hr)								Geometric mean of all pool-tail sites
	1	2	3	4	5	6	7	8	
Tributary-4	18	1,917	5	22	3,676	3,414	4,815	77	252
Tributary-5	3,808	3,078	2,267	4,473	4,670	3,548	2,955	4,826	3,598
Tributary-8	8,250	3,863	2,455	3,016	9,952	3,647	2,111	1,398	3,551
Tributary-9	2,084	2,572	1,675	1,100	3,545	1,278	2,555	3,588	2,117

1999 permeability

Tributary	Pool-tail site (geometric mean of replicate measurement median permeabilities) (cm/hr)								Geometric mean of all pool-tail sites
	1	2	3	4	5	6	7	8	
Tributary-4	3,300	3,656	2,331	6,940	8,601		3,272	218	2,754
Tributary-5	3,771	853	963	2,237	1,403	539	289	908	1,040
Tributary-8	2,487	4,516	628	1,788		2,091		4,583	2,224
Tributary-9	1,411	95	862	1,113	4,196		3,130	4,937	1,354

Note: Tributary-6 sample 6, Tributary 8 samples 5 and 7, and Tributary-9 sample 6 were omitted from the analysis (see 2001 Report).

Similar to the bulk sediment sample analysis, the 2004 permeability data were compared with the 1999 permeability data using the same statistical tests (parametric and nonparametric) statistics. Results from the t-tests show the change at Tributary-4 was significant at the 95% confidence level ($p = 0.059$), and the change at Tributary-5 was significant at the 99% confidence level ($p = 0.0024$); changes at Tributary-8 and -9 were not significant at any reasonable confidence level (Table 4).

Table 4. Probability value (p) results of two-tailed t-tests for changes in log permeability between 1999 and 2004. The results of this test show that Tributary-4 and Tributary-5 are significant at the 95% and 99% confidence levels, respectively (i.e., the sample means have changed). (McBain and Trush's Table 6)

Site	***1999 mean permeability (geometric) (cm/hr)***	***2004 mean permeability (geometric) (cm/hr)***	***Probability (p) value***	***Significant difference at 95%?***	***Significant difference at 99%?***
Tributary-4	2,754	252	0.059	Yes	No
Tributary-5	1,040	3,598	0.0024	Yes	Yes
Tributary-8	2,224	3,551	0.96	No	No
Tributary-9	1,354	2,117	0.41	No	No

Predicting Survival-to-Emergence from Gravel Particle Size Classes and Permeability

The 2001 Report also used particle size and permeability to predict salmonid egg survival. This was done by estimating salmonid egg survival based on: 1) particle size analysis methods of Tappel and Bjornn (1983), and, 2) a preliminary correlation of permeability and salmonid survival-to-emergence using a relationship developed from studies by Tagart (1976) and by McCuddin (1977). The results showed moderate egg survival using the Tappel and Bjornn analysis (mean survival estimates for chinook salmon ranged from 54% to 82% in all ten tributaries sampled); however, the 95% confidence intervals for these estimates were broad (9% to 93%), and the report noted difficulty in drawing any conclusions of spawning habitat quality based on these predictions. Focusing only on the 4 tributaries sampled in 2004, the 2001 results predicted slightly better egg survival, with mean survival estimates ranging from 66% to 82%, and 95% confidence intervals ranging from 41% to 93%. Using the 2004 data, we performed the same analysis and found similar results (Table 5); survival predictions ranged from 60% to 76%, but 95% confidence intervals remained quite broad (6% to 89%).

Survival estimates using the permeability relationship based on Tagart and McCuddin also show similar results to those presented in the 2001 Report with the exception of Tributary-4, where zero survival is predicted due to a very low mean permeability (the mean permeability for Tributary-4 falls at the bottom of the Tagart and McCuddin regression). Excluding Tributary-4, the 2004 survival estimates are very similar to the 2001 results and have similar 95% confidence intervals (Table 6). Because the data used in the Tagart and McCuddin relationship are based on laboratory studies using two different salmonid species, survival estimates for salmonids in Garcia River tributaries should be considered an index only. Moreover, conclusions of egg survival based on these analyses must be tempered with the ability of spawning salmonids to clean fine sediment from spawning gravels during redd construction (Kondolf et al. 1993).

Table 5. Percent survival of salmonid eggs based on Tappel and Bjornn (1983) particle size analysis methods. (McBain and Trush's Table 7a)

	1999			2004		
Tributary	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval
Tributary-1	74	56	87	76	63	85
Tributary-4	70	41	87	60	6	88
Tributary-5	66	44	81	70	40	89
Tributary-9	82	57	93	73	53	86

Table 6. Percent survival of salmonid eggs based on preliminary permeability relationship from Tagart (1976) and McCuddin (1977). McBain and Trush's Table 7b)

	1999			2004		
Tributary	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval	Mean estimated survival	Lower 95% confidence interval	Upper 95% confidence interval
Tributary-4	43	31	49	0		29
Tributary-5	28	18	33	38	35	41
Tributary-8	40	25	47	38	20	46
Tributary-9	37	27	43	31	24	35

Note: Tributary-4 0% mean survival is caused by low mean permeability (see Table 5); lower 95% confidence interval could not be calculated.

Although the number of samples collected in 2004 did not meet the criteria recommended in 1999, the results can still be used to describe the particle size distributions of the pool-tails sampled. If we assume the same statistical validity with respect to the sample population in each of the tributaries sampled, then the data collection quality between 1999 and 2004 studies was not improved (variability was not reduced). However, if we acknowledge the variability and accept this limitation, the data collected for this study are slightly better than the data collected in 1999 based solely on the sample size analyzed.

Table 7. Comparison of the number of bulk sediment samples analyzed in 1999 versus samples analyzed for this report. (McBain and Trush's Table 8)

Tributary	***Number of pool-tail bulk samples analyzed in 1999***	***Number of pool-tail bulk samples analyzed in 2004***
Tributary-4	6	8
Tributary-5	8	8
Tributary-8	7	8
Tributary-9	7	8

Embeddedness Sampling:

Embeddedness was not measured in 1999 but was included by MCRCD as part of the 2004 field data collection. The intent of the embeddedness sampling was to relate the embeddedness measurements to permeability or to the particle size distribution results (T. Barber, personal communication).

Although the permeability and bulk sediment sample results show large variability between individual sites, we analyzed embeddedness as a function of mean permeability and percent fine sediment finer than 8.0 mm for the embeddedness measured on Tributaries -1, -4, -5, and -9. No apparent trend exists for any of the data; a regression of the permeability data yields an R^2 value of 0.05, and a regression of the sediment data yields an R^2 value of 0.003. This result is somewhat expected: embeddedness is a surface feature, whereas bulk sampling and permeability measure subsurface sediments (see Section 2.1.3). Moreover, embeddedness measurements are subjective, subject to observer bias. More research is needed to determine whether embeddedness can be linked to biological criteria or to detect changes in land management activities (Sylte and Fischenich 2003).

Sediment Quality Relative to Garcia River TMDL

TMDL numeric targets for the Garcia River watershed have been established by the USEPA (1998). More specifically, the TMDL targets the percentage of fine sediments finer than 0.85 mm and 6.5 mm, and the numeric targets are <14% and <30%, respectively. These numeric targets represent the optimal conditions for salmonid reproductive success (USEPA 1988); percentages above these targets constitute an impaired condition. Similar to the 1999 results, the 2004 results indicate that the subsurface sediments finer than 0.85 mm are below the TMDL 14% numeric target; however, three of the four tributaries sampled exceed the 30% numeric target for sediments finer than 6.5 mm (Table 8). Recall that a 6.3 mm sieve screen was used instead of a 6.5 mm screen; the results shown in Table 8 were obtained from the particle size distribution curve.

Table 8. Fraction of bulk sediment samples finer than 6.5 mm and 0.85 mm; TMDL numeric targets are <30% and <14%, respectively. (McBain and Trush's Table 9)

Tributary	***Percent finer than 6.5 mm (TMDL target: < 30%)***	***Percent finer than 0.85 mm (TMDL target: < 14%)***
Tributary-1	26.1%	11.2%
Tributary 4	33.4%	10.7%
Tributary-5	32.3%	7.5%
Tributary-9	30.9%	7.8%

Using South Fork Garcia River Results as an Index for Watershed-Scale Change

Basin-wide erosion control efforts in the South Fork Garcia River watershed prompted the MCRCD to investigate whether any linkages could be established between restorative watershed efforts and improvements in permeability or spawning gravel composition. Has permeability or spawning gravel quality in the South Fork Garcia River (Tributary-9) improved? If so, can these changes be attributed to watershed-scale erosion control efforts?

To address this issue, we reviewed changes in South Fork Garcia River permeability and sediment composition from 1999 to 2004. To summarize:

- Mean permeability increased from 1,354 cm/hr to 2,117 cm/hr, but this change was not significant at any confidence level, i.e., the statistical testing could not demonstrate that a change in the means has occurred.
- The percentage of fine sediment < 8.0 mm increased from 29.8% to 34.5%, and the percentage of fine sediment < 0.85 mm decreased from 10.1% to 7.8%. Similar to the permeability results, these changes were not significant at any confidence level, i.e., the statistical testing could not demonstrate that a change in the means has occurred.

Because a change in the means for the above sampling results could not be demonstrated, using the above results to investigate a relationship between restorative watershed efforts and improvements in permeability or spawning gravel quality was not attempted.

More importantly, however, is understanding the context of the focus of such a comparison, i.e., establishing a cause-and-effect relationship between hillslope processes / land management and fluvial geomorphic processes using bulk sediment and permeability data. Bulk sediment sampling and permeability results can be useful to assess the suitability of the gravels for salmonid spawning habitat within a sampling reach. However, because the data collected for the 1999 and 2004 studies were collected within relatively short channel reaches, extrapolating these results to assess changes in sediment production rate at the watershed scale is not possible unless other factors are considered. For example, changes in sediment particle size distributions can result from a number of causes related to changes in the supply of watershed products. Monitoring efforts must therefore be broadened beyond the current sampling scheme of eight sample sites within single, approximately 1,000 ft reaches to determine how differences in

substrate composition in the tributary reaches respond to changes in sediment production at the watershed scale. To do this, a larger-focus investigation would need to be performed, such as a sediment source analysis or a sediment budget. Such an investigation can help identify watershed-scale sedimentation processes (erosion, storage, transportation, deposition) responsible for delivering sediment to, and routing through, the channel. For example, a sediment budget would entail conducting sediment source inventories, calculating transport rates and delivery volumes, examining the interrelationships between transport processes and hillslope form to determine the sediment yield from locations within the basin (these can be tailored to specific monitoring reaches), and repeating the study at a later date to determine changes in the budget. This information, coupled with bulk sediment sampling and/or permeability data, would establish a much stronger linkage between changes in land management and tributary response than using bulk sediment sampling and/or permeability data alone.

In the absence of a sediment budget, sediment yield analysis, or similar watershed-scale monitoring, any changes in South Fork Garcia River substrate based on the 1999 and 2004 data collection (e.g., coarsening or fining) can only be considered as a *possible* result of watershed management efforts, such as upslope sediment reduction from erosion control measures. Presently, other factors such as the magnitude and frequency of storm events, or the number and activity of mass-wasting features in the basin cannot be ruled out as primary causes of change.

Summary and Conclusions

In assessing the relationship between substrate composition and permeability, the 2001 Report focused on sample size (the number of samples per tributary needed to characterize variability). The 2004 sampling focused on collecting samples to compare with the 1999 data, as well as using the results of the comparison to evaluate the effectiveness of the methods for detecting changes. In doing this, we identified additional sources of variability that can affect the sampling results, including: sampler bias (sampling differences between operators), and geomorphic variability (differences between tributaries, reaches, and/or sample sites). Sampler bias was minimized by McBain and Trush and MCRCD field training; however, geomorphic variability persisted, primarily in the form of sample size (the number of samples per tributary reach and collecting a representative sample volume per sample site). Both are given equal weight in terms of their importance, and future sampling efforts should try and meet the sampling criteria described in this report if the objective is to detect change from year to year. Specifically, future data collection should:

- Follow the bulk sediment sampling criteria suggested by Church et al. (1987): the maximum particle size in the sample (D_{max}) should not constitute more than 1% of the total sample mass for particles up to 128 mm (5.0 in), and not more than 5% of the total sample mass for particles greater than 128 mm.

- Follow the sample size recommendations presented in the 2001 Report: to strongly characterize the sampling variance, collect between 15 and 20 bulk sediment samples per tributary to best balance cost and precision. Alternatively, re-evaluate the minimum detectable difference to reduce the number of required samples.

The 2004 data provided a useful comparison of sample means to gauge changes in substrate composition and permeability. Most changes in sample means were not statistically significant. Independent of statistical significance, these results suggest no significant net change has occurred; overall, some of the tributary reaches showed a decrease in fine sediment, whereas others showed a slight increase in fine sediment.

Presently, research to determine a strong relationship between permeability and sediment quality (and to relate the sediment quality to salmonid spawning success) is still developmental. If future sampling is desired to investigate salmonid spawning gravel quality in the Garcia River watershed, the same data collection methods presented herein can be used; however, current literature should be reviewed before developing a study plan, to review advances in the permeability-substrate-spawning habitat relation and to determine how field data collection should be changed. This will aid in determining if permeability sampling is needed in combination with bulk sediment sampling, or if bulk sediment sampling alone will be sufficient to assess changes in spawning gravel quality. Moreover, if future monitoring objectives include a larger-scale understanding of watershed cause-and-effect relationships, monitoring should extend beyond the tributary-reach scale so that the processes responsible for generating changes in spawning gravel quality (e.g., sediment supply, magnitude and frequency of flood events) are identified.

INSTREAM WINTER TURBIDITY AND WATER CLARITY

GOAL

Our goal is to interpret turbidity and suspended sediment concentration data reported in this study to inform CDF, NCRWQCB, Garcia River landowners, and the public about winter water clarity in the tributaries and the mainstem of the Garcia River in terms related to salmonid health and land management.

TURBIDITY DEFINED

Turbidity measures the collective optical properties of a water sample that cause light to be scattered and absorbed rather than passing through a clear sample in straight lines (USGS, 1998). It is generally reported as NTU (Nephelometric Turbidity), FTU (Formazin Turbidity) or JTU (Jackson Turbidity Units). JTUs are no longer commonly used (USGS, 1998). Our study utilized recording Digital Turbidity Sensors (model DTS-12 by Forest Technology Systems) recording in NTUs except for the Salmon Forever lab turbidities from our 2003-04 grab samples, which were recorded in FTUs.

Turbidity measurements represent a gradual occlusion of the clarity of water as NTUs rise. Turbidity is readily observed in North Coast rivers and streams during or after winter storms, when the rivers appear opaquely blue, green or tan after prolonged rains. While turbidity can result from a wide variety of suspended materials, including algae or other organic substances in the water column, turbidity during peak flow events in northwestern coastal California streams is mostly attributable to suspended sediment particles, such as silt and clay (Madej 2005). Organic particles suspended in the water column yield similar turbidity levels but with correspondingly much lighter weight.

SUSPENDED SEDIMENT CONCENTRATION

Suspended Sediment Concentration (SSC) is a laboratory protocol for analysis on a physical water sample. The laboratory procedure for SSC is similar to Total Suspended Solids (TSS) but we duplicated laboratory procedures established for SSC by USFS Pacific Southwest Research Station's Redwood Sciences Laboratory as referenced on their website (www.fs.fed.us/psw/rsl). The basic procedure is to collect suspended particles by vacuum filtration from a water sample of known volume onto a pre-weighed glass-membrane filter. The dry weight of the filtered residue is expressed over the volume of the water sample as milligrams per liter.

INSTRUMENTATION

Sampling of winter water clarity was achieved mostly with the coupling of software and instrumentation that was developed and first implemented by United States Forest Service's Redwood Sciences Laboratory in Arcata, California. Garcia River watershed instrumentation included digital turbidity sensors with a lens wipers (much like a windshield wiper that cleans the lens prior to each measurement, DTS-12, from Forest Technology Systems), pressure transducers (Druck and Water pro) to measure stream stage height, and dataloggers (Campbell Scientific's CR510) for recording the data and downloading into a portable laptop computer. The station at Mill Creek had the benefit of an ISCO 6712 automatic pumping sampler in late winter-spring 2005. Water samples

extracted by the ISCO were approximately 330 milliliters in volume. Grab samples from the other streams were generally extracted with a DH-48 Depth Integrated Sampler in similar volumes.

Turbidity sensors were installed and threaded through a long, hollow square aluminum casing (the "turbidity boom"), and suspended into the thalweg from a cable attached to trees on both streambanks (see plates and cross sections 1-5). The mainstem Garcia station required a bank-mounted boom as the river was too wide for a suspension cable installation. The Inman station was installed with the recycled mainstem bank mounted boom and instrumentation. Aluminum parts were fabricated by a Point Arena welder local to the Garcia River Watershed based on a USFS schematic.

CDF AND NCRWQCB COST SHARE

Most of the instrumentation used in this study was purchased under a contract between the MCRCD and CDF. The North Coast Regional Water Quality Control Board supplied an additional contract with the MCRCD to provide the two years of staffing required to set up the stations each winter, download data, maintain the stations, and take them down again. Contract amendments also allowed for data processing and analysis, landowner contacts, and GIS mapping services. In addition, the ISCO sampler and related equipment was provided separately by CDF.

CALIBRATION AND MAINTENANCE OF INSTRUMENTS

Turbidimeters

DTS-12 turbidimeters were calibrated by the manufacturer specifically for ranges expected in the study - the upper resolution of the instrument (1800 ntu, rather than a low range of 1-10 ntu, which would be more interesting to water purveyors for providing pure, clear water for human drinking water supplies). Because our chosen calibration was at the high end of the range, the lowest turbidity readings (clearest streamwater) sometimes resulted in negative numbers. While this may seem problematic, it is reasonable to expect an instrument calibrated for optimum accuracy at the upper limit of its range to be less accurate at the lowest limit of its range. The negative numbers reached a maximum of –2 NTU in the clearest conditions. We tested these waters in the field with a portable HACH 2100P turbidimeter and found the difference between the low negative values and those more accurate HACH readings were less than 2 ntu, which is within the expected range in variability (Jack Lewis, USFS-PSW, Arcata, personal communication, 2004). Each of the five turbidimeters we employed were re-calibrated at the manufacturer in the summer 2004, between the two monitored winter seasons.

Two of our turbidimeters failed due to wiper malfunction during the early summer prior to disconnection for the summer season. We suspect that small pieces of debris or rock lodged between the joint and wiper blade and caused the motor to stick in the on position until the battery failed. In each of the three wiper arm malfunctions, we decided not to disconnect the turbidimeter to send it to the manufacturer for repair during the monitoring season, but rather kept them connected to continue monitoring and waited till the end of the season for repairs. Randy Klein, RNSP, Arcata, suggested that for next season, to disconnect the wiper arm and let the turbidimeter sense the stream clarity without wiping

the lens in between measurements. This would enable the station to keep running without depleting the station battery. However, this would definitely NOT be advisable in a mainstem application, where the density of suspended instream algae and periphyton increases dramatically. At the the Garcia mainstem station, algae colonized the turbidimeter lens so prolifically that the lens was visibly occluded and turbidity readings were artificially high as a result.

Pressure Transducers

The Druck pressure transducers are roughly calibrated at the manufacturer, but Redwood Sciences Laboratory instructions specify calibrating pressures sensed to water depth at local atmospheric pressures. A wet lab was set up at the Ridge to River office, where the pressure transducer for each station was installed in a vertical pipe then the water level was raised to different levels (feet of stage) and corresponding pressures were read and recorded to determine the relationship between water depth and pressure readings. Data points were entered into an Excel spreadsheet, and a line was run through the points with the corresponding regression equation providing the slope of the line and intercept. Regression equations were entered as variables in the Turbidity Threshold Sampling (TTS) software provided by RSL and customized for each of our five stations. Customized TTS programs were downloaded into dataloggers at each station.

ISCO Automatic Pumping Sampler

We installed one ISCO pumping sampler at Mill Creek and operated it during the spring of 2005 only. We did not receive any calibration services for the ISCO nor did we perform any ourselves. However, Kevin Fauchet,Campbell Timberland Management, was helpful in the initial wet lab setup of the ISCO and its initial connection with a turbidimeter, pressure transducer, and datalogger in a “dry-run” condition.

WATER CLARITY SAMPLING LOCATIONS

The subset of monitored sub basins from the 1999 baseline monitoring project was selected based on the following criteria:

- presently or historically salmon bearing
- landowners willing to authorize the project on their lands

The table below indicates the location, years of operation, landowner, and identifying codes present in the data (see appendix).

Table 9. Garcia River Water Clarity Monitoring Stations, Water Year, ID, Landowner

STATION NAME	WINTER WATER YEAR	IDENTIFICATION	LANDOWNER
Garcia Mainstem	03-04	GAR - 236	Hugh Brady
Inman Creek	04-05	INM – 249	The Conservation Fund
Whitlow Creek	03-04, 04-05	WHI – 240	The Conservation Fund
Mill Creek	03-04, 04-05	MIL – 241	Maillard Ranch
Pardaloe Creek	03-04, 04-05	PAR – 242	Maillard Ranch
South Fork	03-04, 04-05	SFK – 243	Mendocino Redwood Co

A Garmin V Geographic Positioning System (GPS) was used to establish latitude and longitude of the winter water clarity monitoring stations. Drainage areas refer to the total drainage area of the basin as opposed to the drainage area above the monitoring station. A map of these stations is provided as Figure 1. The table below provides the latitude and longitude of the monitoring stations followed by distances upstream from the Garcia confluence with the Pacific Ocean.

Table 10. GPS Location and Drainage Areas Surrounding Turbidity Monitoring Stations

STATION NAME	LATITUDE/LONGITUDE	DRAINAGE AREA (acres)
Garcia	N 38.90195 W. 123.60787	73,223
Whitlow	N. 38.89720 W. 123.36471	1,221
Inman	N. 38.90778 W. 123.48670	5,481
Mill	N. 38.90700 W. 123.35080	4,846
Pardaloe	N. 38.89720 W. 123.36471	5,626
S. Fork Garcia	N. 38.90188 W. 123.60793	5,598

Inman– Garcia River Confluence is approximately 28 miles from the mouth of the Garcia River. The monitoring site is approximately 700 feet above the confluence, within the mapped study reach (see figure 1).

South Fork – Garcia River Confluence is approximately 18.5 miles from the mouth of the Garcia River. The monitoring site is approximately 1 mile above the confluence within the mapped study reach (figure 1).

Whitlow – Garcia River Confluence is approximately 29.5 miles from the mouth of the Garcia River. The monitoring site is approximately 700 feet above the confluence within the mapped study reach (figure 1).

Pardaloe – Garcia River Confluence is approximately 43.5 miles from the mouth of the Garcia River. The monitoring site is approximately 300 feet above the confluence within the mapped study reach (figure 1).

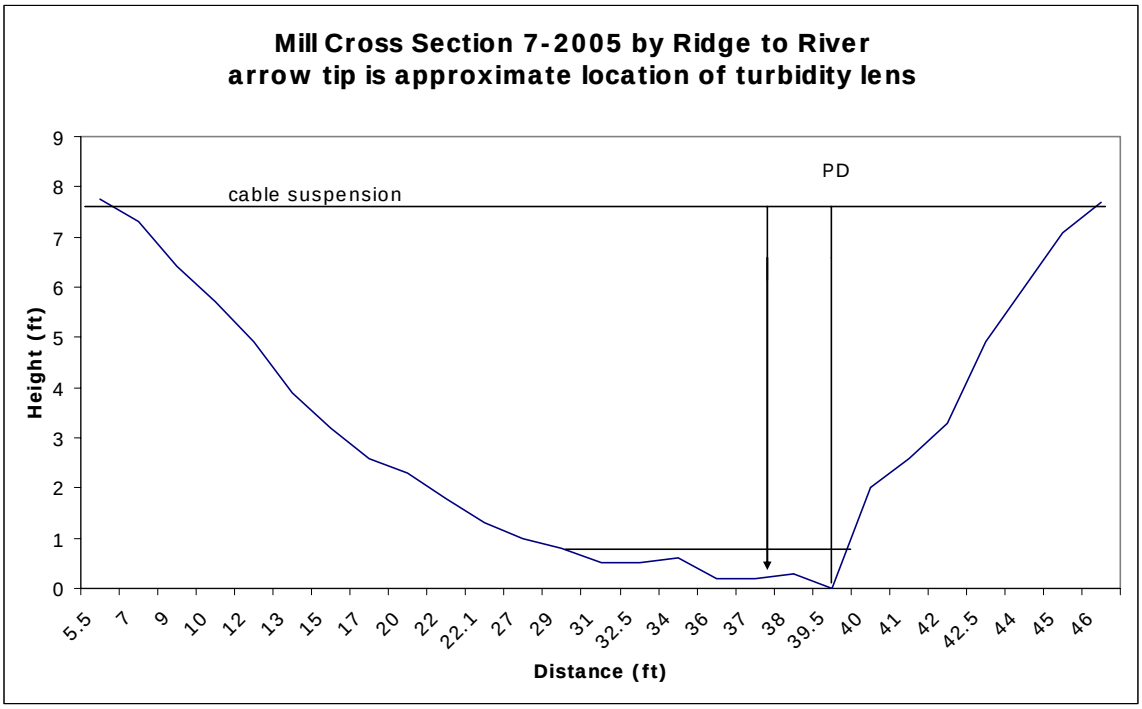
Mill – Garcia River Confluence is approximately 39.5 miles from the mouth of the Garcia River. The monitoring site is approximately 2 miles above the confluence within the mapped study reach (figure 1).

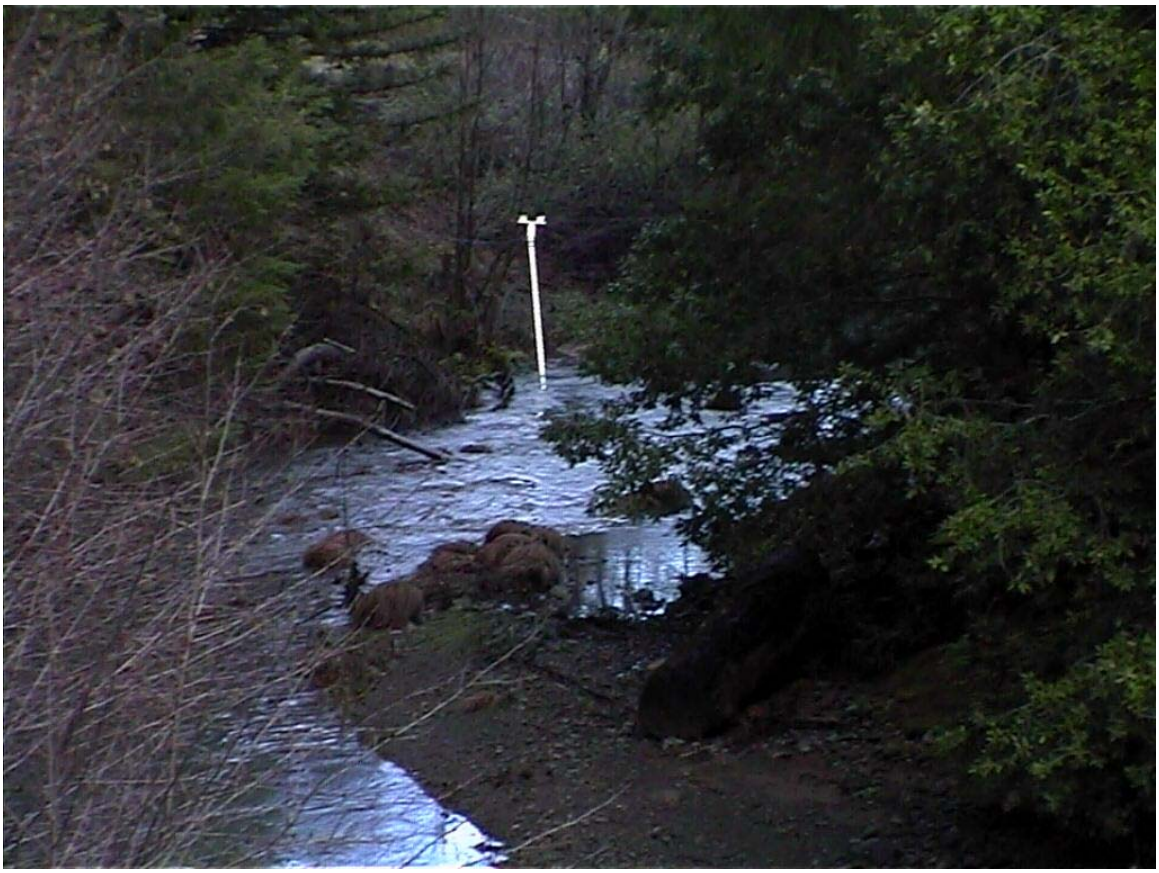
STATION CHANGES BETWEEN WATER YEARS 2004 AND 2005

The mainstem Garcia station was disassembled in fall, 2004 and the equipment from that site was re-installed at a new station at Inman Creek. The streambank that held the bank mounted boom in place at the mainstem station was actively eroding and it appeared likely that the equipment would be destroyed during the upcoming winter. Also, a station was needed at Inman Creek to record existing instream conditions prior to erosion control treatments planned for in 2006. The mainstem Garcia station and Inman Creek did not

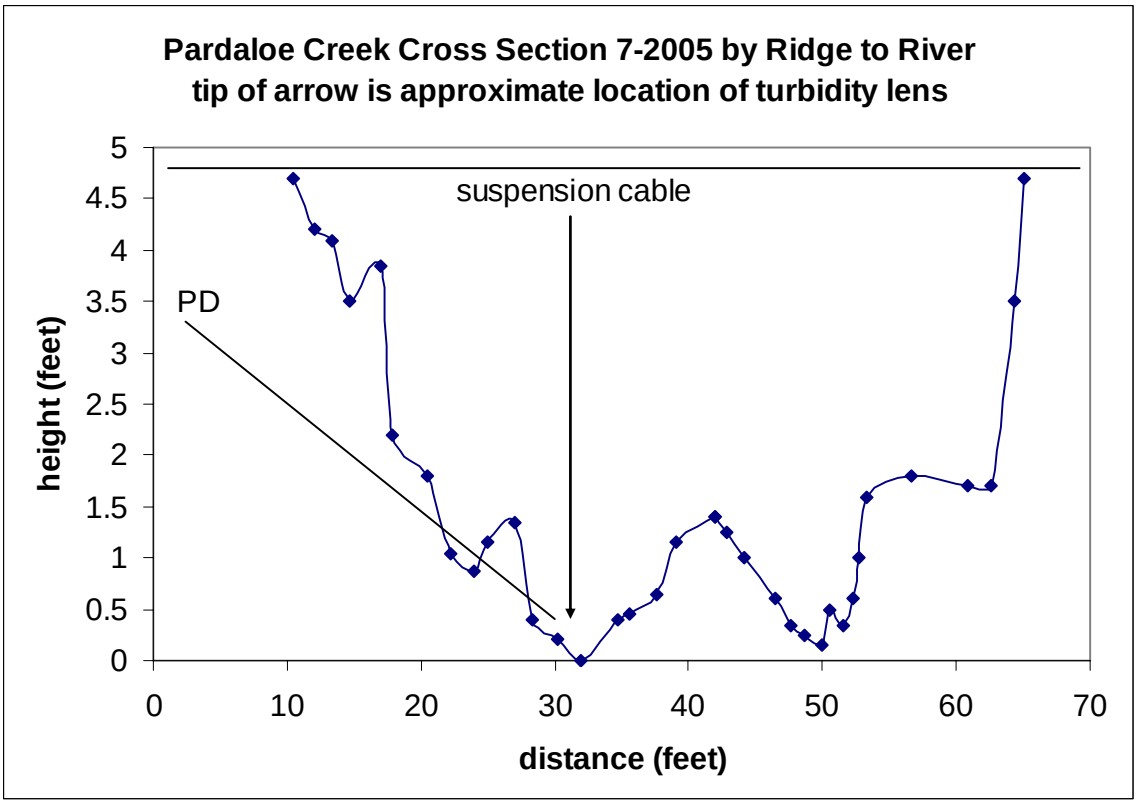
have a properly functioning pressure transducer until CDF provided one for use at the Inman Creek station. This analog instrument, a WaterPro H-310, operated differently than the digital Drucks and required considerable troubleshooting to establish communications between the pressure transducer and the datalogger, which resulted in a lack of accurate stage data at Inman Creek until early 2005.

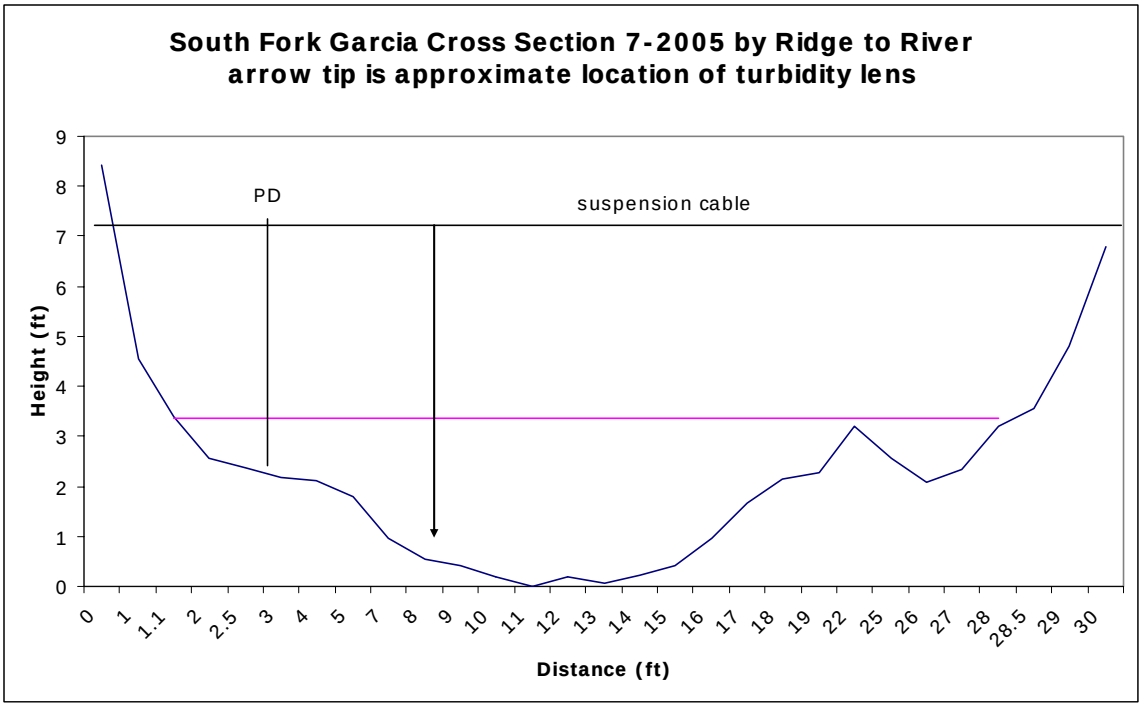
Station Mil: looking upstream at cable-mount turbidity sensor, staff plate, ISCO hose

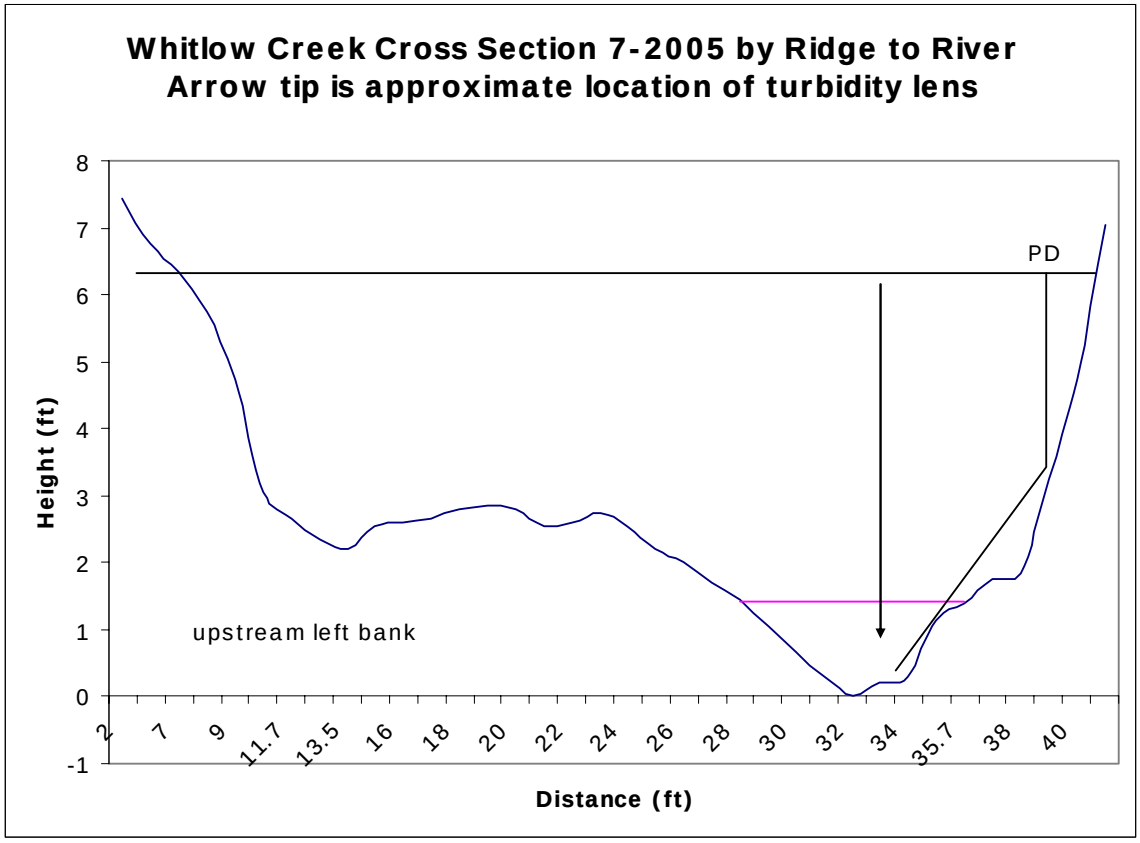


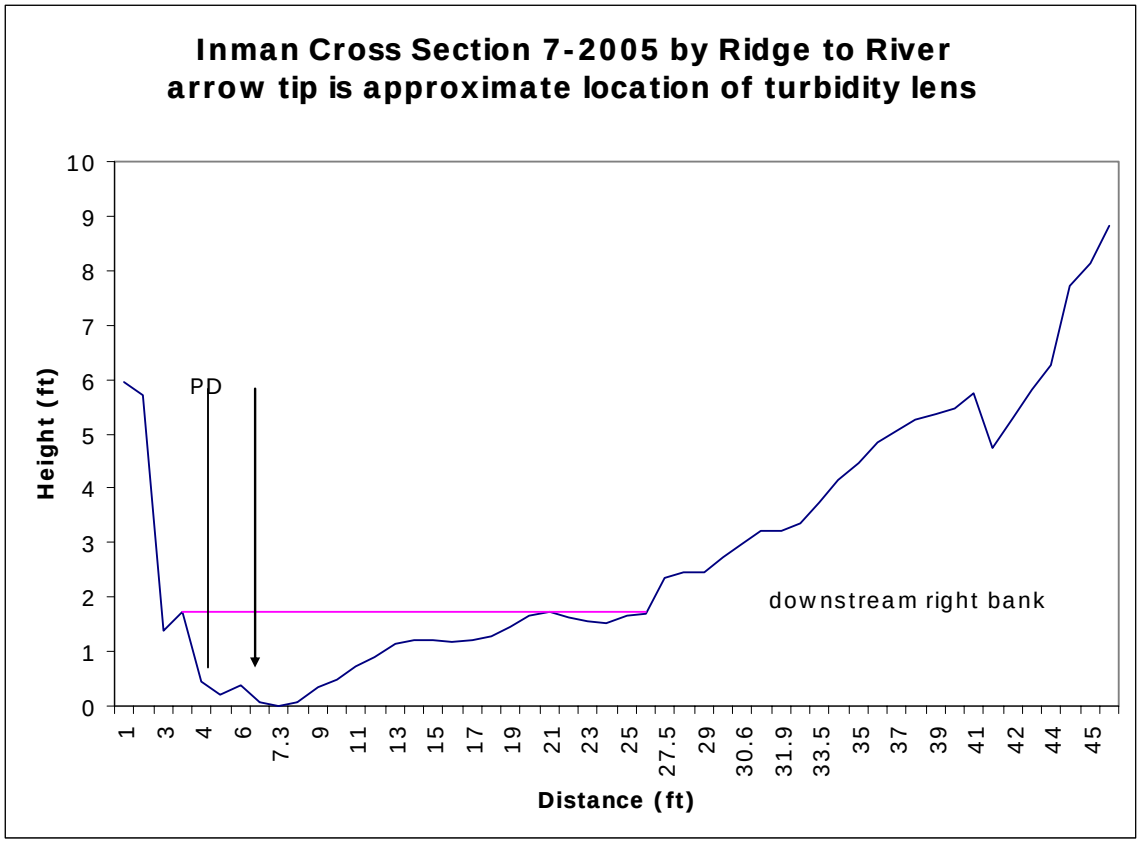


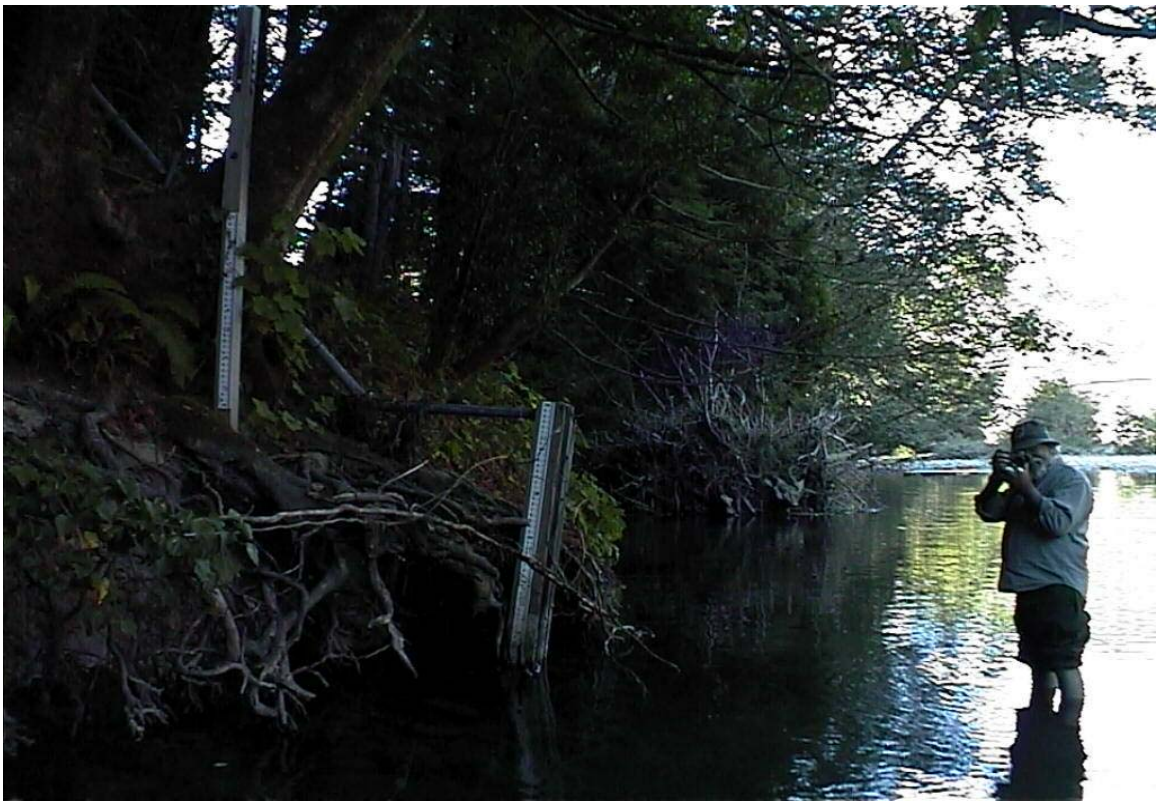
Station Par: looking upstream from Hollow Tree Road view




South Fork Garcia Cross Section 7-2005 by Ridge to River
arrow tip is approximate location of turbidity lens
PD
suspension cable
Height (ft)
0
1
2
3
4
5
6
7
8
9
0
1
1.1
2
2.5
3
4
5
7
8
9
10
11
12
13
14
15
16
17
18
19
22
25
26
27
28
28.5
29
30
Distance (ft)


Whitlow Creek Cross Section 7-2005 by Ridge to River
Arrow tip is approximate location of turbidity lens
Height (ft)
8
7
6
5
4
3
2
1
0
-1
PD
upstream left bank
2
7
9
11.7
13.5
16
18
20
22
24
26
28
30
32
34
35.7
38
40
Distance (ft)





Peter Dobbins at Mainstem Garcia Station observing active bank erosion there

FIELD METHODS

Ben Monmonier, Anna Birkas, and Teri Jo Barber conducted the field setup, downloading data from the dataloggers, and troubleshooting and maintenance of the sensor instruments, dataloggers, and batteries. Field methods included site visits approximately every three weeks to each monitoring station. Field books containing details of the site visits were maintained and kept inside a data box where the datalogger was stored. Standard maintenance included examining the wiper action on the turbidimeter lens, checking the battery voltage, and checking that the pressure transducer was recording accurate stage heights as referenced by the staff plate installed at each station. Examples of problems and maintenance include: Pardaloe's pressure transducer was scoured out by a high flow and had to be reinstalled, bolts holding the angle for the turbidimeter housing had to be changed out on occasion, and batteries had to be recharged on a regular basis. Water samples pumped from Mill Creek by our ISCO were pulled from the sampler approximately every 2 weeks depending on the timing of storms. Grab samples pulled from other streams by hand were also collected. Water samples were stored in a dark cool cabinet prior to processing them in the laboratory.

DATA PROCESSING

Datalogger software PC208w supplied by Campbell Scientific was used for this project. The TTS program from Redwood Sciences laboratory worked well with the statistical program R, to facilitate plotting of the data, but neither software is widely available nor user friendly. Therefore, data files were imported into an Excel spreadsheet and then day numbers 1-352 were translated into a standard date format (e.g., 12-6-2004), which was added to the data files. Raw data files were provided to landowners and are shown in the Appendix.

Raw data was also provided for "sanitization" to Randy Klein, Redwood National and State parks Hydrologist, Arcata, California. There are several sources for erroneously high turbidity including

- bubbles
- turbidimeter too close to streambed
- algal growth on lens
- macroinvertebrates clinging to the turbidimeter
- grass, leaves, etc clinging to the turbidimeter

Mr. Klein manipulated these data to correct for the suspected errors, most of which were confirmed during conversations between Randy Klein and Teri Jo Barber while referencing fieldbooks that contained references to problems encountered during site visits. The resultant finished data set was used for analysis. A summary of techniques used by Randy Klein is described in a document currently under development (Klein, 2003b).

COLLECTING STREAM WATER SAMPLES: GRABBED AND PUMPED

In 2003-04, 14 grab samples were obtained from the monitored tributaries and processed by the Salmon Forever laboratory in Arcata, California. No pumping samplers were available at this time and grab samples were to be taken when streamflows were highest.

As has been shown repeatedly by similar efforts to take samples at high flow, it is very difficult to predict the date and time of peak streamflows. These often occur in the middle of the night when personnel are often unavailable or reluctant to travel long distances to remote places. Therefore, we were not able to obtain samples during peak discharges, as desired. Grab samples were taken with a DH-48 Depth Integrated Sampler and were width integrated as well when the stream could be waded. When flow velocities made streams unsafe to wade, channels were sampled from as close as possible to the turbidity sensor. Pumping samplers alleviate these types of problems.

In 2004-05, 94 water samples were extracted from Garcia river tributaries. Twelve of these were "grab samples" and 82 were pumped by the ISCO pumping sampler at Mill Creek. Pumped samples from Mill Creek were made possible by the ISCO 6712 automatic pumping sampler provided by CDF. These are not depth or width-integrated, but originate at the same point in the water column as the turbidity sensor.

LABORATORY METHODS

Water samples taken from either the ISCO pumping sampler, or the DH 48 sampler were refrigerated out of the light until processing at the laboratory of Salmon Forever (2003-04 samples) or the Ridge to River laboratory (2004-05 samples). The USGS guide (1998) states that turbidity is optimally measured immediately on collecting a sample, preferably in the field. Holding the sample longer than 24 hours predisposes the measurement to biofouling which tends to bring the ntu value artificially down (USGS, 1998). Avoiding sunlight and keeping the sample cold limits biofouling. Turbidity values can be artificially high if the glass cuvette bottle becomes scratched or is not inserted with the same orientation for each reading. Care was taken to avoid these pitfalls by cleaning the cuvette with the special oil provided and wiping with a lint-free cloth before and after each measurement.

ISCO samplers collect 24 sample bottles over a period typically varying from two weeks to one month, making the 24-hour shelf-life untenable. Hydrologic year 2004-05 water samples were processed several months after collection, due both to the ISCO collection delay period and because the CDF contract providing funds for analysis was not effective until July 18, 2005. Biofouling is often indicated by the presence of algae in the sample, but none of the samples contained any visible algae. Our laboratory manager stated that algae in the sample behaves consistently regardless of color, such that it swirls when stirred. In contrast, suspended sediments that we expected in our sample did not swirl, but rather settled out on the bottom after stirring (Susan Wright, personal communication). Mrs. Wright performed approximately half of the turbidity measurements in the lab from sample bottles. A Hach 2100P turbidimeter was used, the qualities of which are reported in the USGS 1998 guide.

All 2004-05 water samples were processed for lab grade turbidity in October, 2005 with a HACH 2100P turbidimeter at the Ridge to River laboratory. Water samples remained in dark, cool storage until December when they were analyzed for SSC by Chemist Ruth Dobberpuhl. Labeled glass filters with residues intact are stored in the laboratory and were examined while preparing the section in this report addressing water sample results.

The ISCO with its hard hat off, exposing programmable brain, installed at Mill Creek

Mill Creek water samples, 2 from the ISCO (photo left) and 1 depth integrated sample

CHRONIC TURBIDITY IN RELATION TO BIOLOGICAL THRESHOLDS

Sediment is produced naturally from the watershed's hillslopes, river banks, and streambed during episodes of erosion from high intensity rainfall. This is commonly referred to as "background erosion." Accelerated erosion caused by human activities has been widely documented. Primary causes of accelerated erosion include alteration of natural drainage patterns by roads, removing soil cover, and by placement of unstable fill material in a position where it can be delivered to streams.

Once the products of erosion are delivered to the stream channel, entrained course sediments deposit in point bars or in the active streambed. The smaller particle fractions (sand, silt, and clay) stay suspended in the water column for longer periods of time (the smaller the particle, the longer they will be suspended) and settle in pools or on banks and in riffles when higher flows recede.

Land management practices that disturb soil and drainage patterns have increased erosion and the delivery of sediment to rivers and streams, to the detriment of salmonid habitat. Deep rearing pools have been shallowed and spawning gravels have been degraded by sand, silts, and clays that clog pore spaces. Winter water clarity between winter storms is important for anadromous fishes so that they can keep gills clean, see to feed, and have gas exchange for alevins developing in redds. When between storm water clarity decreases due to chronic recession limb turbidity, the lack of water clarity inhibits a fish's ability to see and capture prey, suspended sediments can clog sensitive gill tissue, and light is inhibited from reaching the benthos where periphyton grow as primary food production.

Sands, silts, and clays are the finer particle sizes found in sediment. Silt and clay particles become entrained during the rise of a stream in response to a rainstorm and stay suspended longer than do the larger sediment size classes. When these smaller particles remain in suspension between major storms, this creates a condition that is often referred to as "chronic turbidity". Chronic turbidity refers to long durations of turbidity exposure, while acute turbidity exposures refer to very short periods of high turbidity.

Acute turbidity from elevated suspended sediment concentrations in the water column occur during relatively brief periods of high runoff in response to intense, prolonged rainfalls that can also cause flooding. These episodes of intense rainfalls and flooding can also provide the opportunity for alluvial rivers to form or reform their beds and banks, which may include lateral bank erosion, changes meander patterns, and sorting and cleaning of gravel. This natural disturbance pattern is typical for undammed alluvial rivers like the Garcia and illustrates that rivers are changing features in terms of their position within floodplains and terraces between valley walls, rather than static features on the landscape.

One example at the reach scale is the immediate flush of suspended sediment derived turbidity that occurs immediately downstream of a bank collapse. This type of sediment pulse includes the short term entrainment of sediments, downstream transport of the finer sediment particles in the washload, and local deposition of the coarsest sediment

materials into the bedload. The short duration of these events is tolerated by anadromous fishes, owing to adaptations developed in co-evolution with their native streams over geologic time scales.

Elevated chronic exposure to turbidity and suspended sediment between storms is perhaps a more recent experience for salmonids. We assume that chronic turbidity exposure is elevated over background conditions in duration and magnitude due to watershed disturbance from land management practices. Klein (2003) recently reported that for eight turbidity-instrumented small streams from Mendocino County to the Oregon border from water years 2000 to2002, land use practices explained more of the chronic turbidity variation than did the natural sources of variation combined (geology, climate, vegetation). Land use most directly correlated to chronic turbidity in that study was summarized in two measurements: percent of watershed area harvested per year and road density in miles of road per square mile of watershed area (Klein, 2003).

Sublethal effects of chronic turbidity on aquatic organisms has been explained and documented by a variety of researchers. In the report of the Scientific Review Panel on California Forest Practice Rules and Salmonid Habitat (Ligon et al. 1999), the sub-lethal effects of chronic turbidity on salmonids were listed as reduction in feeding by juvenile salmonids, thereby reducing growth rates, irritation and abrasion of gill tissues, avoidance behaviors, and mortality at high concentrations as documented and reported by Noggle (1978).

Barber (1997) reported a series of biological responses of salmon and steelhead to varying concentrations of suspended sediment and turbidity in fresh water based on a review of the literature as follows. It was stated that water appears clear to 2 NTU. Fishes avoid turbid water sources and begin seeking of cover when instream turbidities rise to 5 NTU. At 6, streamwater is often colored, appearing blue or green and is barely clear enough to see through. At about 10, water clarity appears noticeably diminished to the human eye, rainbow trout growth rates slow, and at 1 meter depth light in the water column is 77% of what is available at the surface. At 20 NTU, fishermen go elsewhere, perhaps because coho salmon (and other fishes) reactive distance is reduced by 52%. Sigler et al (1984) reported that at 25 NTU, steelhead juveniles ceased to grow. Trush (2001) reported that when turbidity reaches 25-38 NTU, a fish's ability to feed is cut in half. Hadden (et al. 2004) reported that both field and laboratory studies revealed that while the foraging efficiency of juvenile salmonids was decreased by increased turbidities, fish continued to capture prey at turbidity levels in the range of 40-50 NTUs.

A turbidity value of 30 NTU stimulates a major increase in macroinvertebrate drift downstream, which may be an avoidance technique. At 50 light is reduced to 60% of what is available at the surface and streamwater appears like chocolate milk. At 60 reduced capture success of prey by fishes is exhibited. At 86 a marked reduction in growth rate in brook trout juveniles was reported. At 100 coho juveniles avoid turbid waters by swimming away to clearer waters if they are available. At 200, steelhead exhibit the same avoidance technique. When turbidities reach 1000-2000, light at 0.1 meter in depth is reduced to only 4% or what is available at the surface. No lethal effects of turbidity have been reported, however lethal effects on fishes due to extremely high

suspended sediment concentrations have been documented at 500-2000 mg/l (Barber, 1997).

Klein (2003) determined turbidity durations greater than or equal to the following thresholds: 25, 50, 70, 100, 150, 200, 500, 1000, 2000 NTUs during a single water year. Of these, thresholds of 25, 60, and 150 NTUs were selected for use in this study because the biological effects of these turbidity thresholds are well-reported in the literature.

Turbidity peaks are usually related to rises in stream heights, which, in turn, can be traced to periods during and immediately after rainfall. Long durations of turbidity not explained by rainfall and stream stage rises might be caused by emergency road repairs installed in the rain or winter vehicle traffic on a dirt road, etc. Klein's (2003) results indicated that two basins in his study expressed larger chronic turbidities, reflecting a high percent of roaded drainage area and high frequency of post 1988 timber harvest expressed as a percent of basin area.

WATER CLARITY RESULTS

Figures 7-16 display the turbidity values recorded in NTU for the Garcia River mainstem and tributary stations by water year. Raw digital turbidity data was utilized to prepare the graphs for presentation and for analysis except where "suspect data" (as identified by Randy Klein) were corrected. The red line indicates the whole corrected dataset and the green line indicates which suspect raw data were corrected. Tributary graphs also feature a horizontal line across the data indicating the three turbidity thresholds we selected as an index of water clarity due to biological differences in overwintering salmonids: 30, 60, and 150 NTU. Tables 11 and 12 and figures 18 and 19 summarize duration of chronic turbidity, the hours of duration by water year and tributary sustained in each creek above the 30, 60, and 150 threshold levels. Physiological and behavioral changes exhibited at these thresholds are summarized above.

Figure 7. Garcia Mainstem Turbidity 2003-2004

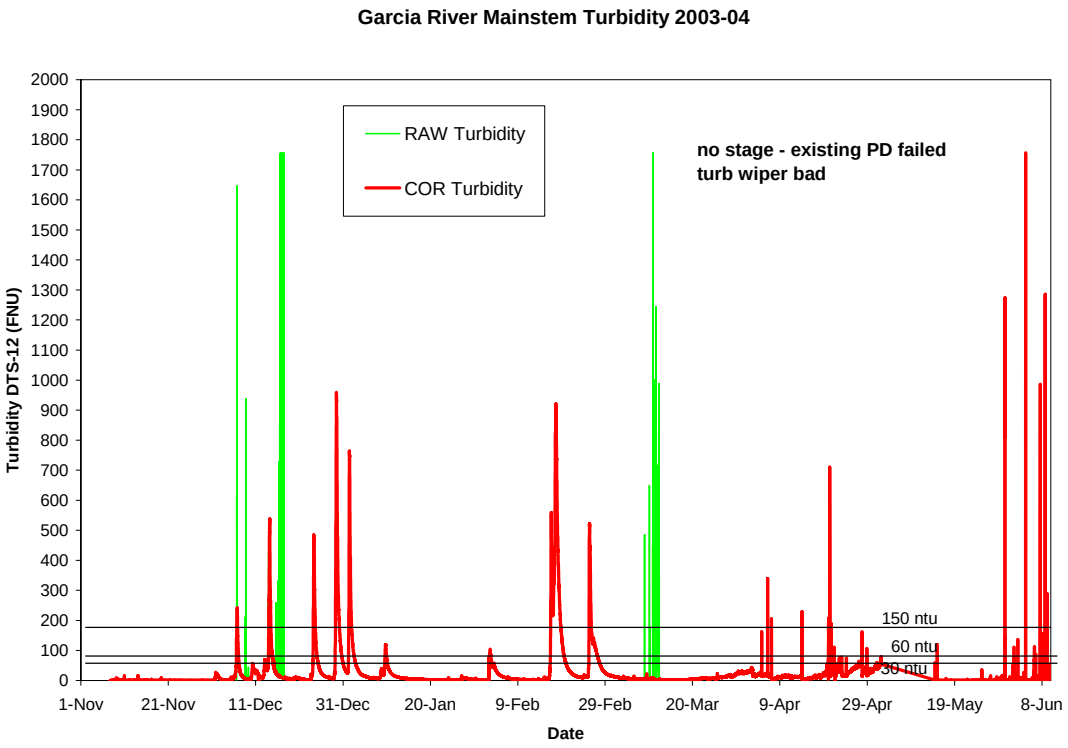


Figure 8. Mill Creek Turbidity 2003-2004

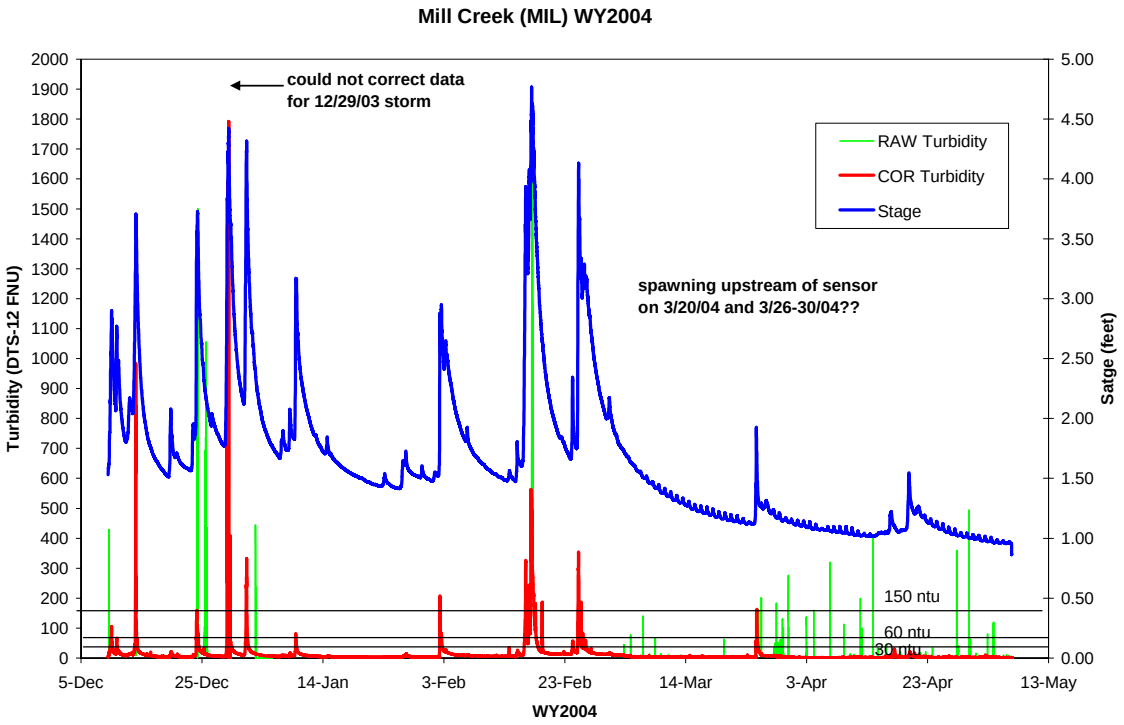


Figure 9. Mill Creek Turbidity 2004-2005

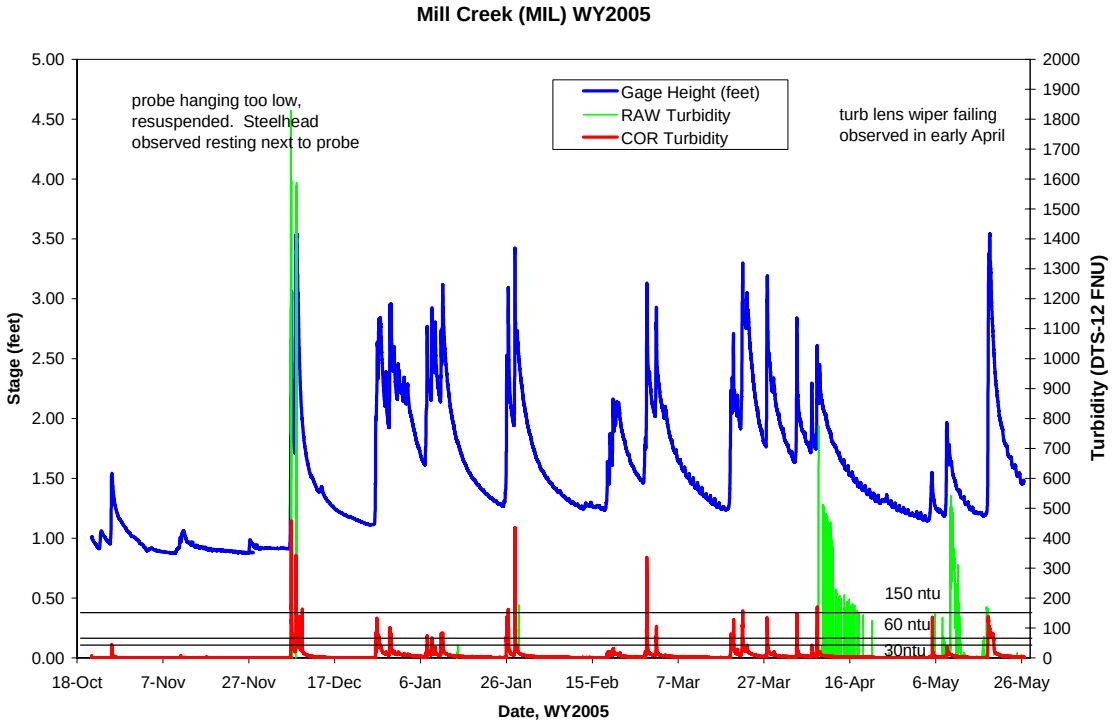


Figure 10. Pardaloe Creek Turbidity 2003-3004

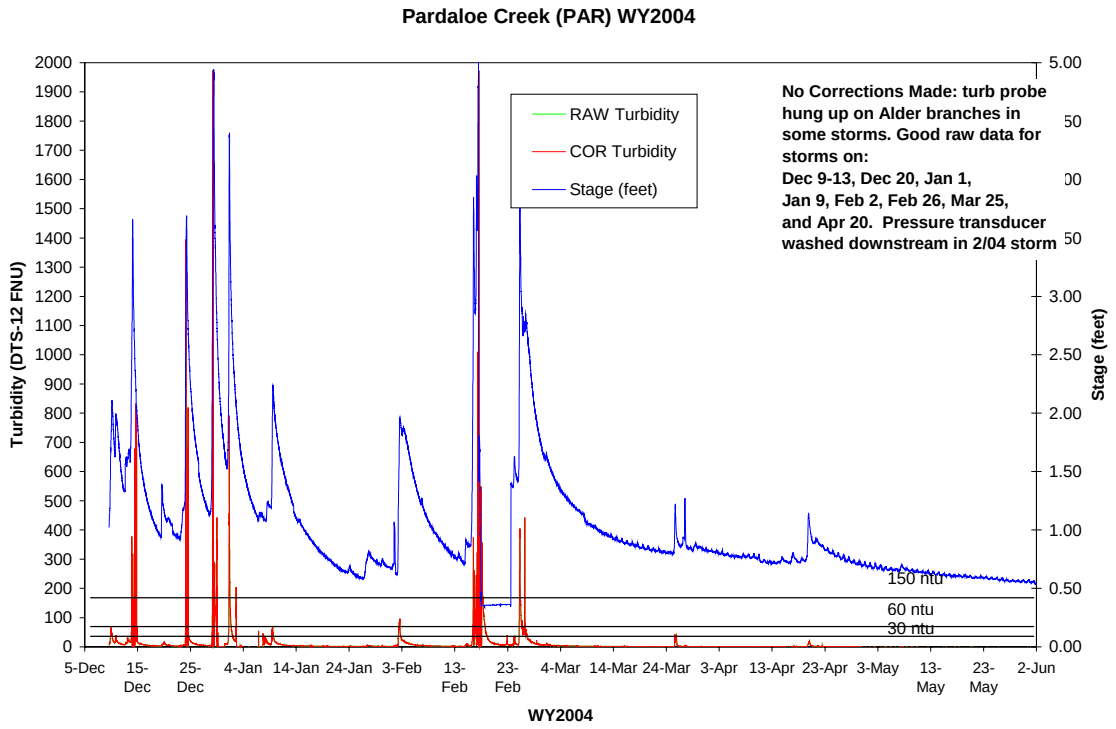


Figure 11. Pardaloe Creek Turbidity 2004-2005

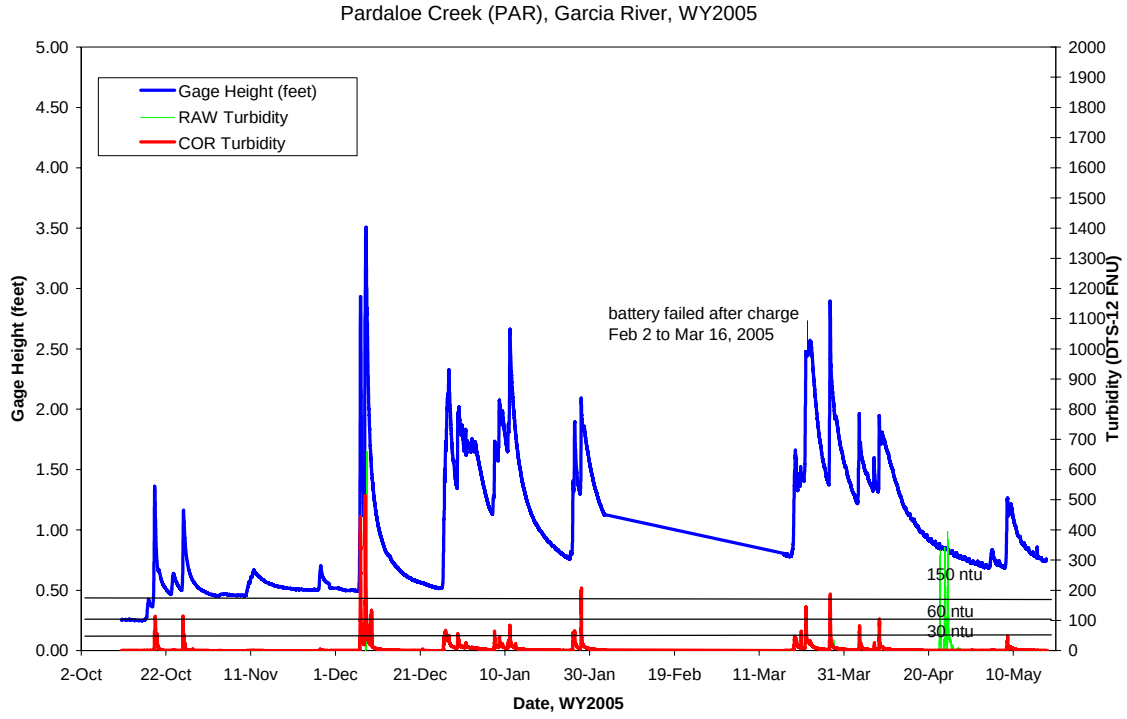


Figure 12. Whitlow Creek Turbidity 2003-2004

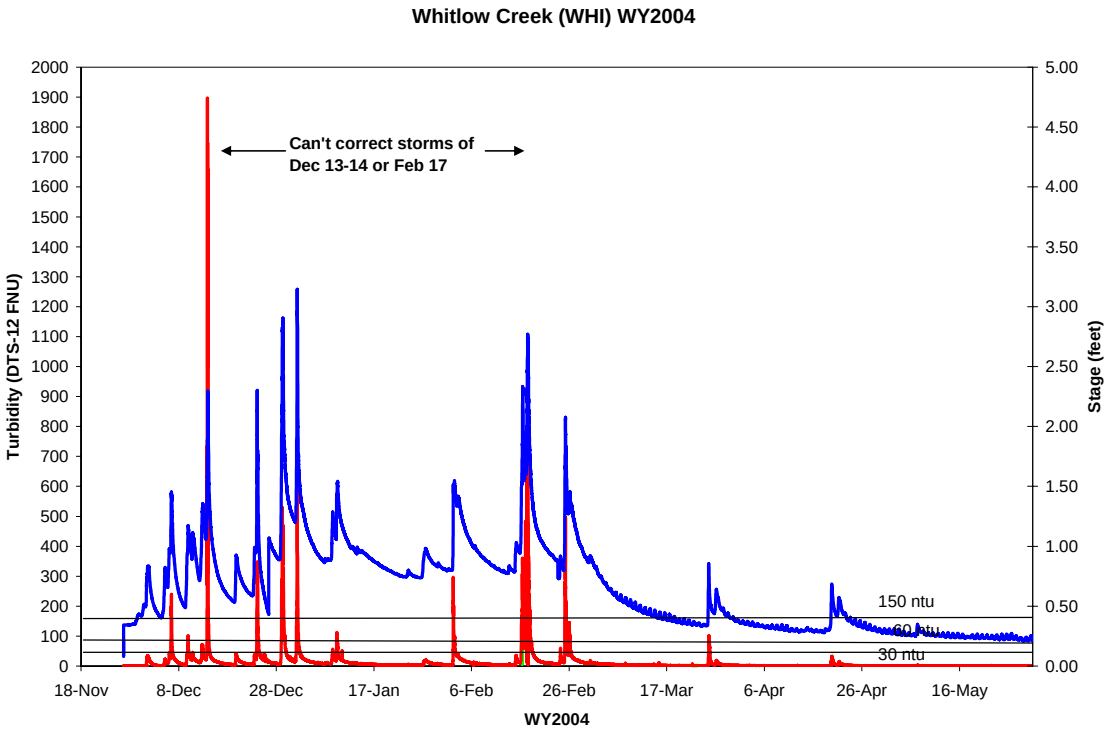


Figure 13. Whitlow Creek Turbidity 2004-2005

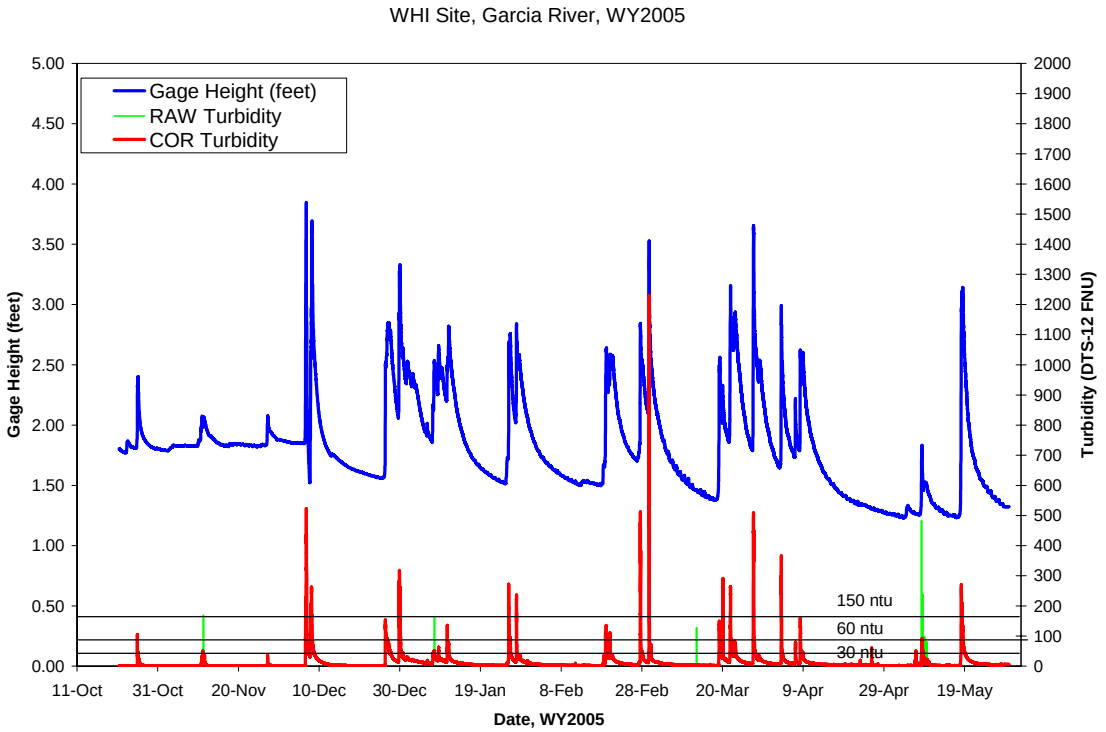


Figure 14. South Fork Turbidity 2003-2004

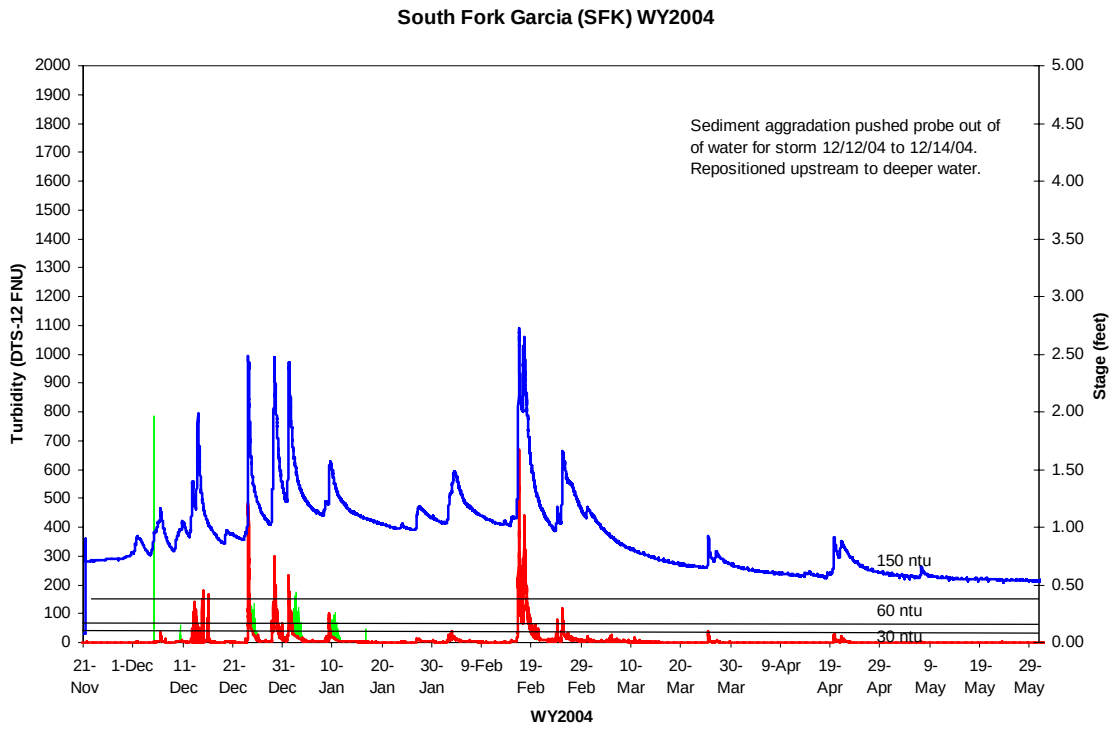


Figure 15. South Fork Turbidity 2004-2005

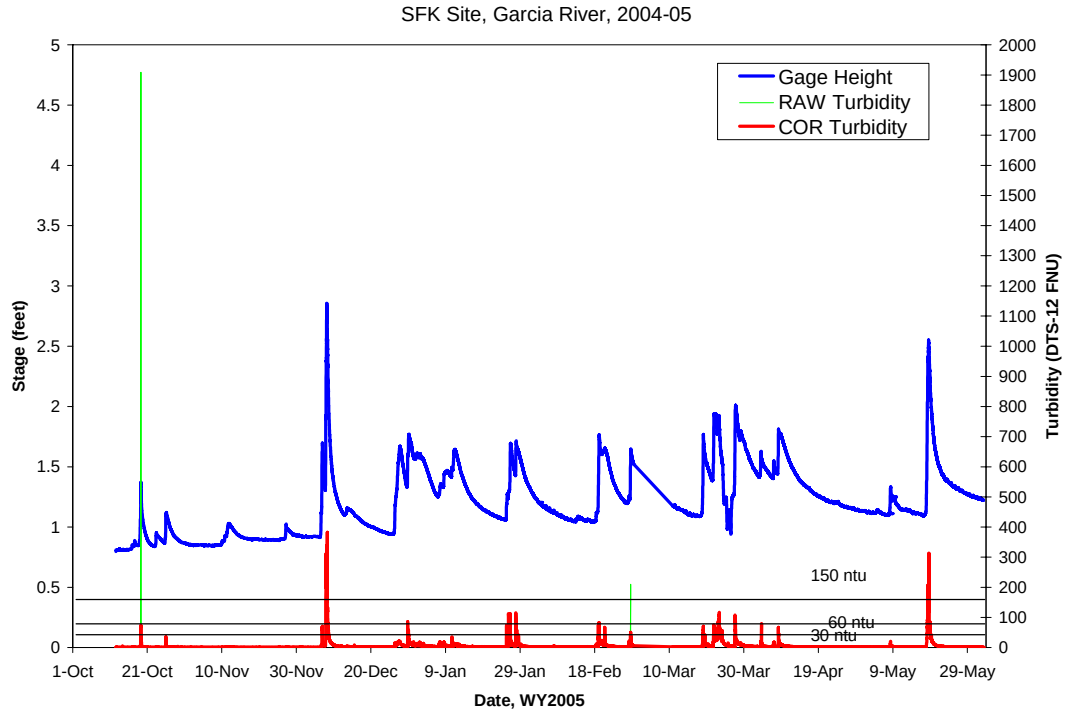
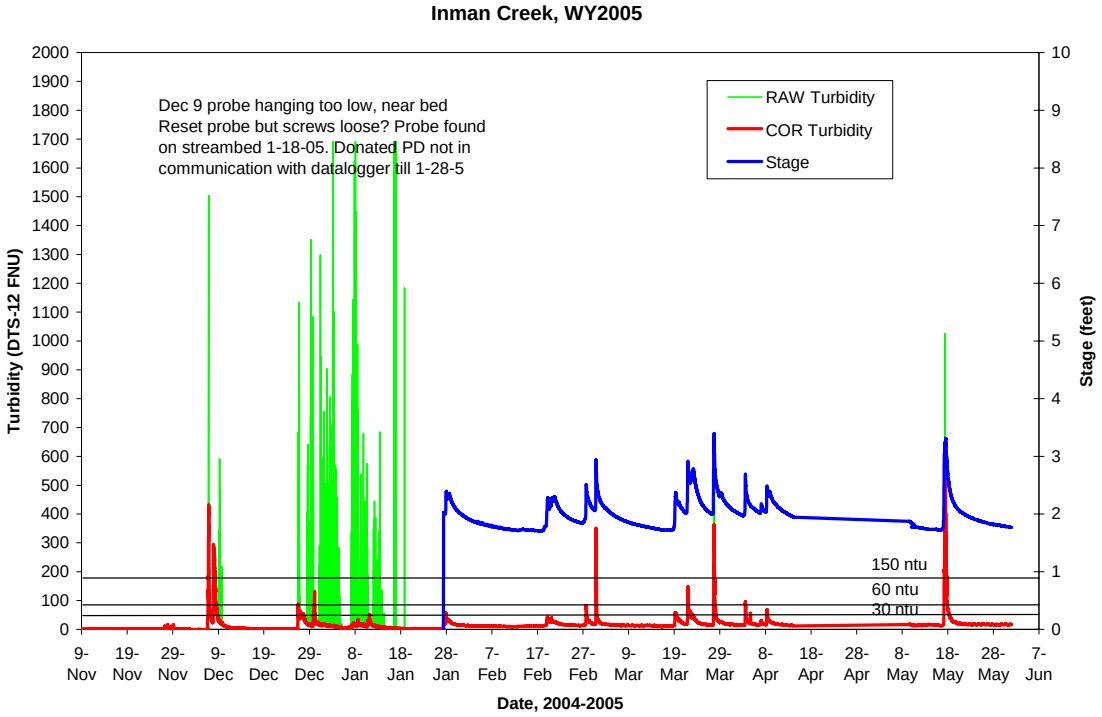


Figure 16. Inman Creek Turbidity 2004-2005



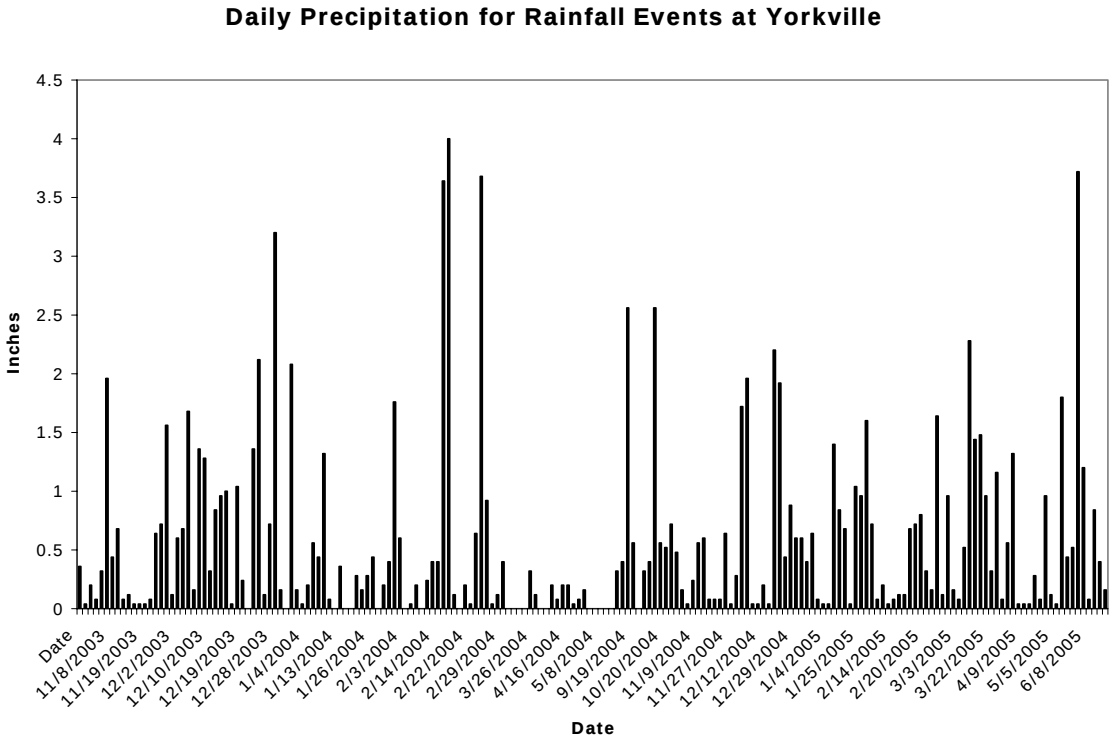
PHYSICAL FEATURES OF MONITORED GARCIA RIVER SUB BASINS

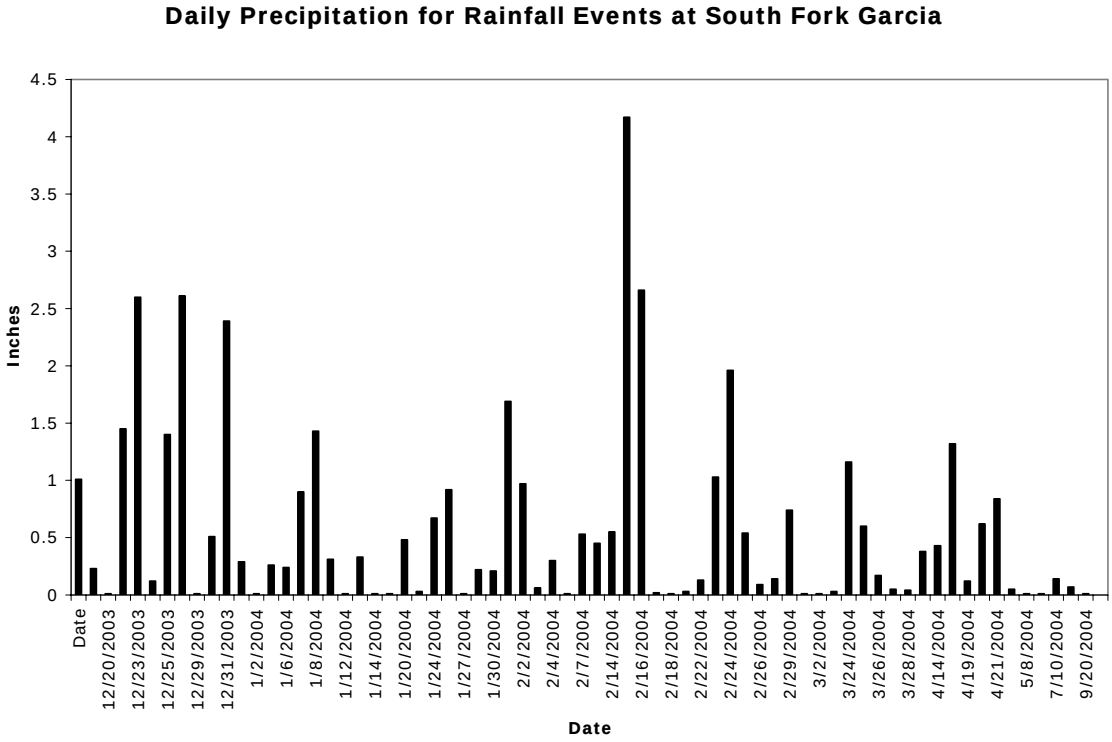
RAINFALL

No rainfall stations were installed in Garcia River watershed tributary basins. Data from the Yorkville weather station is attached, courtesy of the California Department of Water Resources' web site. This station resides in the Dry Creek watershed, and is a tributary to the Russian River. It shares a ridge with the Garcia in the upper reaches beyond Mill and Pardaloe Creeks. Precipitation information was provided from a gauge operated by Mendocino Redwood Company in the South Fork Garcia basin (see Data Appendixes). Referencing rainfall from the two extreme ends of the basin provide a context with which to make assumptions about the rainfall experienced in the individual tributaries.

Average annual precipitation from the Yorkville station is 43.5 inches based on records from 1948-1951 and from 1998-2005. During our study period above-average annual precipitation occurred in Yorkville: 60.5 inches in WY2003, 52.2 inches in WY2004, and 60 inches in WY2005 suggesting a rather wet study period. Precipitation data from South Fork station was not complete, measuring 40.8 inches between December 2003 and October 2004.

Figure 17. Rainfall Events Surrounding Garcia River Monitoring WY 04-05





LAND MANAGEMENT HISTORY IN THE GARCIA RIVER WATERSHED

The most comprehensive history of land management in the Garcia River Watershed is Monschke and Caldon's (1992) Garcia River Watershed Enhancement Plan. It includes old maps and photos, accounts of Spanish, Native American, early white settler history, a logging history, and interviews with several long-time landowners.

LEGACY CONDITIONS

Historical logging photographs reveal the extreme impacts of logging that took place, especially near mills, at the turn of the last century and through the early 1900s. Even more detrimental effects of timber harvest on instream ecology, especially in the Garcia River, occurred following World War II, as the use of tractors for timber harvest came into full swing. Erosion rates were accelerated well-beyond background levels due to extremely poor logging practices in and near stream channels. Pacific Watershed Associates estimated the rate of erosion to be 1380 tons per square mile per year in the period 1952-1997 for the Garcia River watershed (USEPA, 1998). The cumulative damage across the 1950s and into the early 1970s as a result of unregulated tractor logging, combined with erosive effects of the 1955 and 1964 record floods, had an enormous impact on the Garcia River's sediment regime. The combination of these past impacts are referred together by the term "legacy conditions." Most scientists agree that the stream channels today still reflect these legacy conditions (Knopp 1993).

Table 11. Total hours above turbidity thresholds: 30, 60, and 150 ntus Water Year 2004

Turbidity (ntu) thresholds	Garcia River Stations in Water Year 2004				
	Garcia	Mill	Pardaloe	South Fork	Whitlow
>30	759.8	207.3	205.7	203.8	343.7
>60	335.7	101.5	110.3	125.3	152.5
>150	156.8	39.5	42.2	39.8	62.8

The mainstem Garcia station consistently experienced twice as many hours over turbidity thresholds than did any tributaries, yet turbidity peaks were about the same. Elevated Garcia mainstem exposures could be a cumulative effect but certainly suspended algae is a prominent feature of a mainstem river due to direct insolation and lack of overhead canopy. The suspended algae source is consistent with the river continuum concept where insolation stimulates primary algal production in open rivers rather than the allochthenous detritus driven food web of creeks under canopy. When the turbidity lens wiper arm failed in the mainstem, the lens was quickly colonized by periphyton which supports the concept of greater algae derived turbidity in the mainstem. Conversely, wiper arm failure at Mill Creek resulted in no noticeable lens colonization.

In WY 2004, South Fork experienced the least number of hours where turbidity exceeded 30 ntu while Mill Creek experienced the least number of hours where turbidity exceeded 60 and 150 ntu.

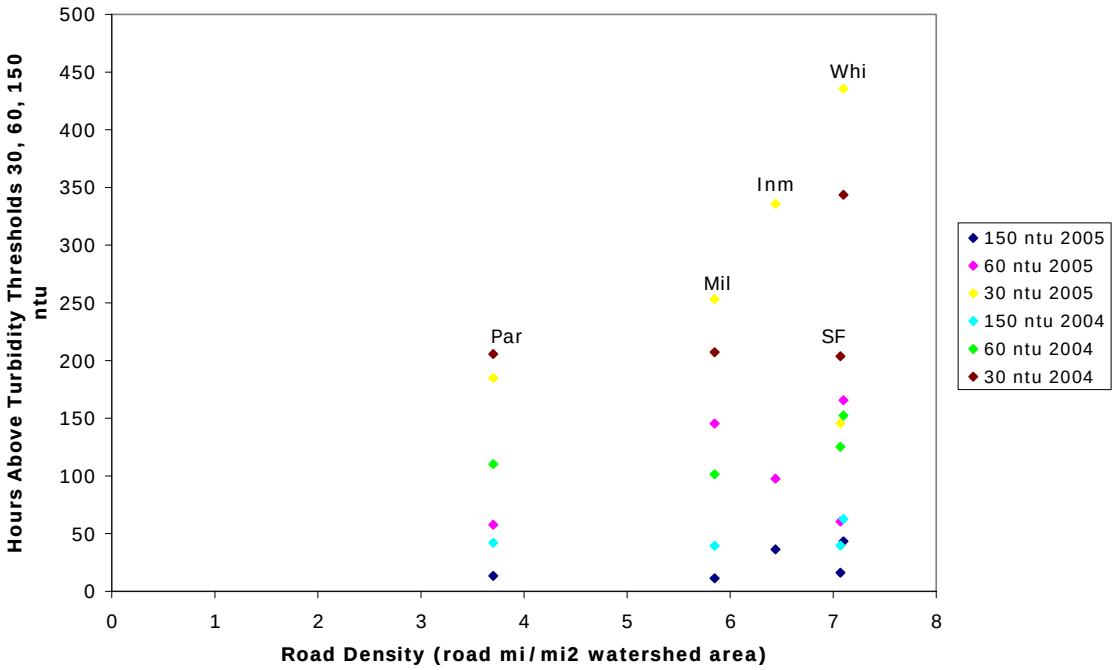
Table 12. Total hours above turbidity thresholds: 30, 60, and 150ntus Water Year 2005

Turbidity (ntu) thresholds	Garcia River Stations in Water Year 2005				
	Inman	Mill	Pardaloe	South Fork	Whitlow
>30	335.8	253.3	184.8	145.7	435.5
>60	97.7	145.5	57.8	60.5	165.7
>150	36.5	11.3	13.5	16.2	43.5

In 2005, South Fork experienced the least number of hours where turbidity exceeded 30 ntu, Pardaloe Creek experienced the least number of hours where turbidity exceeded 60 ntu, and Mill Creek experienced the least number of hours where turbidity exceeded 150 ntu.

Pardaloe Creek Watershed experienced the lowest Road Density at 4 miles of road per square mile of watershed area while the other watersheds experienced road densities of between 5.5 and 7.5. Pardaloe Creek also experienced the lowest Timber Harvest Intensity. South Fork experienced slightly more Timber Harvest Intensity than Pardaloe. Mill experienced a medium level of road density and Timber Harvest Intensity. Whitlow and Inman experienced relatively intense Timber Harvest Intensity.

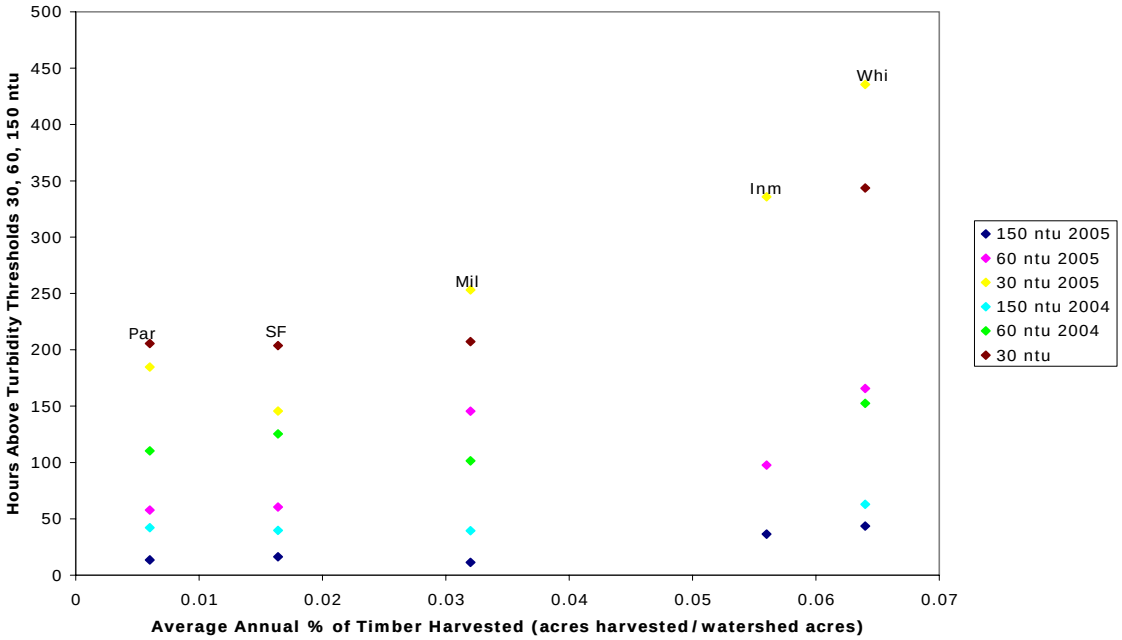
Figure 18. Hours Above Turbidity Thresholds vs. Road Density



There seems to be a positive linear relationship between Hours above Turbidity Thresholds (tables 11 and 12) and both Road Density (Figure 18) and Timber Harvest Intensity (Figure 19). The exception to this trend is at South Fork where road density is

moderately high relative to the other basins (over 7 miles per square mile of watershed area) yet hours sustained above turbidity thresholds were relatively low.

Figure 19. Hours Above Turbidity Thresholds vs. Timber Harvest Intensity



The storms that produced the highest stages did not necessarily produce the highest turbidity. For the biggest storms of each water year, we pulled the highest turbidity experienced by each tributary. These are presented in Table 13.

Table 13. Largest Storms in the study period over ½ Bankfull by Date and Turbidity (ntu)

Storm Date	South Fork	Pardaloe	Mill Creek	Whitlow Cr.	Inman Cr.
12-11-2003	7	70	105	102	NA
12-14-2003	180	NA	982	NA	NA
12-24-2003	485	NA	158	495	NA
12-29-2003	298	NA	1792	529	NA
1-1-2004	229	791	332	582	NA
2-16-2004	669	NA	563	483	NA
2-25-2004	114	443	349	495	NA
12-8-2004	381	513	459	523	NA
12-26-2004	86	67	132	318	NA
1-11-2005	34	84	68	136	NA
1-29-2005	116	203	436	272	59
3-1-2005	50	NA	330	1229	351
3-22-2005	117	31	155	291	148
3-27-2005	99	188	135	509	364
5-17-2005	298	48	138	264	611
Average ntu	*210.8*	*221.6*	*383.3*	*415.2*	*255.5*

In both 2004 and 2005 South Fork experienced the lowest average peak turbidity during storms, followed by Pardaloe. Figures 20 and 21 compare these average peak turbidities with Road Density and Timber Harvest Intensity. Again, South Fork has a relatively high density of roads yet has lower peak turbidity.

Figure 20. Average Peak Turbidity vs. Road Density

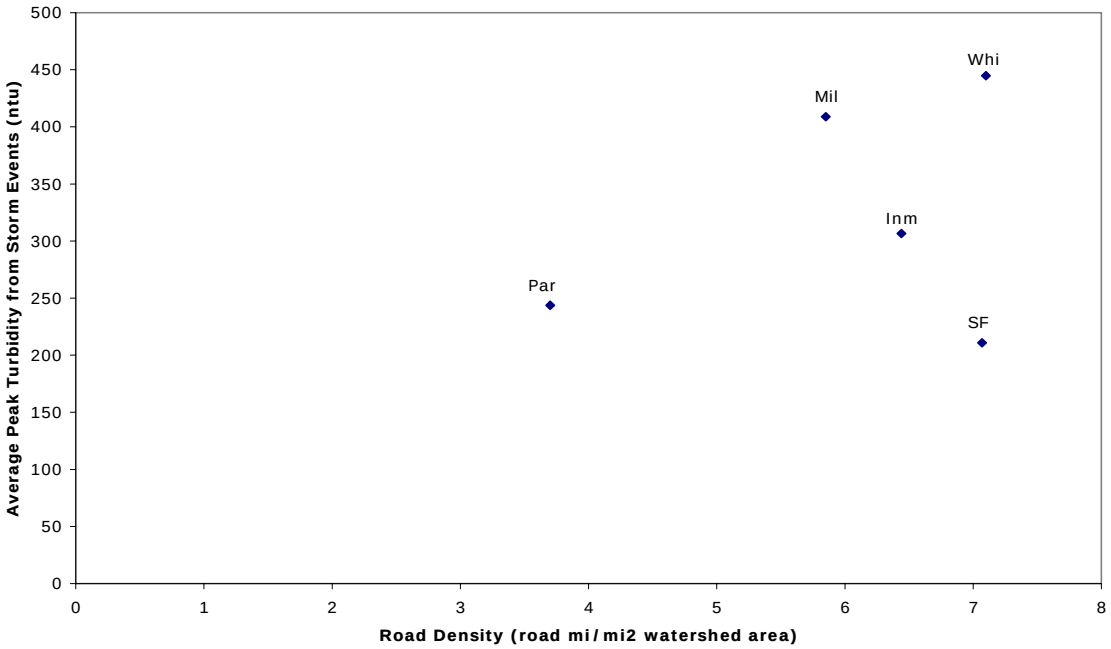
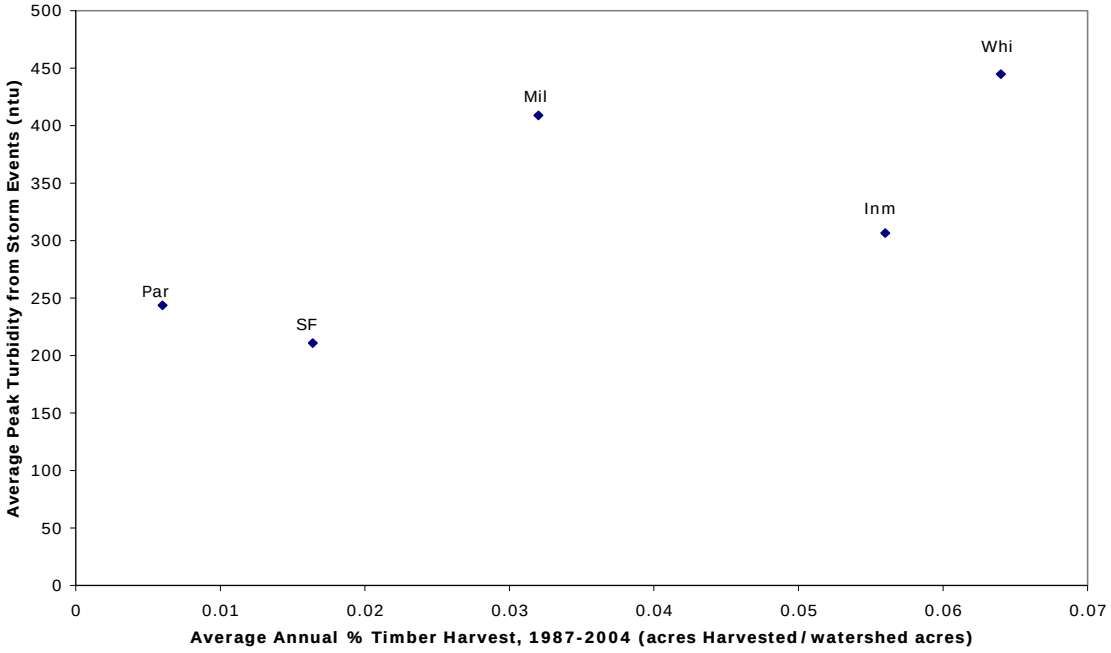


Figure 21. Average Peak Turbidity vs Timber Harvest Intensity



LAND USE IMPACTS VERSUS NATURAL VARIATIONS

A description of land uses that may have contributed to current instream conditions is provided below for each tributary watershed. It is understood that current conditions are a result of interacting watershed –related parameters, including precipitation patterns, geology, vegetation, and soil types, which vary naturally. Therefore, variation in instream conditions is a constant in watershed science that must be expected, tolerated, and embraced. This broad spectrum of variation could be used to explain or mask virtually any instream conditions. However, we hope to pull back the curtain of natural variation on the question of whether there is a measurable difference in spawning gravel quality or water clarity after road based erosion control restoration based on the data collected by this project. In doing this, we are looking directly at two types of land uses: restoration and disturbance.

SUB WATERSHED RESTORATION

Support for restoration of salmon bearing watersheds and funds for granting agencies to implement restoration projects ultimately comes from taxpayers. Politicians who bring forth the spending bills that support watershed restoration are looking for evidence that watershed restoration can be used effectively to repair critical conditions in salmon bearing streams to increase their productivity.

South Fork Garcia River

Craig Bell, active Garcia River Coordinator, was pivotal in the restoration of the South Fork Garcia tributary on property owned and managed by Mendocino Redwood Company. He summarized the watershed and instream restoration implemented there as follows (Bell, personal communication, 2004):

> *"In 1998 the South Fork Garcia River was chosen as the trial project for Trout Unlimited's North Coast Coho Project. The work involved a comprehensive assessment and implementation plan developed by Pacific Watershed Associates for upslope road-based erosion control and drainage improvements as well as the design and implementation of instream installation of woody debris as fish habitat structures by Craig Bell and Trout Unlimited. The upslope assessment mapped 148 individual sites had the risk of delivering sediment to stream channels, along 22 road segments totaling nearly 25 miles. The assessment documented 39,700 cubic yards of future sediment delivery if no efforts were made to correct road conditions.*
>
> *In 1999 TU submitted and was awarded a DFG grant to treat 8.75 miles in length (36%) of the total inventoried miles), 82 of the inventoried sites (55% of the total), and prevent over 28,000 cubic yards of sediment delivery (72% of the estimated total delivery). In addition ten instream habitat sites were funded for implementation. The work was carried out in 2000 and 2001.*

In 2005 Trout Unlimited in partnership with Landowner Mendocino Redwood Company has submitted a grant to DFG for implementation of measures to prevent the remaining 25% of the controllable sediment delivery from entering the South Fork Garcia. If funded, erosion control work is expected to be carried out in the summer of 2006. Mendocino Redwood Company owns virtually all of the South Fork Garcia sub basin. Ongoing monitoring is important to answer the question of response time to comprehensive upslope erosion control measures"

.

Inman Creek

Because Inman Creek has been an important tributary for reproduction of anadromous salmonids, The Conservation Fund and Trout Unlimited developed a grant proposal to the California Department of Fish and Game to prepare a subwatershed-wide roads assessment by Pacific Watershed Associates for the Inman Creek subwatershed. If granted, implementation is expected as early as 2006.

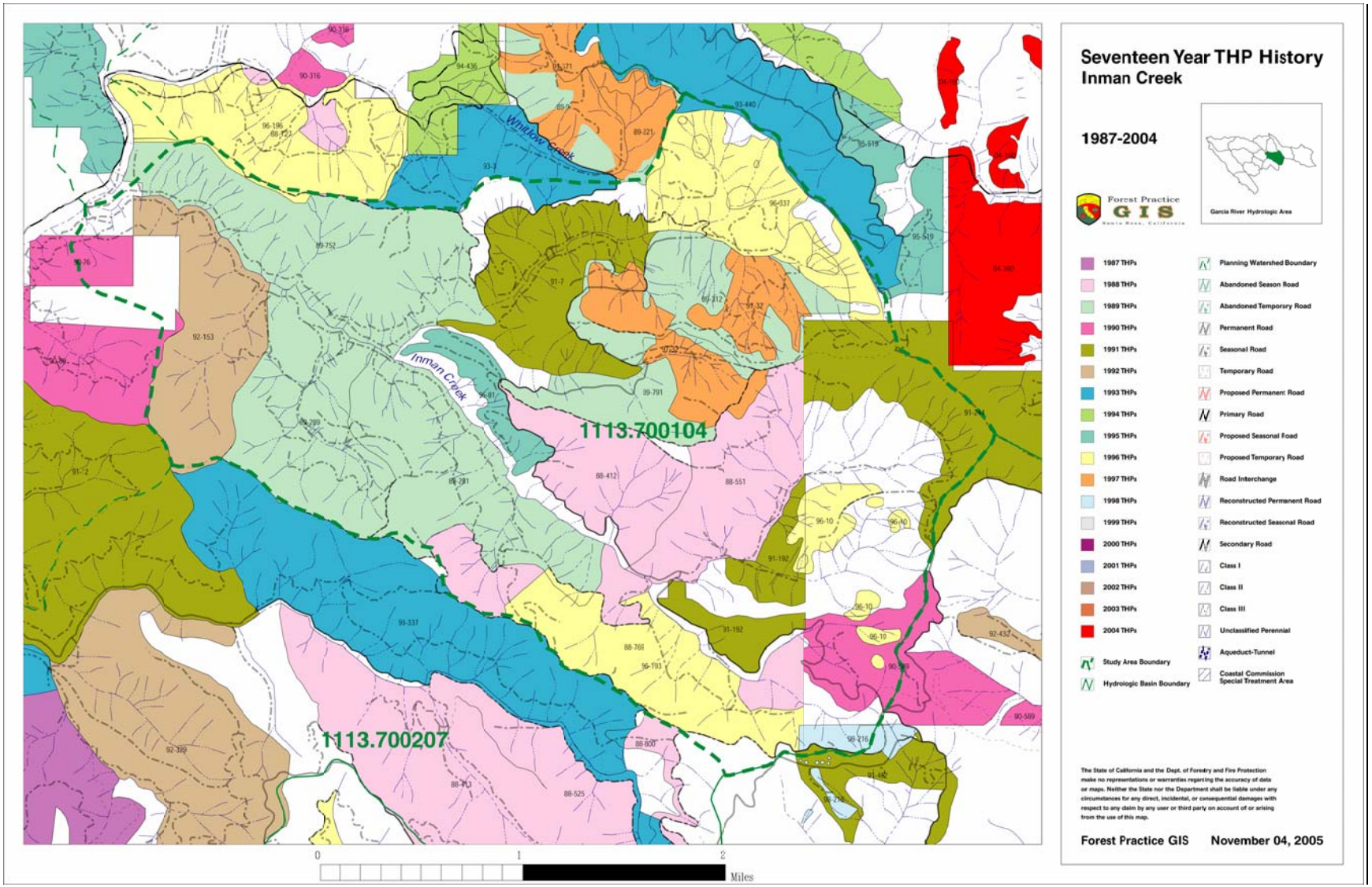
SUB WATERSHED TIMBER HARVEST AND ROAD DENSITY DISTURBANCES

Documenting disturbance is a broad goal that changes from year to year, place to place, and at the discretion of the landowner. As a result, we are documenting just three land use disturbance measures that are publicly available through CDF and have been used by watershed scientists in the past to gauge watershed disturbance. These are: percent of watershed acres of timber harvested in a 10- year period (Trush 2005), percent of watershed area harvested annually (Klein 2003), and road density expressed as miles of road per square mile of drainage area (Trush, 2005; Klein, 2003). For our study we received GIS services provided by Ms. Suzanne Lang at CDF's Santa Rosa office, who mapped timber harvest history and road density from1987-2004 (see figures 18-27 supplied in hard copy).

Road density (miles of road per square mile of watershed area) and timber harvest intensity expressed as a percentage of sub- watershed harvested in a 1 year or 10 year period are units of land use that may influence changes in water clarity (Klein 2003). CDF provided a 17-year timber harvest history map showing 1987-2004 THPs, complete with roads, for use in our analysis (figures 18-27). Two sets of maps were provided: THPs color-coded by year and THPs color coded by silvicultural method. The "No Harvest" portion of the map is white and stands out in contrast to the areas that have been harvested, which are represented in color. White areas of the Pardaloe and South Fork dominate maps indicating a low rate of harvest within the 17-year period compared to the other basins. Based on this information, the intensity of timber harvest was ranked qualitatively with a number varying from 1 to 5, with 1 being the lowest harvest intensity and 5 being the highest.

Table 14. Road Density, Timber Harvest History 1987-2004 (data courtesy CDF)

Stream	PAR	SF	MIL	WHI	INM
Drainage Area - acres	5626	5598	4846	1221	5481
Road Density mi/mi^2	3.70	7.07	5.85	7.09	6.44
THP 1987 a	21.56	54.4	315.68	0	0
THP 1988 a	0	627.15	0	272	1019.83
THP 1989 a	0	224.31	13.07	217.71	1952
THP 1990 a	0	4.27	0	42.98	50.76
THP 1991 a	27.29	0	177.19	7.88	714.9
THP 1992 a	0	0	0	42.52	329.23
THP 1993 a	0	0	139.75	182.78	54.15
THP 1994 a	0	63.45	192.11	137.12	83.12
THP 1995 a	0	0	0	0	0
THP 1996 a	175.32	0	720.84	256.59	746.19
THP 1997 a	0	0	0	172.95	259.78
THP 1998 a	3.62	143.35	344	0	28.15
THP 1999 a	0	66.88	0	0	0
THP 2000 a	187.39	0	351.91	0	0
THP 2001 a	0	126.68	171.92	0	0
THP 2002 a	0	0	0	0	0
THP 2003 a	0	0	0	0	0
THP 2004 a	164.32	250.94	191.59	0	0
Total acreage harvested in 17 years	579.5	1561.43	2618.06	1332.53	5238.11
proportion of watershed area annually harvested (17 year avg)	0.0061 = 0.61%	0.0164 = 1.64%	0.0318 = 3.18%	0.0642 = 6.42%	0.0562 = 5.62%


Seventeen Year THP History
Inman Creek
1987-2004
Forest Practice GIS
Garcia River Hydrologic Area
1987 THPs
1988 THPs
1989 THPs
1990 THPs
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2003 THPs
2004 THPs
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Season Road
Abandoned Temporary Road
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporary Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Seasonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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Forest Practice GIS November 04, 2005
Inman Creek
Window Creek
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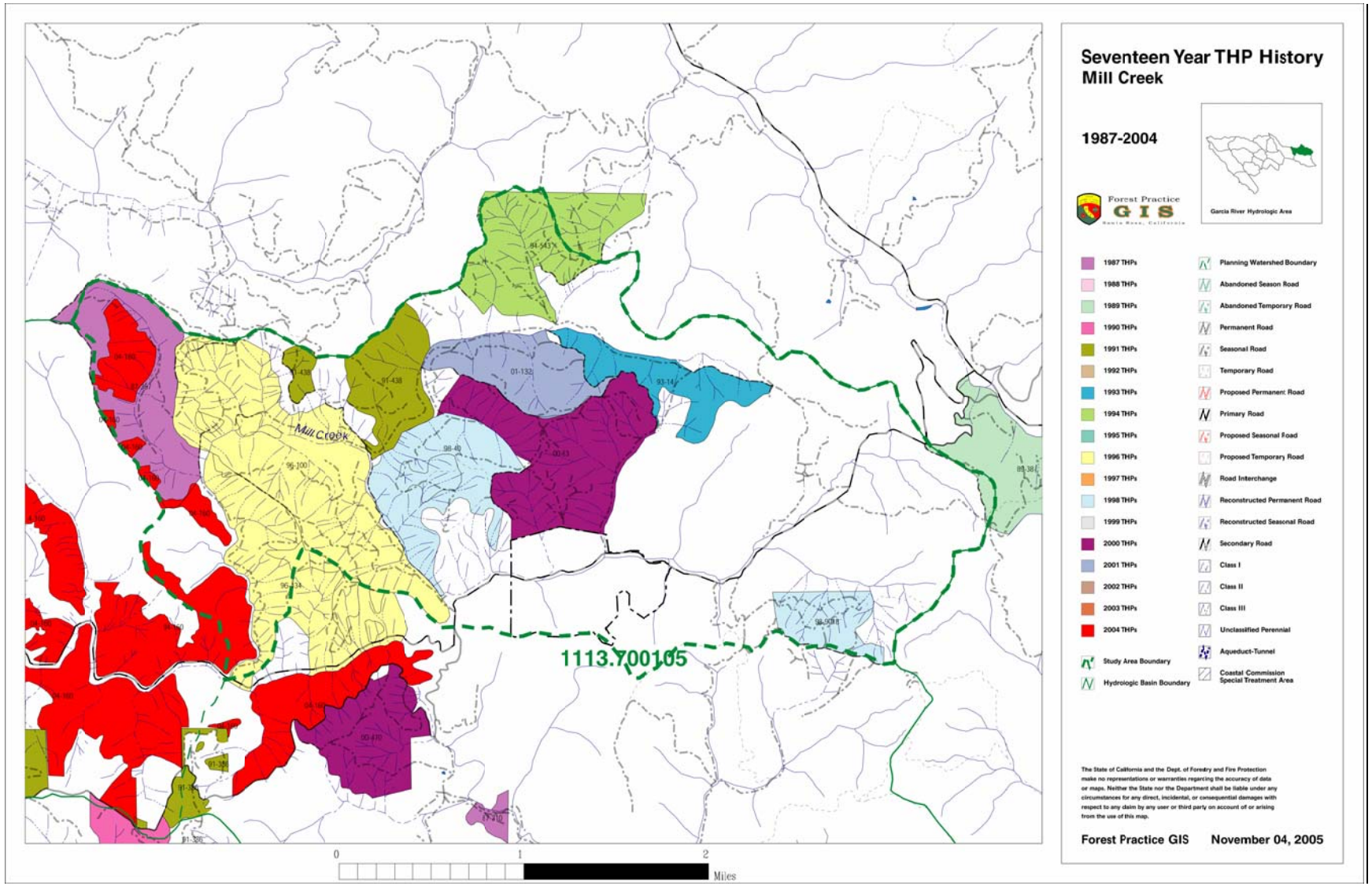
1113.700207
0
1
2
Miles


Seventeen Year THP History
Mill Creek
1987-2004
Forest Practice GIS
Santa Rosa, California
Garcia River Hydrologic Area
1987 THPs
1988 THPs
1989 THPs
1990 THPs
1991 THPs
1992 THPs
1993 THPs
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2002 THPs
2003 THPs
2004 THPs
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Season Road
Abandoned Temporary Road
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporary Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Seasonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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November 04, 2005
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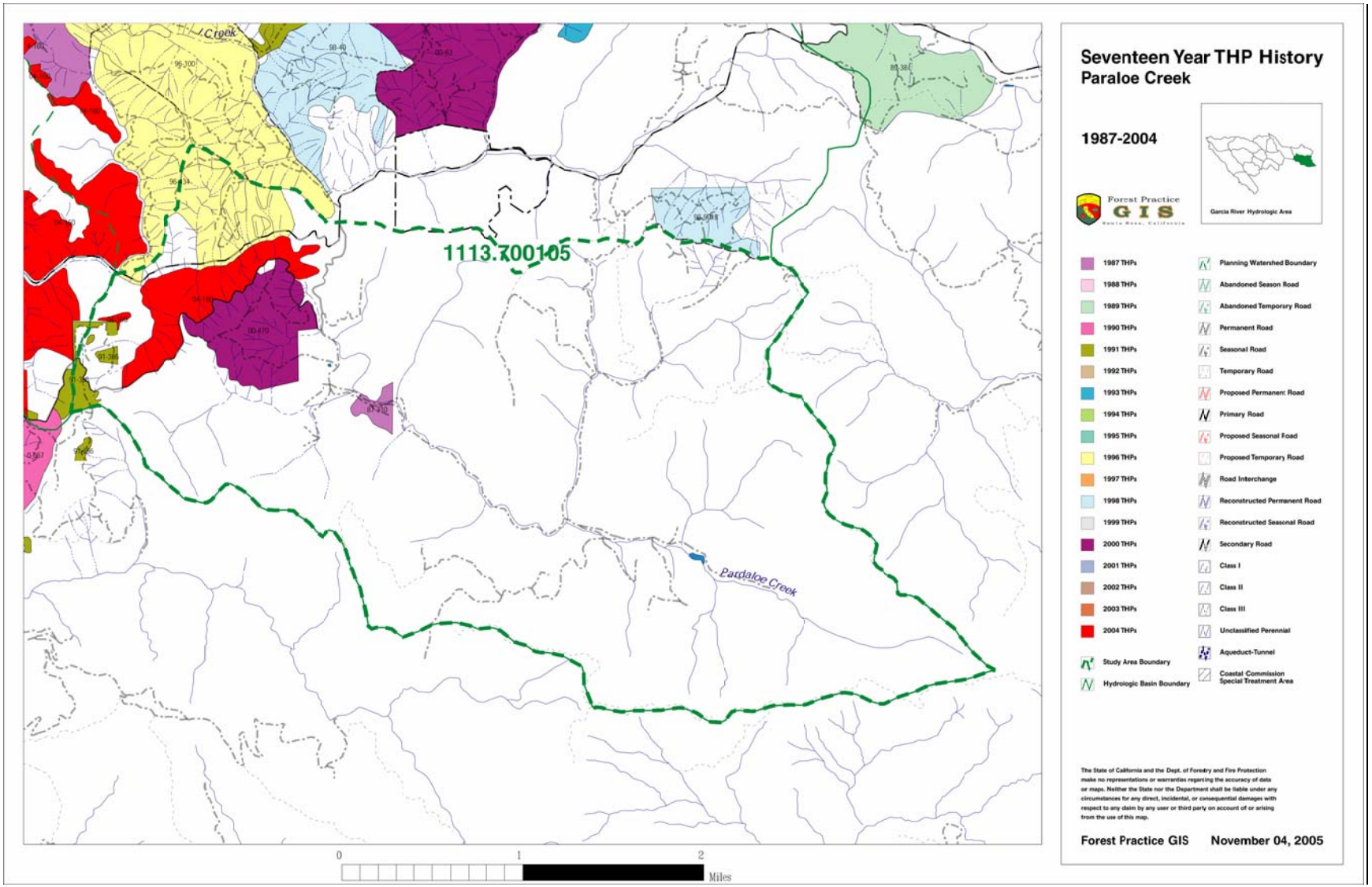
2
Miles


Seventeen Year THP History
Paraloe Creek
1987-2004
Forest Practice GIS
Garcia River Hydrologic Area
1113.700105
Paraloe Creek
1987 THPs
1988 THPs
1989 THPs
1990 THPs
1991 THPs
1992 THPs
1993 THPs
1994 THPs
1995 THPs
1996 THPs
1997 THPs
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1999 THPs
2000 THPs
2001 THPs
2002 THPs
2003 THPs
2004 THPs
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Season Road
Abandoned Temporary Road
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporary Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Seasonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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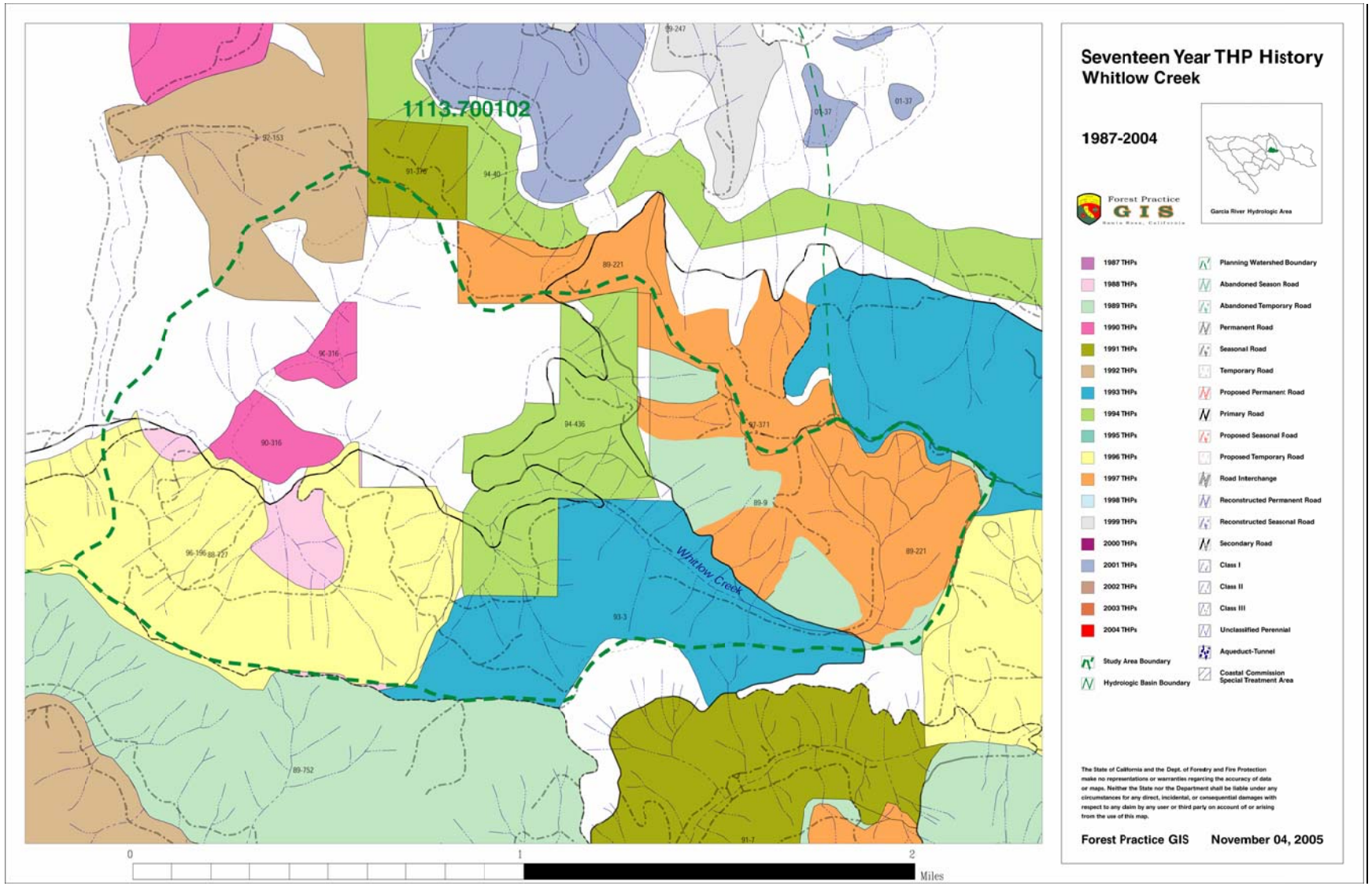
Forest Practice GIS November 04, 2005
0
1
2
Miles


1113.700102
Whitlow Creek
92-153
91-196
94-40
89-247
01-37
01-37
89-221
90-316
90-316
94-436
97-371
89-9
96-396
88-727
89-221
93-3
89-752
91-7
0
1
2
Miles
Seventeen Year THP History
Whitlow Creek
1987-2004
Forest Practice
GIS
Santa Rosa, California
Garcia River Hydrologic Area
1987 THPs
1988 THPs
1989 THPs
1990 THPs
1991 THPs
1992 THPs
1993 THPs
1994 THPs
1995 THPs
1996 THPs
1997 THPs
1998 THPs
1999 THPs
2000 THPs
2001 THPs
2002 THPs
2003 THPs
2004 THPs
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Season Road
Abandoned Temporary Road
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporary Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Seasonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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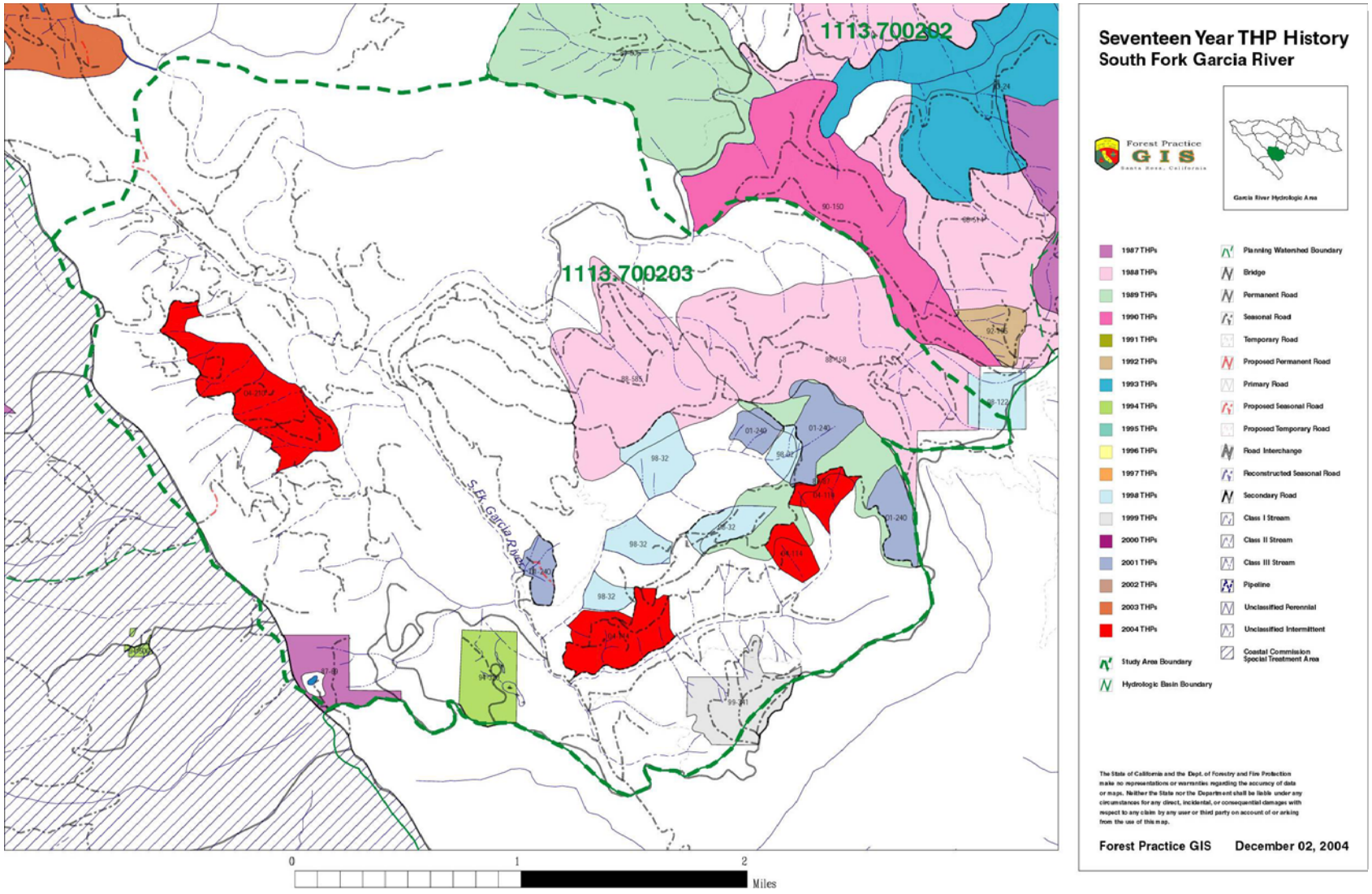
Forest Practice GIS
November 04, 2005


1113.700202
1113.700203
S.Fk. Garcia River
90-150
88-458
88-585
98-32
01-240
04-114
04-114
04-114
99-141
92-146
98-122
01-24
0
1
2
Miles
Seventeen Year THP History
South Fork Garcia River
Forest Practice
GIS
Santa Rosa, California
Garcia River Hydrologic Area
1987 THPs
1988 THPs
1989 THPs
1990 THPs
1991 THPs
1992 THPs
1993 THPs
1994 THPs
1995 THPs
1996 THPs
1997 THPs
1998 THPs
1999 THPs
2000 THPs
2001 THPs
2002 THPs
2003 THPs
2004 THPs
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Bridge
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporary Road
Road Interchange
Reconstructed Seasonal Road
Secondary Road
Class I Stream
Class II Stream
Class III Stream
Pipeline
Unclassified Perennial
Unclassified Intermittent
Coastal Commission Special Treatment Area
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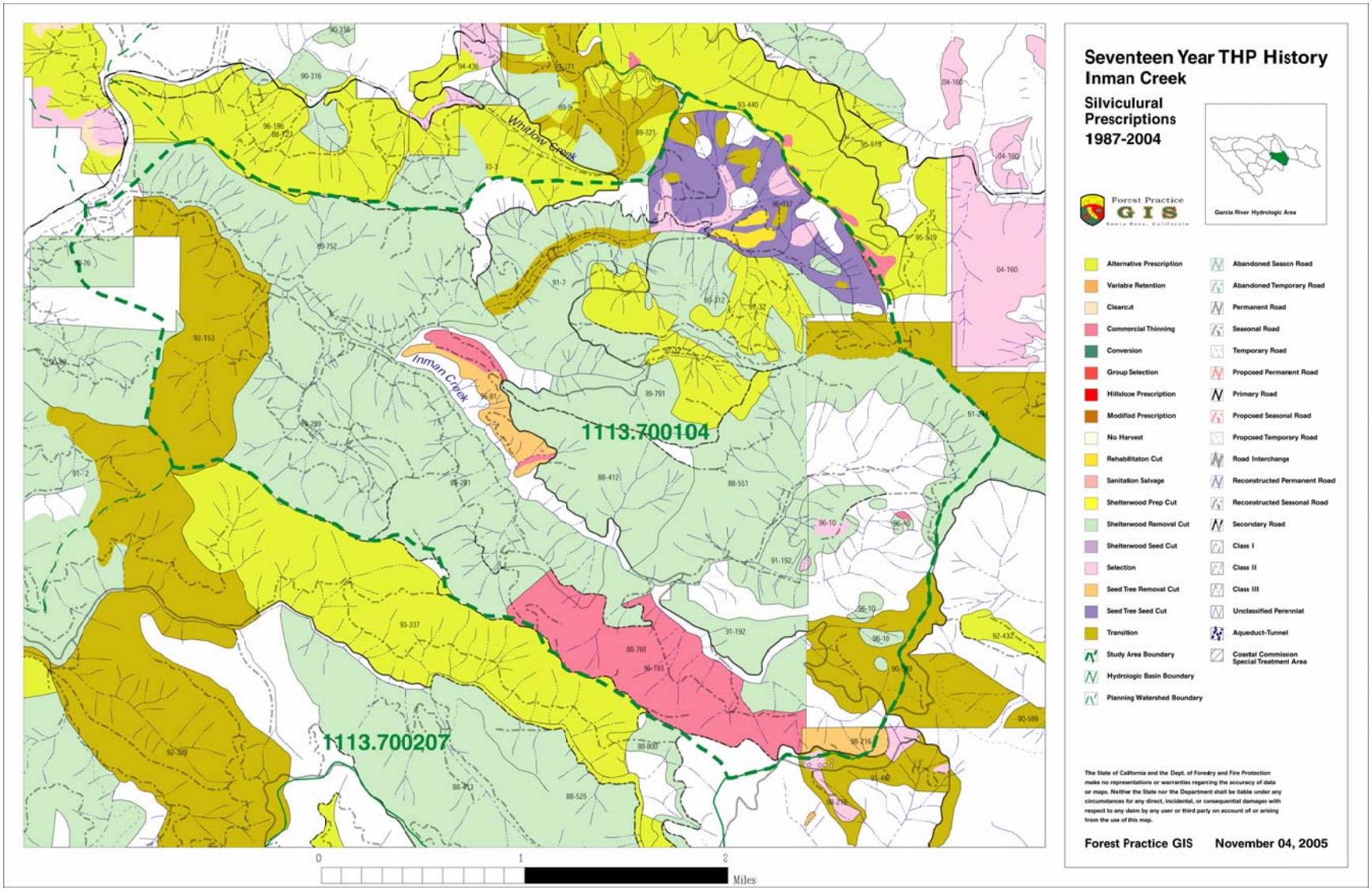
Forest Practice GIS
December 02, 2004


Seventeen Year THP History
Inman Creek
Silvicultural Prescriptions
1987-2004
Garcia River Hydrologic Area
Forest Practice GIS
Alternative Prescription
Variable Retention
Clearcut
Commercial Thinning
Conversion
Group Selection
Hillslope Prescription
Modified Prescription
No Harvest
Rehabilitaton Cut
Sanitation Salvage
Shelterwood Prep Cut
Shelterwood Removal Cut
Shelterwood Seed Cut
Selection
Seed Tree Removal Cut
Seed Tree Seed Cut
Transition
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Seasn Road
Abandoned Temporary Road
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporsry Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Sesonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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Forest Practice GIS November 04, 2005
Whitlow Creek
Inman Creek
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1113.700207
0
1
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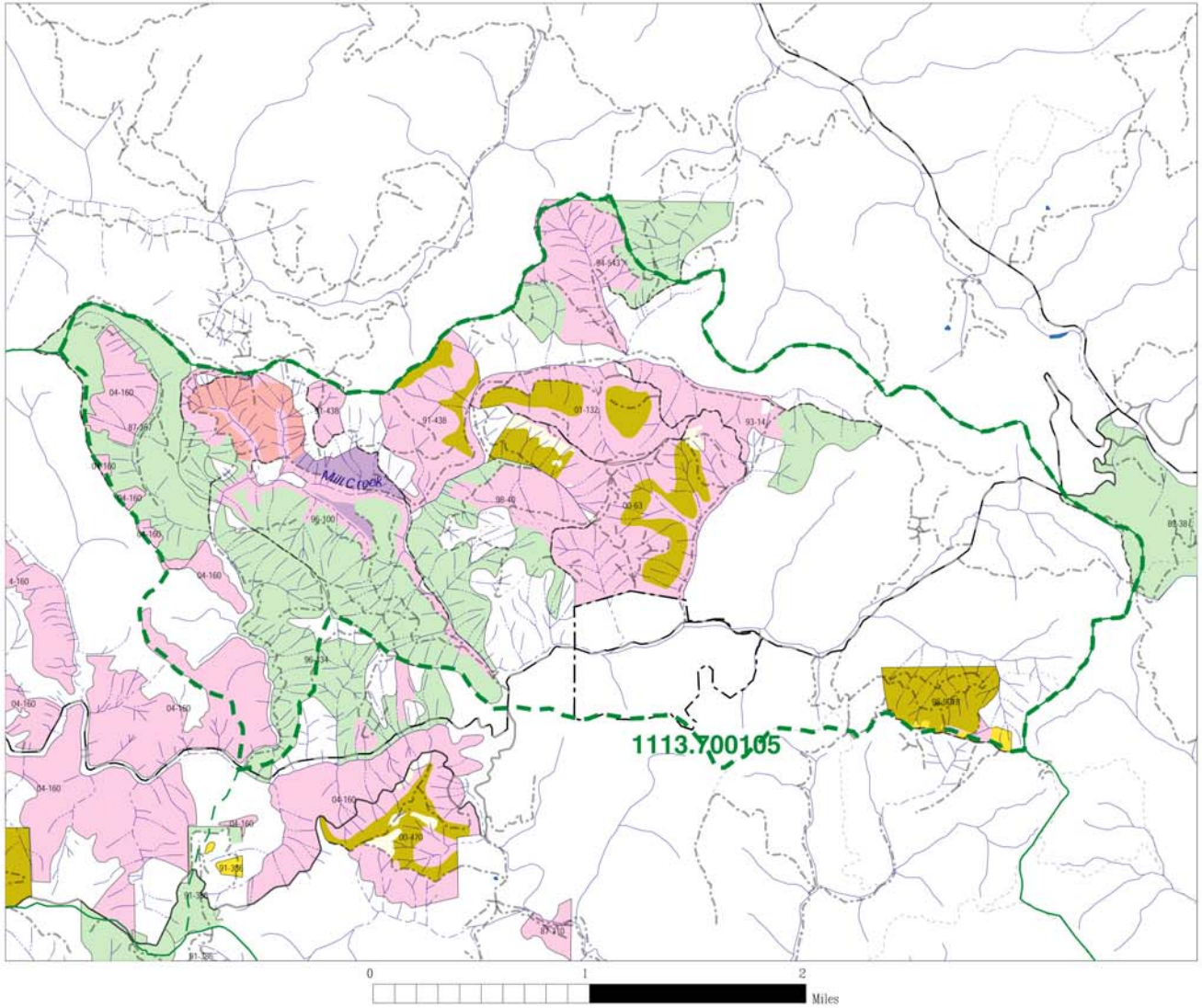
Miles



Seventeen Year THP History
Mill Creek

Silvicultural Prescriptions 1987-2004

Forest Practice GIS
Santa Rosa, California

- Alternative Prescription
- Variable Retention
- Clearcut
- Commercial Thinning
- Conversion
- Group Selection
- Hillslope Prescription
- Modified Prescription
- No Harvest
- Rehabilitaton Cut
- Sanitation Salvage
- Shelterwood Prep Cut
- Shelterwood Removal Cut
- Shelterwood Seed Cut
- Selection
- Seed Tree Removal Cut
- Seed Tree Seed Cut
- Transition
- Study Area Boundary
- Hydrologic Basin Boundary
- Planning Watershed Boundary
- Abandoned Season Road
- Abandoned Temporary Road
- Permanent Road
- Seasonal Road
- Temporary Road
- Proposed Permanent Road
- Primary Road
- Proposed Seasonal Road
- Proposed Temporary Road
- Road Interchange
- Reconstructed Permanent Road
- Reconstructed Seasonal Road
- Secondary Road
- Class I
- Class II
- Class III
- Unclassified Perennial
- Aqueduct-Tunnel
- Coastal Commission Special Treatment Area

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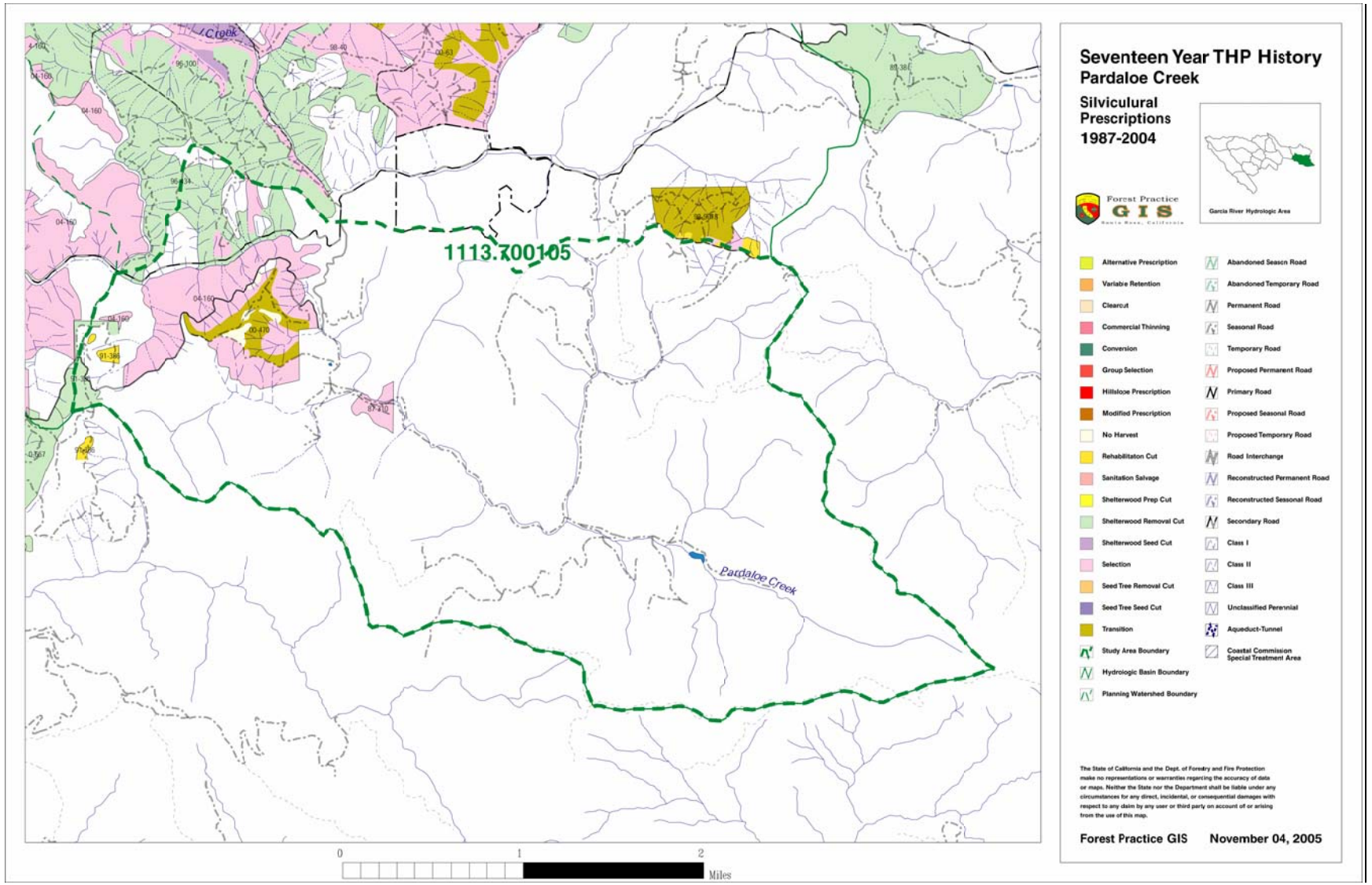
Forest Practice GIS **November 04, 2005**


Seventeen Year THP History
Pardaloe Creek
Silvicultural Prescriptions
1987-2004
Forest Practice GIS
Santa Rosa, California
Garcia River Hydrologic Area
1113.700105
Pardaloe Creek
Alternative Prescription
Variable Retention
Clearcut
Commercial Thinning
Conversion
Group Selection
Hillslope Prescription
Modified Prescription
No Harvest
Rehabilitaton Cut
Sanitation Salvage
Shelterwood Prep Cut
Shelterwood Removal Cut
Shelterwood Seed Cut
Selection
Seed Tree Removal Cut
Seed Tree Seed Cut
Transition
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Seasonal Road
Abandoned Temporary Road
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporary Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Seasonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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Forest Practice GIS
November 04, 2005
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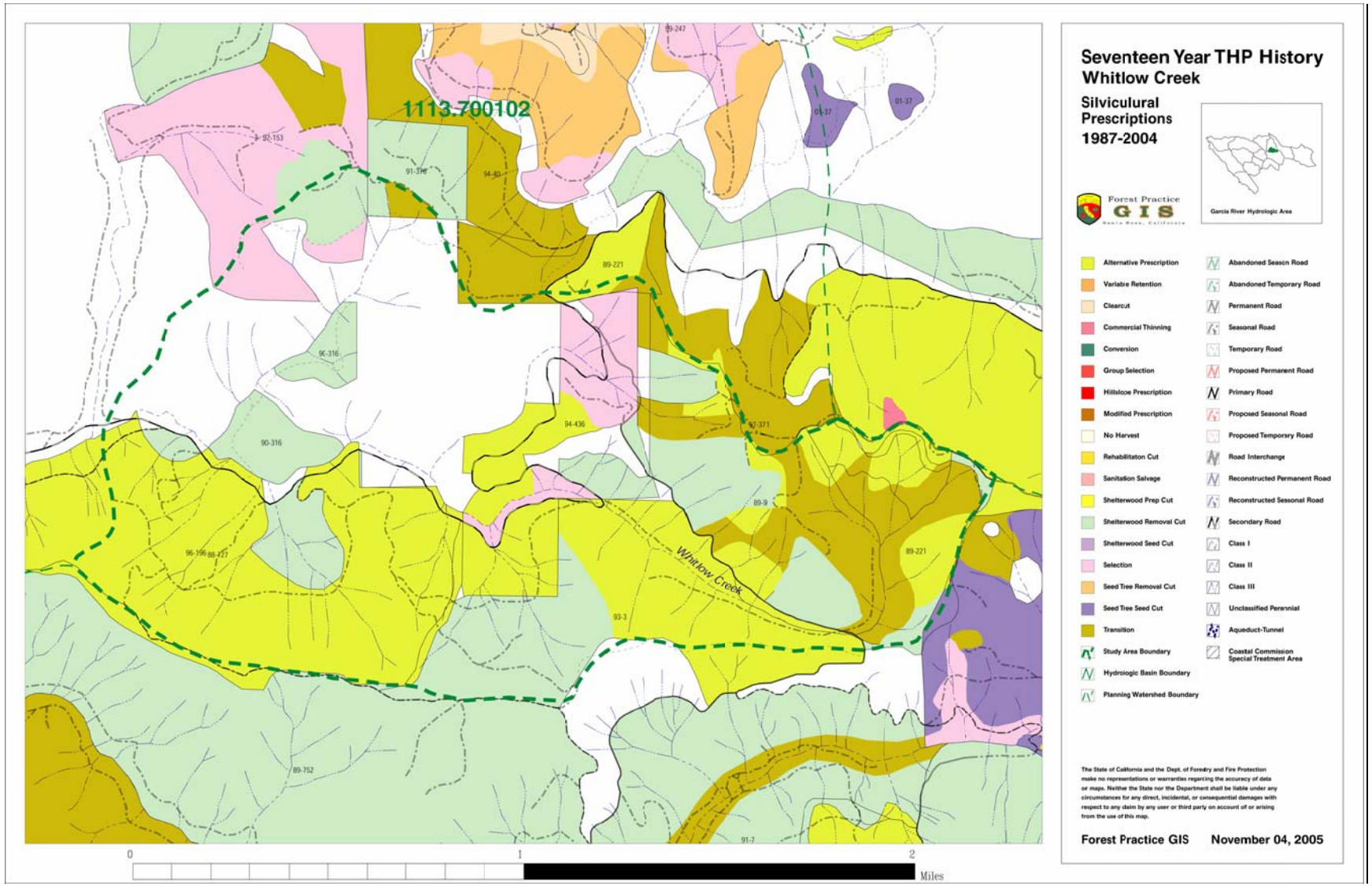
Miles


1113.700102
Whitlow Creek
92-153
91-316
94-40
89-247
01-37
01-37
89-221
96-316
90-316
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97-371
89-9
89-221
96-396
88-727
93-3
89-752
91-7
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Miles
Seventeen Year THP History
Whitlow Creek
Silvicultural Prescriptions
1987-2004
Garcia River Hydrologic Area
Forest Practice GIS
Santa Rosa, California
Alternative Prescription
Variable Retention
Clearcut
Commercial Thinning
Conversion
Group Selection
Hillslope Prescription
Modified Prescription
No Harvest
Rehabilitaton Cut
Sanitation Salvage
Shelterwood Prep Cut
Shelterwood Removal Cut
Shelterwood Seed Cut
Selection
Seed Tree Removal Cut
Seed Tree Seed Cut
Transition
Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Seasn Road
Abandoned Temporary Road
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Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporsry Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Sesonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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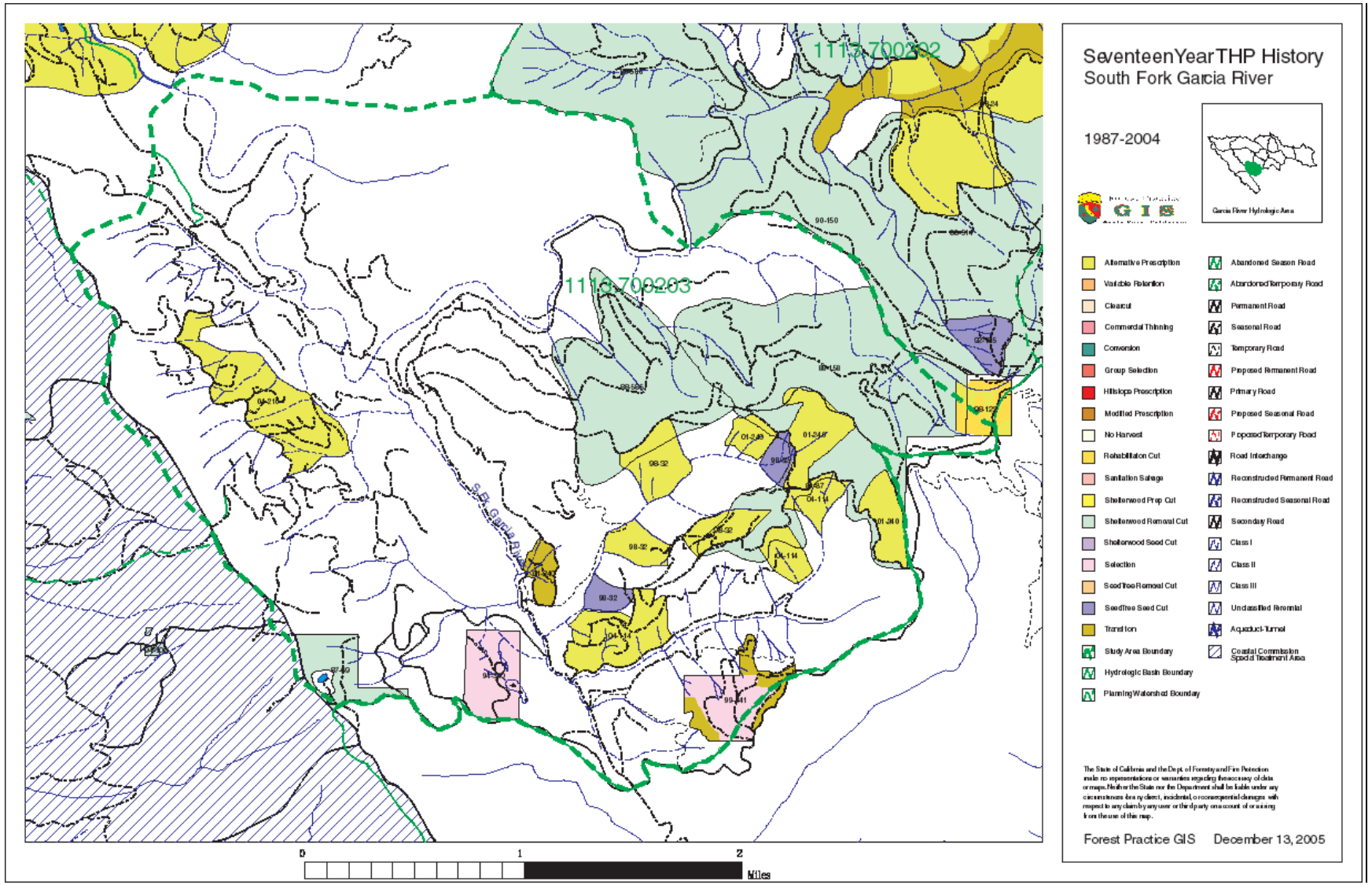
Forest Practice GIS
November 04, 2005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SeventeenYearTHP History
South Fork Garcia River
1987-2004
Garcia River Hydrologic Area
Alternative Prescription
Variable Retention
Clearcut
Commercial Thinning
Conversion
Group Selection
Hillslope Prescription
Modified Prescription
No Harvest
Rehabilitation Cut
Sanitation Salvage
Shelterwood Prep Cut
Shelterwood Removal Cut
Shelterwood Seed Cut
Selection
SeedTree Removal Cut
SeedTree Seed Cut
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Study Area Boundary
Hydrologic Basin Boundary
Planning Watershed Boundary
Abandoned Seasonal Road
Abandoned Temporary Road
Permanent Road
Seasonal Road
Temporary Road
Proposed Permanent Road
Primary Road
Proposed Seasonal Road
Proposed Temporary Road
Road Interchange
Reconstructed Permanent Road
Reconstructed Seasonal Road
Secondary Road
Class I
Class II
Class III
Unclassified Perennial
Aqueduct-Tunnel
Coastal Commission Special Treatment Area
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Forest Practice GIS
December 13, 2005
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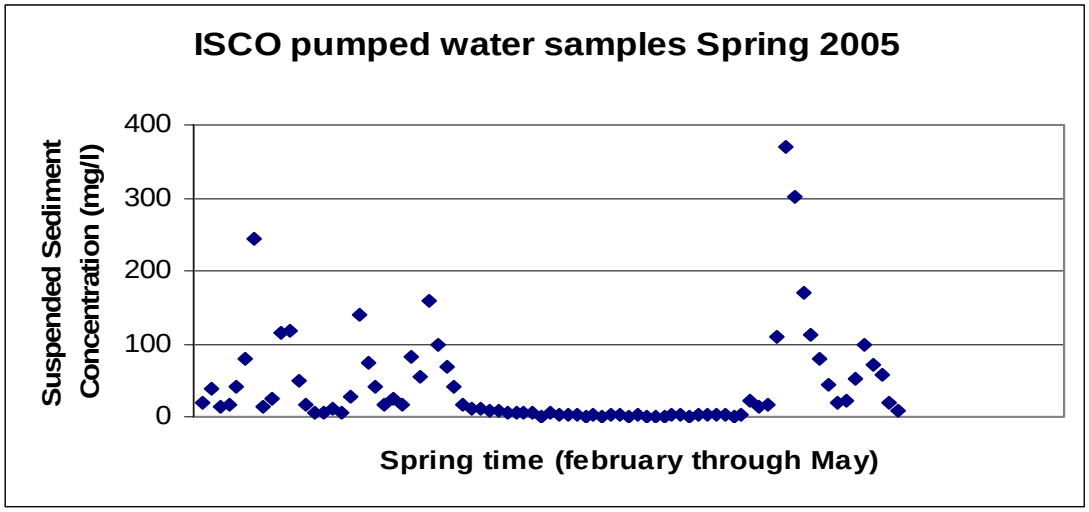
Miles

LABORATORY ANALYSIS AND INTERPRETATION OF WATER SAMPLES

ISCO water samples from Mill Creek were collected at various dates, times, and stages between February and May, 2005. The following text describes our analysis and interpretation of the water samples we collected on Mill Creek by the ISCO automatic pumping sampler and from the grab samples we collected from the other Garcia River streams in our study.

Figure 32. ISCO Water Samples extracted from Mill Creek water column over time



ANALYSIS A: DTS-12 TURBIDITY ON LABORATORY TURBIDITY
This analysis was performed to examine whether field turbidity equipment (DTS-12) remained well-calibrated over time by comparing DTS-12 turbidity to lab grade turbidity. Mill Creek water samples were analyzed for laboratory grade turbidity (superior in accuracy to field grade turbidity). Results were compared to samples measured at the same time and place with the field grade instream turbidimeter.

ANALYSIS B: LAB TURBIDITY ON SUSPENDED SEDIMENT CONCENTRATION
We also utilized the ISCO samples to compare turbidity with suspended sediment concentration (SSC). In similar studies, SSC is the real variable of interest and turbidity is used as a surrogate variable to predict suspended sediment concentration (SSC). Turbidity can be measured digitally in the field by machines (relatively efficient) but SSC requires actual water samples and laboratory analysis (relatively expensive). Correlation can be established between SSC and NTU when single water samples are examined for both parameters: SSC values were plotted against turbidity values from each water sample yielding a regression equation that defines the relationship whereby SSC is predicted from ntu.

The subset of points swarming upwards from the origin in relation to other points may represent a sub-population. We took the two populations apart from each other and graphed them separately. In attempt to explain why the low range in turbidity would

have a higher concentration of suspended sediment, we looked to Hysteresis. We divided the whole group of points again and separated them into falling limb and rising limb points. For example, if a sample was taken as the stream was rising in stage, it was grouped with rising limb points. The outlying data point had relatively high sand content (see photo).

ANALYSIS C: SSC ON DIGITAL FIELD TURBIDITY

If we were to utilize the field NTU recorded at Mill Creek to predict SSC, we would regress SSC on field turbidity and use that regression equation to calculate SSC for each turbidity measurement recorded. The regression equation technique can be applied to all Mill Creek turbidity data in order to predict corresponding SSC. This might be done should we desire to perform an "area under the curve" type analysis and sum the areas to get to total suspended sediment yield.

ANALYSIS D: COMBINED GRAB SAMPLES; LAB TURBIDITY ON SSC

This analysis presents the results of water sample analysis from the grouped "grab" samples we pulled from each of the Garcia River Tributaries we sampled, combined. One outlier was pulled from the main graph. We could not explain why this South Fork sample had a much higher SSC than expected from a moderately turbid sample. We concluded that the sample was not kept in a cool dark location post-sampling or there was an error in the lab analysis. Although efforts were made to obtain grab samples from streams at high flow levels, all grab samples recorded suspended sediment concentrations below 60 mg/L and under 40 ntu. Many samples collected by the ISCO recorded much higher values than our grab samples. This is because the ISCO is stationed on site and works nights, weekends, and in extremely wet weather without need of travel or sleep.

ANALYSIS E: INDIVIDUAL TRIBUTARIES; LAB TURBIDITY ON SSC

This analysis examines the tributaries individually. Grab samples are divided according to which tributary stream they were pulled from, then SSC was graphed on turbidity (ntu). This is appropriate in that streams from the same watershed can have different sediment weights for a given particle size. This would reflect in different SSC for a given turbidity.

Analysis A: Figure 33: Laboratory Turbidity on Field Turbidity, February 2005

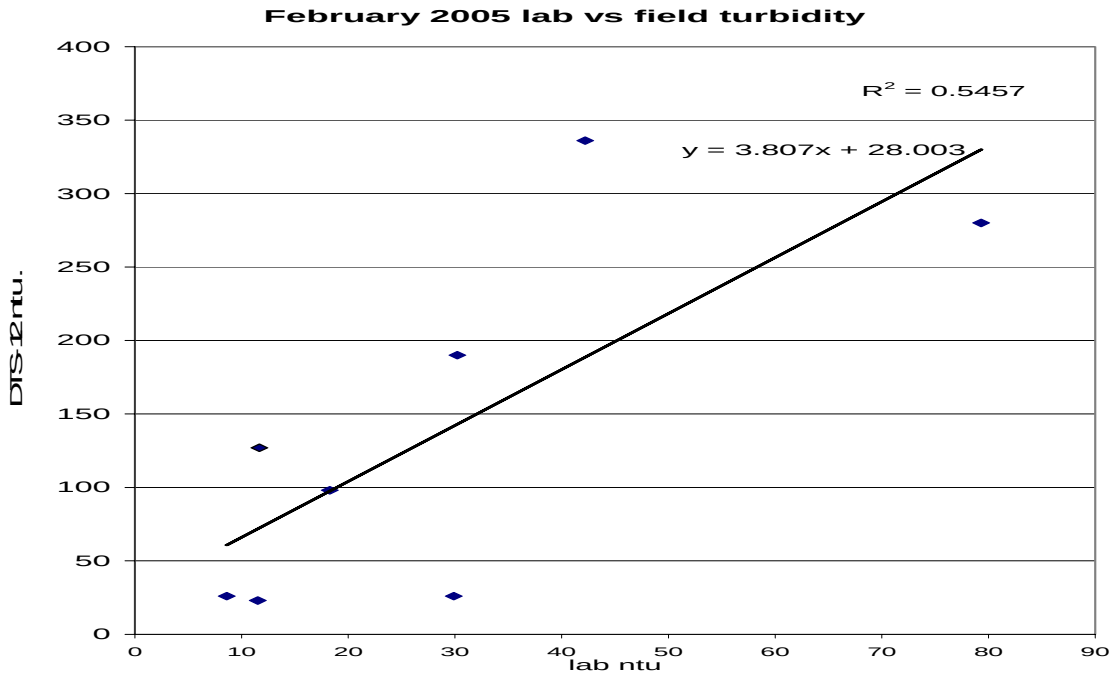
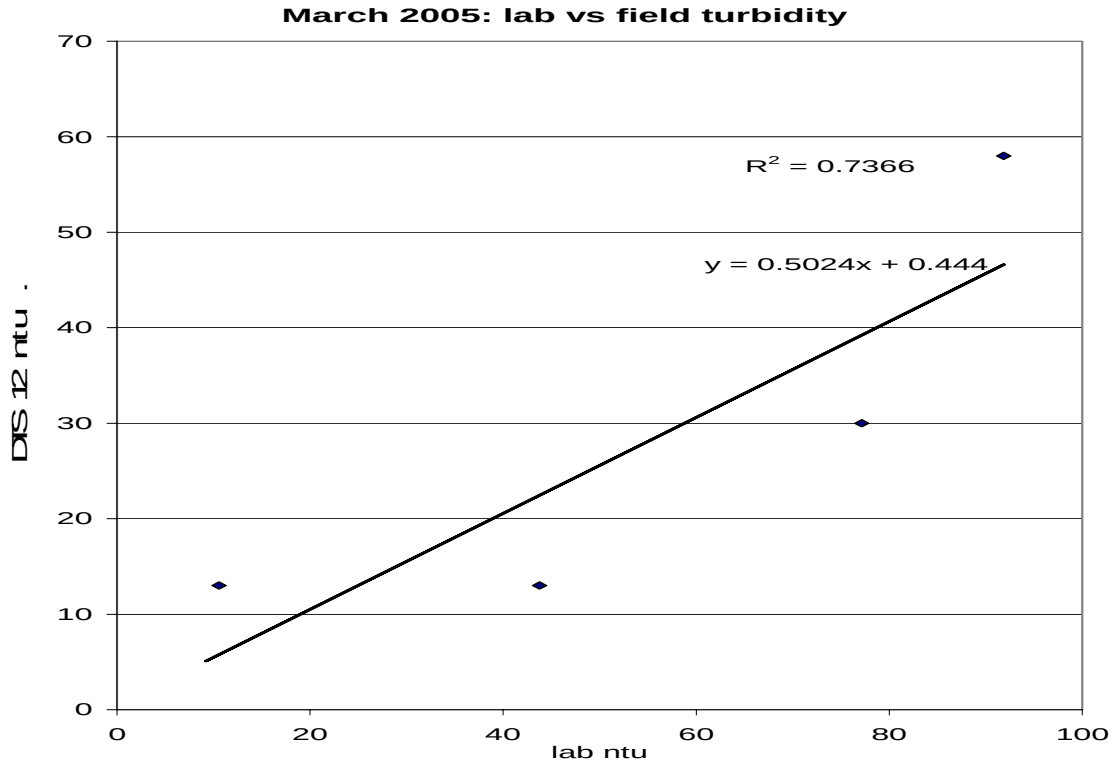
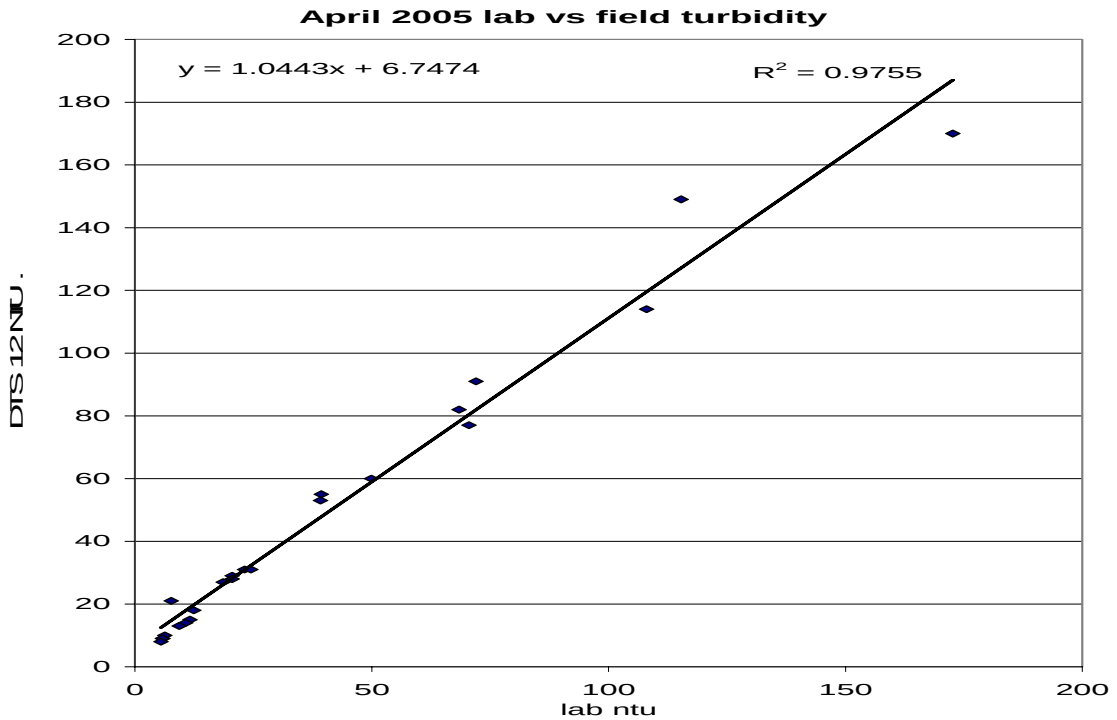


Figure 34: Laboratory Turbidity on Field Turbidity, March 2005



Analysis A: 35: Laboratory Turbidity on Field Turbidity, April 2005

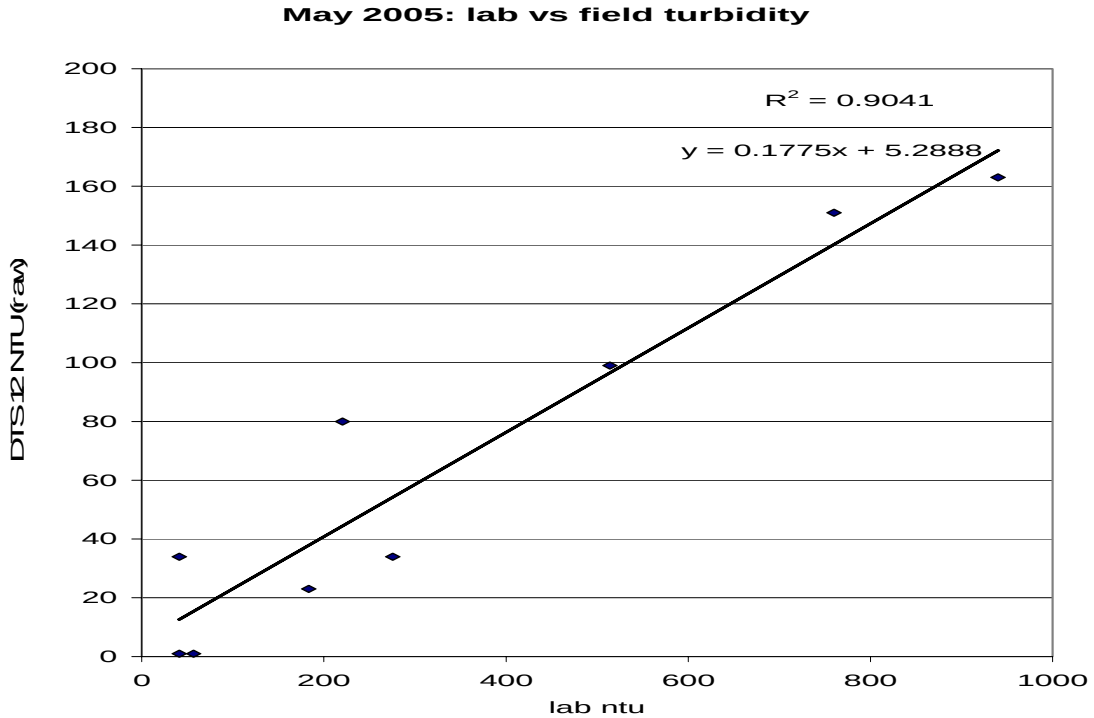


Analysis A

On Mill Creek turbidity sensing equipment appeared to remain accurate during the ISCO phase of our experiment. Correlation values from ISCO-pumped lab turbidity and DTS-12 field turbidity appeared poorly correlated as a group but when we separated them into chronological groups, R^2 values increased to between 0.55 and 0.98. Why would the lab analyzed turbidity vary from DTS-12 logged turbidity differently over time if not for sensor "drift"? In discussing this issue with Jack Lewis, Statistician at USFS Redwood Sciences Lab, it appears rather commonly that field sensors read somewhat higher or lower as the source of the turbidity changes in a creek (Jack Lewis, 2006 personal communication).

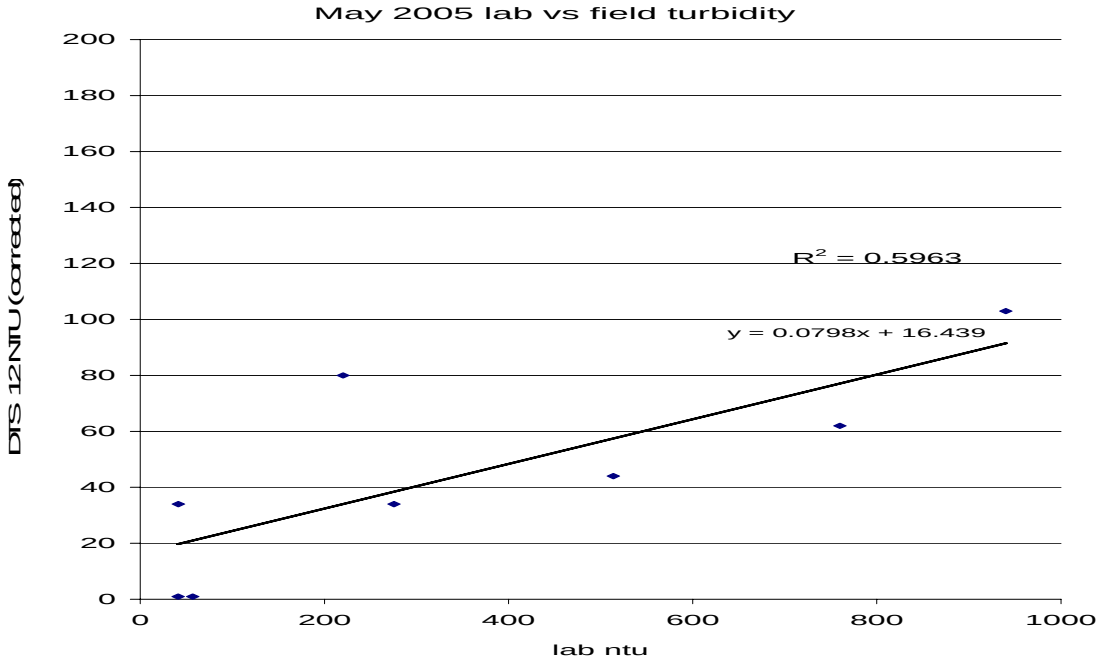
In May, 2005, turbidity data from Mill Creek was corrected because the "windshield wiper" arm on the turbidity sensor failed. In comparing raw and corrected turbidity values with laboratory tested turbidity (assumed to have greater accuracy) (Figure X) it appears that raw data was more accurate with a R2 value of 0.90 vs 0.60 for corrected data. Data were corrected at Mill Creek and at other tributaries where digital turbidity data was suspected to be erroneously high and so DTS-12 reported turbidity was reduced to be more in line with expected turbidity. This experience suggests that we may have reduced Mill Creek turbidity too far in the correction process. In this case, despite the wiper arm failure, the raw DTS-12 field turbidity was better correlated to lab turbidity than was the "corrected" turbidity. The wiper arm is critical where periphyton populations are high as in a solar production autochthenous food web but Mill Creek has a dense canopy, and is allochthenous in nature.

Analysis A: Figure 36. Raw Digital Field Turbidity on Laboratory Turbidity



Uncertainty in some displayed raw data suggested it was not realistic. But in this case, it appears that the raw data was actually more accurate than the "corrected" data. Water sample analysis was not available at the time the corrections appeared necessary and insufficient water samples negate the opportunity to examine accuracy of corrected data from the other streams.

Figure 37. "Corrected" Digital Field Turbidity on Laboratory Turbidity



Analysis B Figure 38. All Mill Creek ISCO Water Samples: SSC on Turbidity

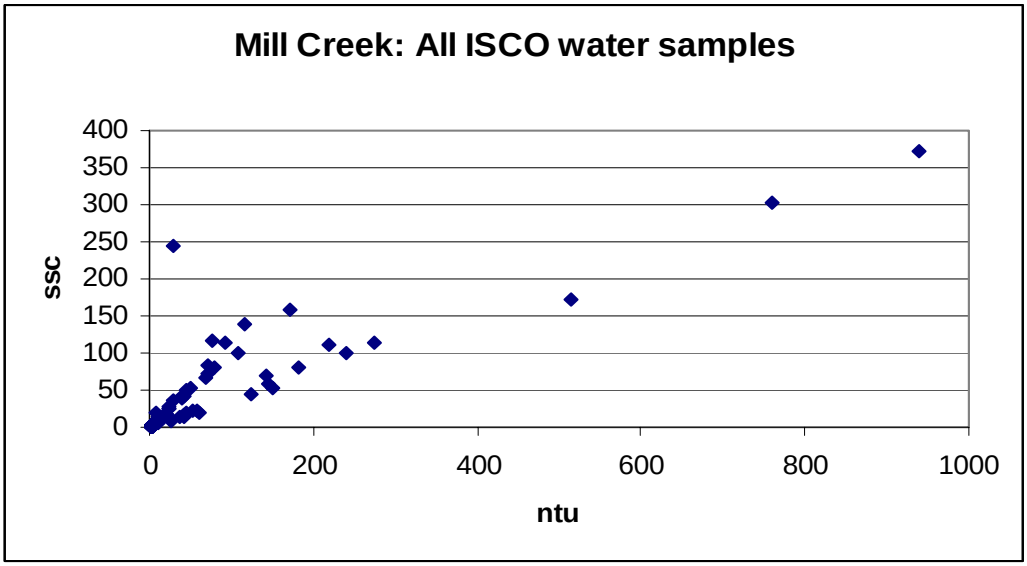
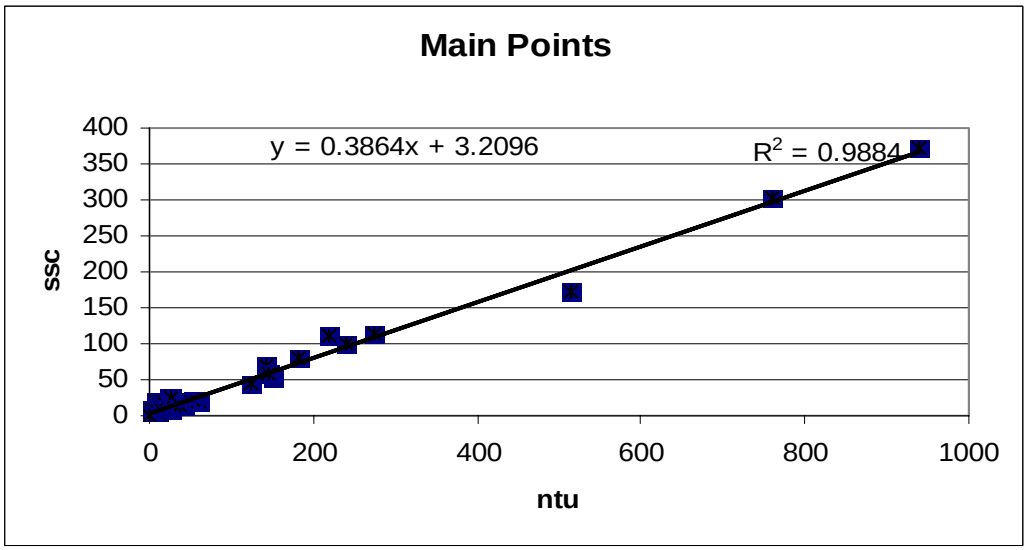


Figure 39. Mill Creek ISCO Water Samples: SSC on Long Range Turbidity



The two graphs above present all the Mill Creek water samples pumped from the ISCO automated sampler between February and May, 2005. The top graph presents them all together, including the outlier referred to earlier. The lower graph has "main points" that draw a diagonal between the graph's origin at 0 and the high ends of the data range.

Next we exhibit the "short range" (middle cloud of points) points graphed with both the outlier included and with the outlier omitted, and separates the "short range points" from the data set.

Figure 40.
Mill Creek ISCO Water Samples: SSC on Short Range Turbidity (outlier removed)

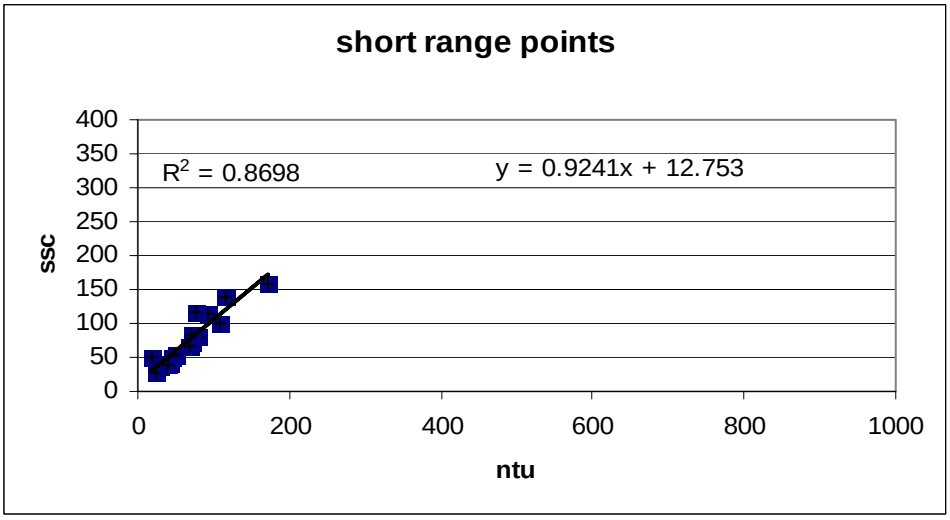
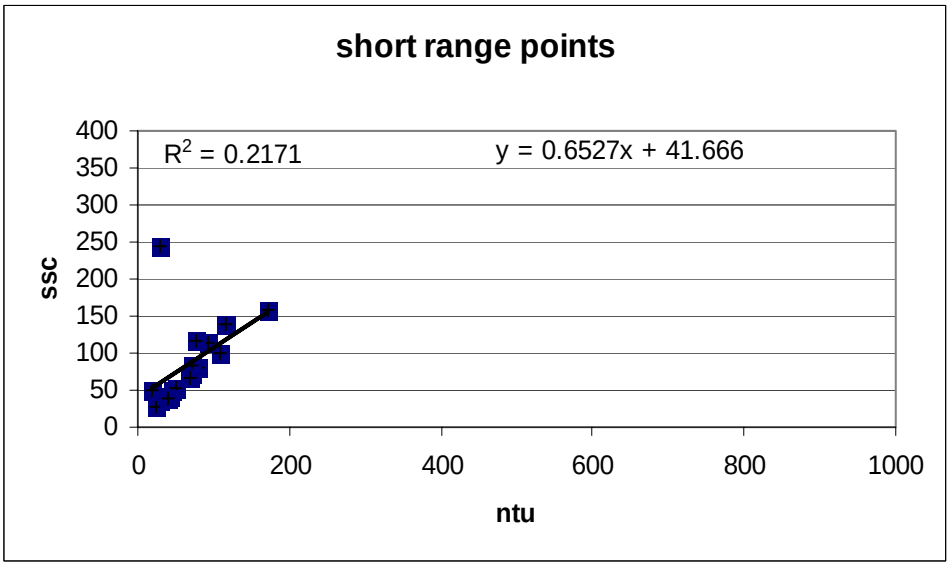


Figure 41. Mill Creek ISCO Water Samples: SSC on Short Range Turbidity



Correlations between SSC and Turbidity analyzed from the same ISCO samples show two distinct relationships and a prominent outlier. The long range or "Main" points show a lower SSC with a given turbidity than the short range points. This could be explained perhaps if the short range sub-populations happened to correspond to rising limb samples on a storm hydrograph while long range points represented falling limb samples on a storm hydrograph, a phenomenon termed "hysteresis". Alternately, long range points might have organic matter suspended as well as inorganic particulate. Inorganic particles would result in a higher SSC than would organic particles in suspension when turbidity is equivalent. One prominent outlier exists within the short range samples. This outlier had visibly more sand in it than the other samples from this analysis. This resulted in a much higher SSC for a moderate turbidity (see photo).

Analysis B: Hysteresis

Figure 42. Mill Creek Hysteresis: Rising Limb Water Samples

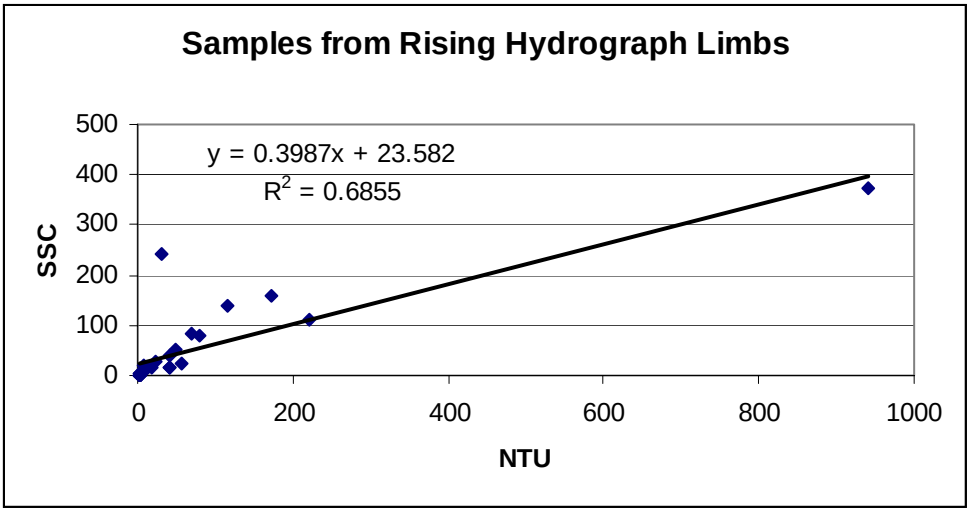
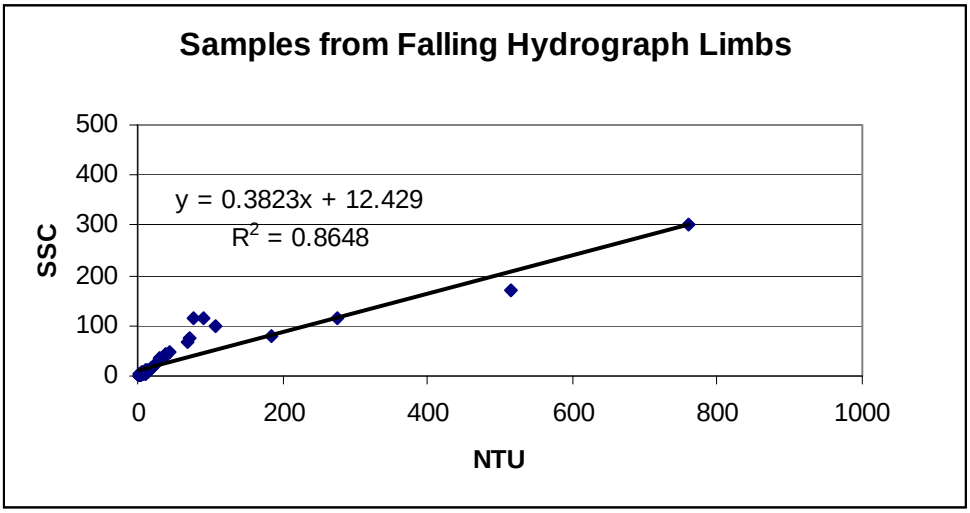


Figure 43. Mill Creek Hysteresis: Falling Limb Water Samples



It appears that short range and long range points occur in both rising and falling limb categories. However examining sediment residues collected from water samples on the glass membrane filters suggests long range points have more organic residue than short range points. Some short range residues appeared to contain a small sand fraction and one of these has a large sand fraction (the one prominent outlier presented in Analysis B). The outlier with unusually high suspended sediment concentration did occur on the rising limb of the hydrograph, as might be expected.

Analysis B: Photographs of filtered sediment residues from winter water samples

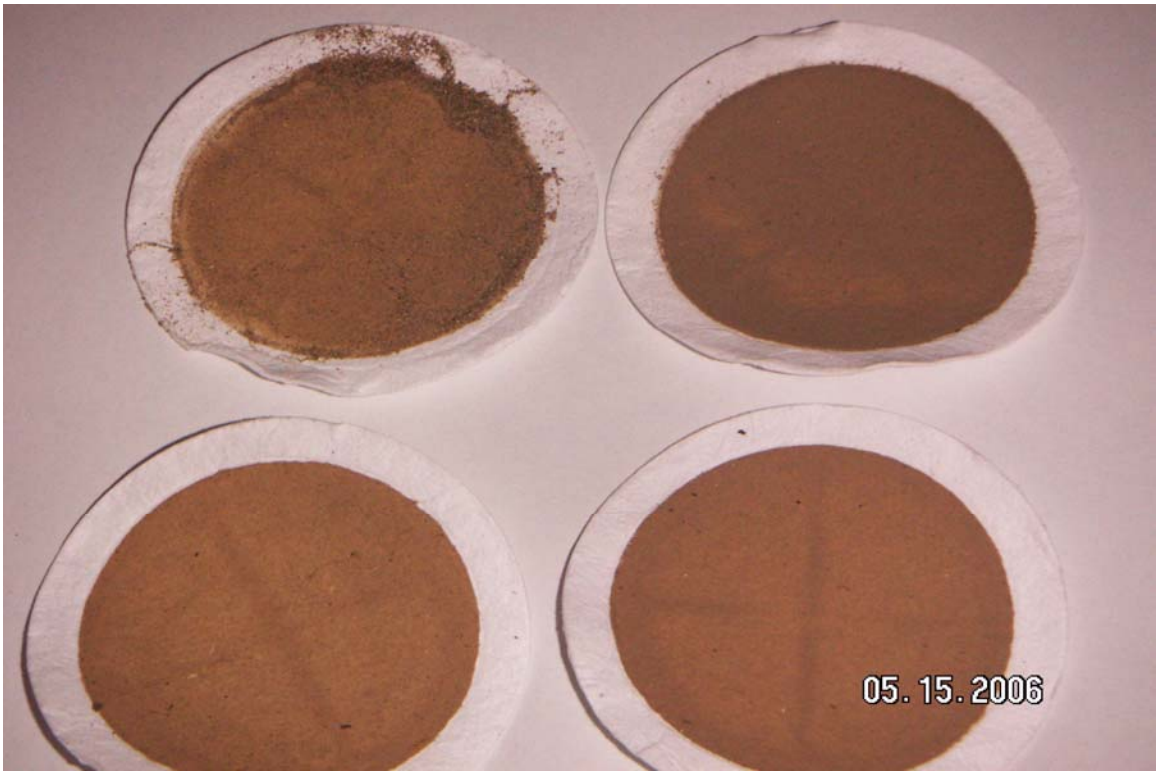
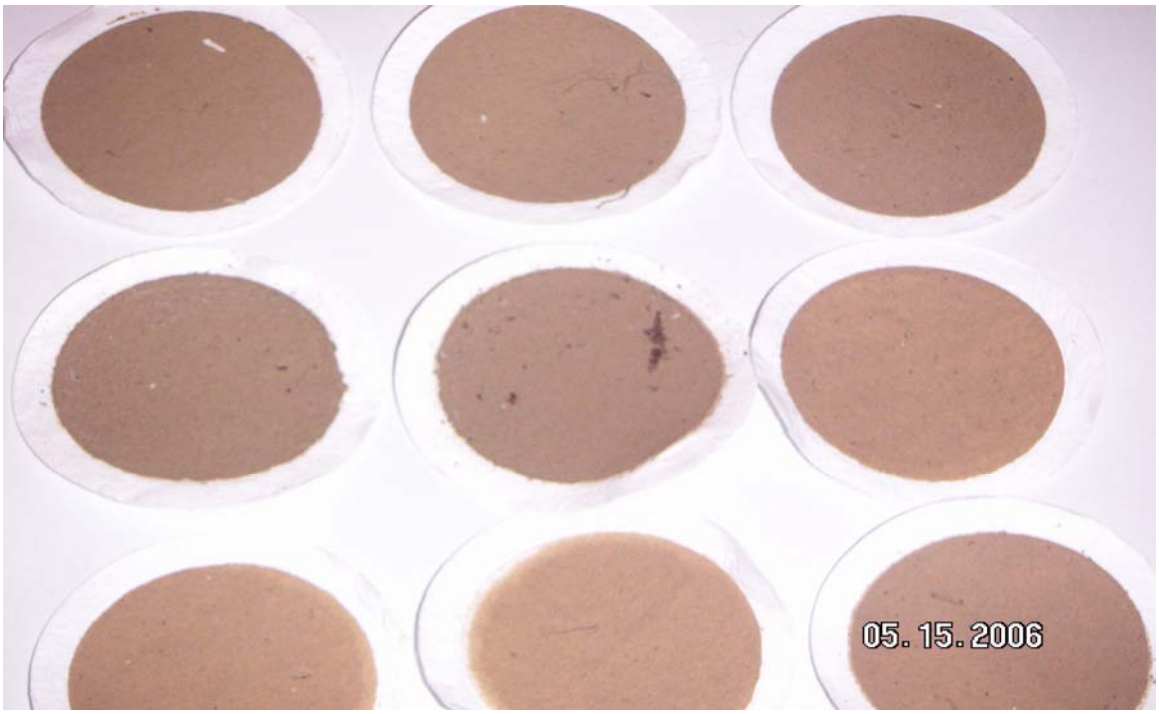


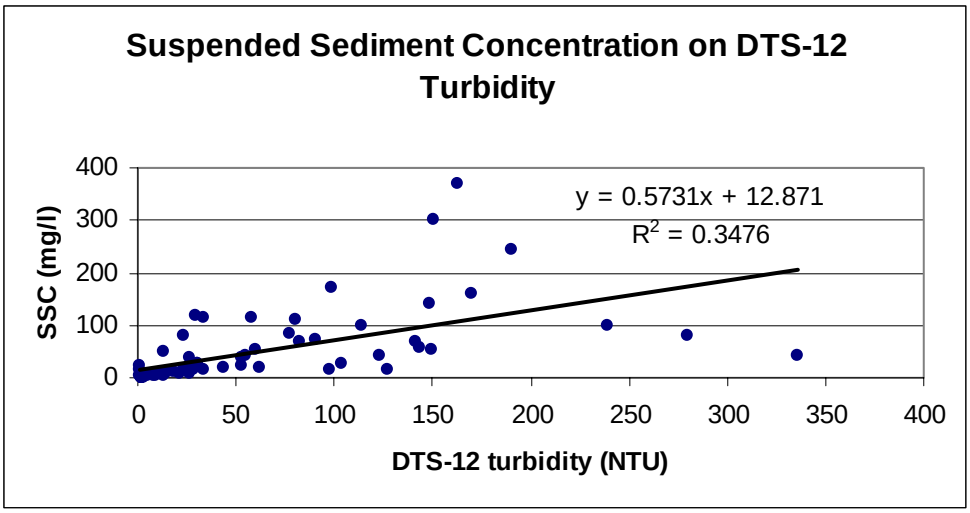
Photo 12. Mill Creek filtered suspended sediment residues: Above: Short Range example. The sample in top left corner includes a heavy sand fraction unlike others in the group having some sand but mostly finer silts and clays. Below: Long Range Points, including organic particles, particularly in the center sample.



Analysis C

If we were to want to convert all the turbidity recorded in Mill Creek to Suspended Sediment Concentration, perhaps to estimate total suspended load, we would first regress SSC on field turbidity. The R-squared would evaluate how accurate the prediction of SSC is likely to be from turbidity. This is the relationship graphed as Analysis C. In this graph the mid-range turbidities have wide variation in corresponding SSC, and after consulting our filters and their residues, we believe the breadth in SSC stems from the relative fraction of organic matter suspended in the water column. With this level of precision, the error imparted to a suspended sediment yield calculated from this data source would have to be considered a "ball park" figure.

Figure 44. Mill Creek Suspended Sediment Concentration on Digital Field Turbidity



Analysis D:

Figure 45. Grab Samples from All Garcia Tributaries Sampled

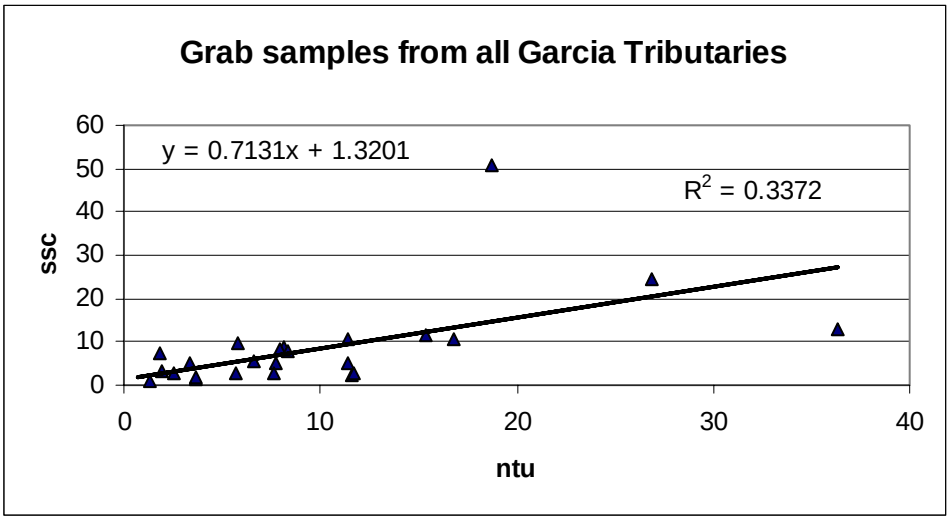
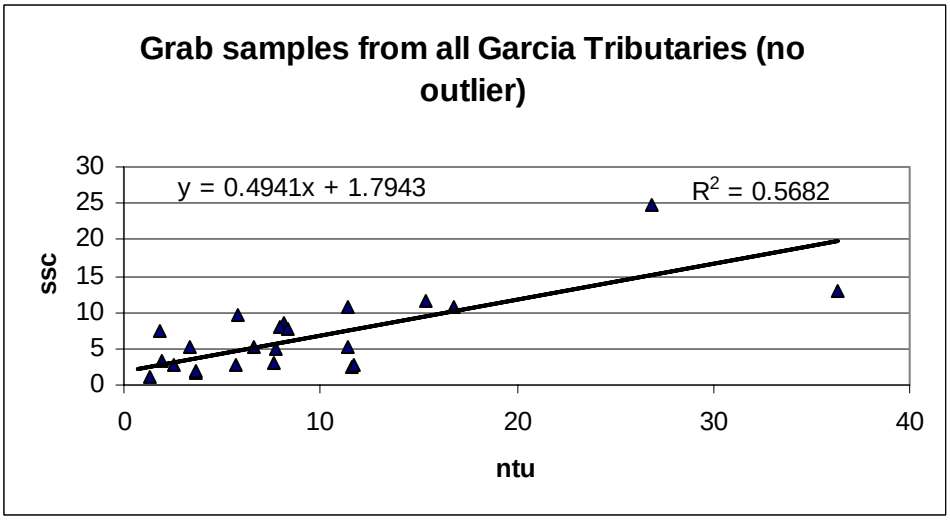


Figure 46. Grab Samples from All Garcia Tributaries Sampled (outlier omitted)



Although efforts were made to obtain grab samples from streams across the range of conditions and especially at high flow levels, all grab samples obtained contained suspended sediment concentration levels below 60 mg/L and turbidity levels below 40 ntu. The R^2 value for grab sample suspended sediment concentrations on lab turbidity is 0.34. One outlier had a higher SSC value than others for the given turbidity. A visual assessment of this sample's filtered residue indicated that it had more sand than other samples. When this outlying sample was removed the R^2 value improved to 0.57. It is logical to presume that tributaries in the same watershed would exhibit similar relations between turbidity and SSC. Yet to isolate any differences between tributaries and improve our R-squared correlation coefficient, we separated them out in Analysis E.

Analysis E:

Figure 47. Mill Creek Grab Samples: SSC on Lab Turbidity

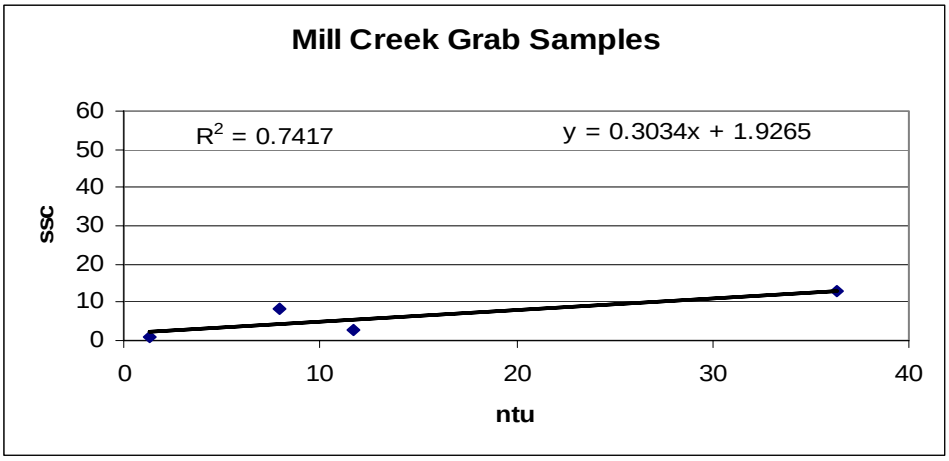


Figure 48. South Fork Grab Samples: SSC on Lab Turbidity

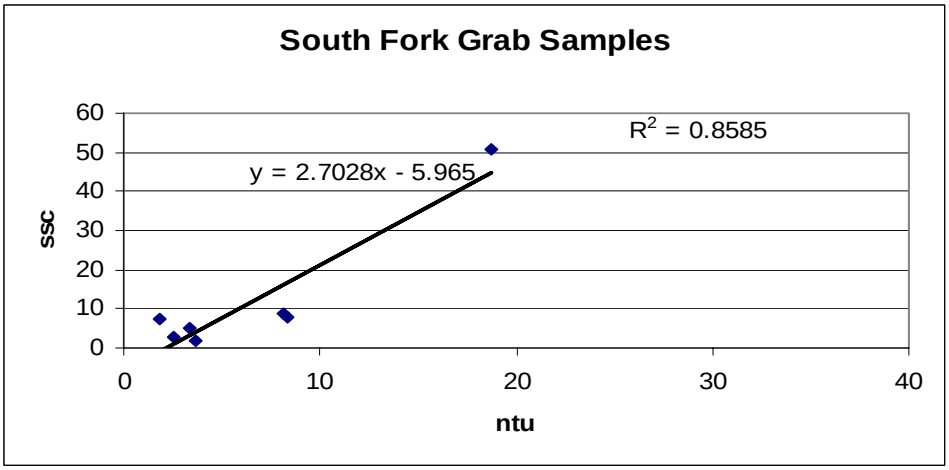


Figure 49. Pardaloe Grab Samples: SSC on Lab Turbidity

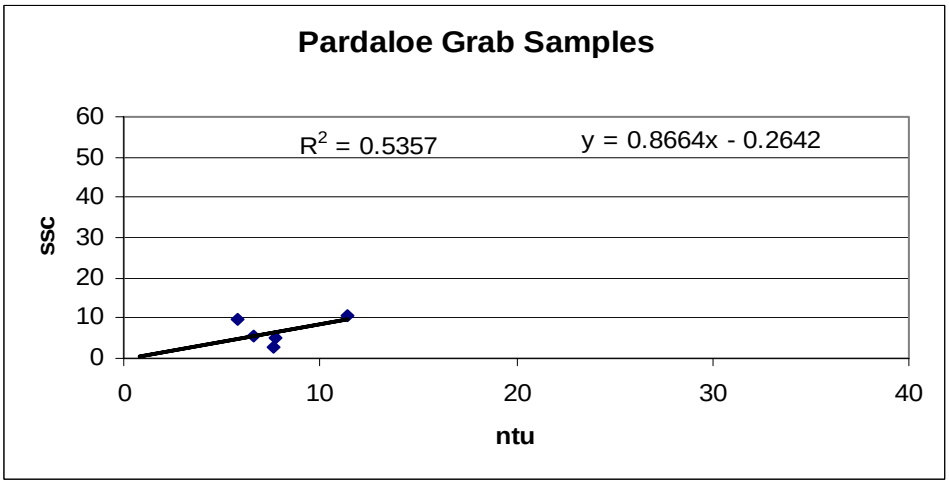


Figure 50. Whitlow Creek Grab Samples: SSC on Lab Turbidity

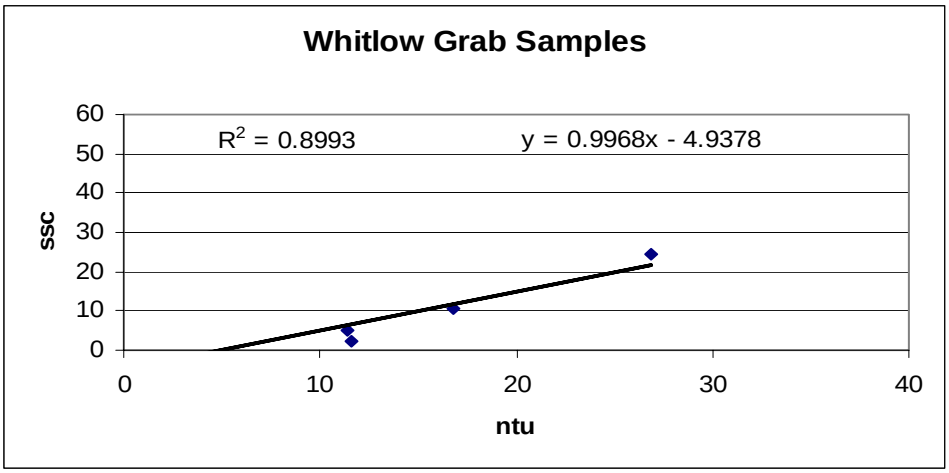


Figure 51. Inman Creek Grab Samples: SSC on Lab Turbidity

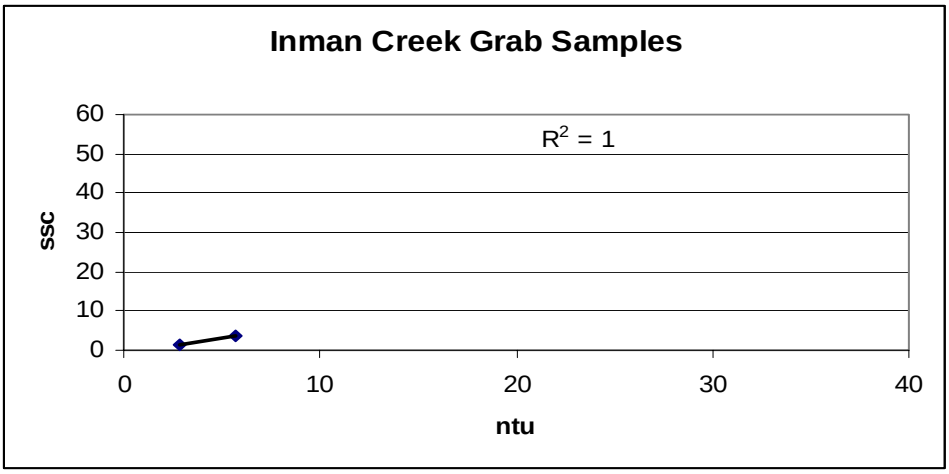
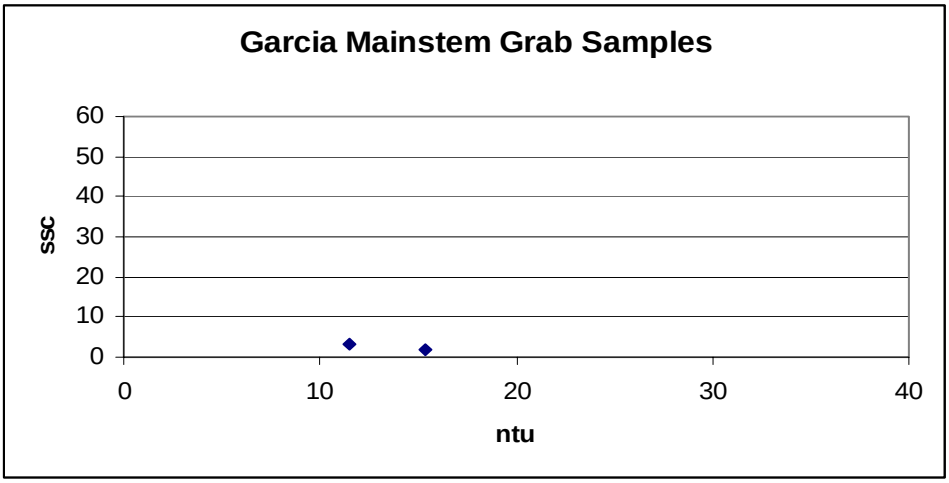


Figure 52. Garcia Mainstem Grab Samples: SSC on Lab Turbidity



Analysis E

Separating the tributaries certainly did increase the R-squared correlation coefficients indicating tighter correlation. In looking at the correlation between SSC and turbidity by tributary we can see that South Fork of the Garcia stands out because the relationship is much steeper indicating heavier particulate for a given turbidity. The presence of the outlier at South Fork contributes to the steepness of this relationship; however, we saw no reason to remove it especially because this sample reflects the highest turbidity we sampled at South Fork. This outlier appeared to have more sand in it than other samples, which suggests that it would have a higher SSC value for the given turbidity. It may be that at higher turbidity levels there is more sand present within the water column on this tributary. On the other hand, there may have been an undetected sampling mistake, which would result in a shallower correlation more similar to those from other tributaries.

In looking at the two grab samples from the Mainstem Garcia, one can see that SSC was surprisingly low for the two moderate turbidities sampled. This is probably due to the relatively high density of algae suspended in the mainstem compared with algae levels in tributaries. Visual assessment of lens colonization on the mainstem suggests that there is much more periphyton present there than in tributaries where no lens colonization occurred. Suspended algae that lend the rather green water color of the mainstem captured in the cover photo may also be experienced as turbidity. The greater solar exposure experienced by the river given the high fraction of open canopy above it explains why more photosynthetic organisms live there as compared to the limited open water surface in tributaries where riparian trees nearly close the canopy.

SUMMARY INTERPRETATION OF WATER SAMPLES ANALYSES A-E

A: Dts-12 Turbidity On Laboratory Turbidity

Data from the ISCO sampler shows more accurate correlations between digital field grade turbidity and the more precise laboratory turbidity, at higher turbidity values. This suggests that the higher turbidity values obtained with the DTS-12 Digital Turbidity Sensor should be more accurate than low turbidity values. This was by design. We requested factory calibration to the higher end of expected values because we thought it was more important to get the high values correct than the lower values in this application. The relationship of lab grade turbidity to field grade turbidity changes over time. One regression equation is not adequate to describe this relationship as is suggested by changes in the curves we plotted during consecutive springtime months. Data correction should be approached very carefully. In this situation Mill Creek ISCO water samples indicate that corrections made to improve accuracy at Mill Creek (and perhaps at others but we have an insufficient number of water samples with which to test) actually reduced accuracy: In this case raw field turbidity predicted lab grade turbidity more closely than corrected field turbidity.

B: Lab Turbidity On Suspended Sediment Concentration

Two sub-populations appeared when SSC was plotted on turbidity: the short range group had heavier SSCs for low to moderate turbidities and the long range group had lighter SSCs across the turbidity range experienced. One grab sample from South Fork plotted as

a clear outlier (30.2 ntu, 243.06 mg/l). It had much higher SSC for a moderate turbidity. We examined hysteresis in the data set as well as the filtered sediment residues (see photo). The South Fork grab sample outlier had an unusually high sand fraction for a low turbidity. None of the other filtered residues had nearly as much sand. Long range residues had organic content visible in the filtered residue, which would add less weight (higher SSC) for a given turbidity. The difference in organic content versus heavier inorganic particulate explains the presence of two sub-populations.

C: SSC On Digital Field Turbidity

A regression equation is presented graphically and mathematically that defines the relationship correlating SSC with field grade turbidity. We presented the graph and regression statistics for information purposes. The tighter the correlation between SSC and turbidity, the better in predicting accurate SSC from turbidity. This relationship is not particularly linear, and the wide scatter at moderate turbidity levels suggests that without considerable effort to refine the data, pull outliers, and explain wide variation around the center, this analysis does not appear to justify a plan to predict SSC (and then predict suspended sediment yield) from field grade turbidity. Perhaps efforts to refine this dataset could improve the certainty and accuracy with which Mill Creek SSC could be predicted from Mill Creek field grade turbidity.

D: Combined Grab Samples; Lab Turbidity On SSC

The R^2 value for combined grab samples for suspended sediment concentrations on lab turbidity was 0.34, a very poor correlation. One outlier had a higher SSC value than others for the given turbidity. A visual assessment of this sample's filtered residue indicated that it had more sand than other samples. When this sample was removed the R^2 value increased to 0.57 but still SSC appears poorly correlated to turbidity when grab samples from all Garcia River tributaries were combined.

E: Individual Tributaries; Lab Turbidity On SSC

Once the grab samples were divided so as to represent single, independent tributaries, then variation in the relationship of SSC on lab turbidity is reduced and the R-squared improved substantially. This indicates that the Garcia tributaries should not be represented as a group but rather in scientific discussion pertaining to water quality, the tributaries should be treated individually to improve on accuracy in predictions and decision making.

CONCLUSIONS

The data collected in this study was used to address the following questions:

- Does this recent data suggest a trend of improvement in spawning gravel quality toward attainment of regulatory targets? IN SOME STREAMS
- Is there a measurable improvement in spawning gravel quality at South Fork Garcia as a result of watershed restoration work conducted between the 1999 and 2004 measurements? MEASURABLE IMPROVEMENT, YES
- Does between-storm turbidity impose a threat to over wintering juvenile salmonids? YES
- Has winter water clarity improved following watershed restoration at the South Fork? YES
- Do land management practices exert a measurable influence on winter water clarity? YES
- If so, how problematic is that influence on anadromous salmonids?

GRAVEL CONDITIONS IN 2004 COMPARED TO 1999 BASELINE

Particle Size Distribution

Table 4 indicates Whitlow Creek had more streambed fines smaller than 0.85mm in 2004 than in 1999. That conclusion is validated by Dr. Baker's parametric tests. His parametric tests also conclude that there was no statistically significant difference between 1999 and 2004 samples from the other tributaries yet there were measurable differences: Compared with 1999 samples, in 2004: Whitlow Creek had less fines in the <8.0mm size class; Mill Creek had more fines in both the <0.85mm and the <8mm size classes; South Fork had more fines < 8.0mm size class but less fines <0.85mm; Pardaloe has less fines in both the <0.85 and <8.0mm size classes.

Permeability

Spawning gravel permeability at Mill Creek was slower in 2004 than in 1999. At Pardaloe Creek permeability was faster in 2004 than in 1999 which is desirable because permeability through gravel interstices brings more dissolved oxygen to the salmon redd as well as more flushing of metabolic wastes. Both of these findings were statistically significant. Inman and South Fork permeabilities were measurably faster in 2004 but these differences were not found to be significant statistically.

Embeddedness

No embeddedness measurements were taken in 1999 with which to compare 2004 results. Embeddedness measurements in 2004 were tried as an attempt to correlate this relatively simple technique which has been recorded for a large number of California streams (Doug Albin, personal communication) to particle-size distributions and/or permeability. McBain and Trush's correlation analysis indicated embeddedness explains 0.3% of the variability in the percentage of gravel smaller than 8.0mm and explained 5% of the variability in the percentage of the gravel smaller than 0.85mm. This lack of correlation

may be explained in that embeddedness is measured at the bed surface but both bulk gravel and permeability are measured several inches below the surface.

Sediment Quality Relative to Garcia River TMDL

EPA in its TMDL targets the percentage of fine sediments in spawning gravels finer than 0.85 mm and 6.5 mm at <14% and <30%, respectively. As in 1999, 2004 gravels finer than 0.85 mm fall below the 14% numeric target, indicating less of the bedload is in that very fine category. However Mill and Pardaloe creeks exceeded the 30% numeric target for sediment finer than 6.5 mm suggesting spawning gravels are still impaired with by too many fines in pea gravel category.

What is the effect of these trends on Salmon using these Spawning Gravels

McBain and Trush used gravel particle size composition and permeability data to predict egg survival to emergence in gravel salmon redds. In 2004, survival to emergence was predicted to be higher at Whitlow and Pardaloe creeks than in 1999 but lower at Mill and South Fork based on particle size composition. Survival to emergence was predicted to be higher at Pardaloe Creek in 2004 but lower on the other tributaries based on permeability data.

As is shown in the table below, the gravel particle size distribution suggests that all monitored tributaries now have spawning gravels that meet the targeted proportion of fines smaller than 0.85 millimeters (target is <30%). For particles smaller than 6.5 millimeters, spawning gravels are hovering around the target established by EPA (target is <14%). There has been discussion as to whether these targets are applicable when discussing gravels that are dried prior to sieving and weighing. Drying gravels prior to sieving reduces water tension between particles and reduces water weight held by wet particles.

Do South Fork Gravel Measurements reflect Watershed Restoration Efforts?

Between 1999 and 2004 mean permeability increased from 1354 cm/hr to 2117 cm/hr and the percentage of fine sediment <0.85 mm decreased from 10.1% to 7.8%. These changes were measurable, but they were found not to be statistically significant. In the Author's opinion, measured spawning gravel quality improvements may be a result of watershed restoration.

Winter Water Clarity

Mill Creek, Pardaloe, and South Fork had the clearest winter water in the study period (tables 11 and 12). South Fork Garcia had the lowest peak turbidity for most of the largest storms we extracted from the data set (followed by Pardaloe) and had the lowest turbidity when we averaged those peak turbidities (table 13). In Water Year 2004 South Fork experienced the least number of hours above the >30 ntu turbidity threshold while Mill Creek experienced the lowest number of hours above the 60 and the 150 ntu turbidity thresholds. In WY 2005 South Fork experienced the lowest number of hours above 30 ntu, Pardaloe Creek experienced the least number of hours where turbidity

exceeded the 60 ntu threshold, and Mill Creek experienced the least number of hours where turbidity exceeded 150 ntu.

Does clearer winter water quality reflect Watershed Restoration Efforts?

The water samples we collected from tributaries indicate that at low and moderate turbidity levels, filtered suspended matter consists mostly of inorganic particles of clay, silt, and some sand. This is the type of sediment one might expect in run off from road surfaces during small to moderate storms or sustained light rainfall. It follows logically that after road-based erosion control that sediment delivery would be lessened and water clarity would improve between storms (less hours of turbid water exceeding 30 ntu). During storm flows, road based erosion is perhaps more likely to result from problematic stream crossings than road surfaces. Upgraded stream crossings like those implemented in South Fork are designed to reduce sediment delivery to streams and therefore would increase water clarity in storms. The improved water clarity exhibited in South Fork over other streams with equivalent or higher road density suggests that watershed restoration has been effective in reducing sediment delivery that impairs winter water clarity. However, we have no pre-treatment data from South Fork to support this conclusion, and are relying only on comparative data between Garcia River Tributaries.

Most surface erosion from areas disturbed by road erosion control work typically occurs during the first three years following implementation. For the South Fork Garcia River, that period was from 2002-2003. Our 2004-05 data suggest that South Fork turbidity exposures, in hours above 30, 60, and 150 NTU, did decline in duration between WY04 and WY05, as would be hoped in the years following erosion control restoration. In WY04, South Fork experienced the fewest hours above the 30 NTU threshold. In WY05 South Fork experienced fewer hours above the 30 and 150 NTU threshold exposures than did the other monitored tributaries, as well as recording the lowest peak turbidities in monitored storm events.

This information is likely well received for those planning to reduce sediment delivery to fish bearing streams by road rehabilitation. The Author is excited to bring these conclusions to light. However, lack of pre-treatment data, and confounding influences supplied by natural sources of variation, does dampen such conclusions that might be drawn regarding causation until more focused and detailed studies emerge. We have applied for additional funding for that purpose.

Can we attribute clear waters to less disturbance?

The timber harvest maps included (figures 22-31) and Timber Harvest Intensity data (Table 14) indicate that both Pardaloe and South Fork have had comparatively lower rates of timber harvest in the last 17 years compared to other Garcia Rive tributary watersheds included in the study.

What is the Winter Water Clarity like in the other Garcia River Tributaries?

Mill Creek experienced the least number of hours where between storm instream turbidity was higher than the 150 ntu threshold during both water years. Yet Mill Creek

showed an increase in duration of threshold turbidity exposures from WY-04 to WY-05 by about one-third for the >30 and >60 ntu thresholds, without any obvious change in land use practices or restoration efforts. This illustrates the difficulty in trying to draw conclusions based on very limited datasets.

Whitlow and Inman showed the longest duration of exposures over chronic turbidity thresholds, and these watersheds had the most upstream timber harvesting of the monitoring sub basins. The Garcia River mainstem had the highest chronic turbidity in WY04, possibly as a result of cumulative watershed effects, but the weight of suspended sediment was unusually low compared to tributaries. We observed lens fouling by periphyton in a 24-hour period there on the mainstem but not for weeks on tributaries. This observation suggests that mainstem turbidity is often algal in nature and doesn't weigh very much. The greenish color of the mainstem between storms (as shown in cover photo) supports the observation of periphyton or suspended algae in the mainstem as a dominant source of mainstem turbidity.

Is chronic winter turbidity a hardship on overwintering salmon and steelhead?
This question is certainly relevant but outside the scope of this project. The expertise of fisheries biologists is required to answer these questions. What we can say is that the hours spent in streams over 150 ntu are likely to be hours spent without feeding. Hours spent over 60 ntu are challenging for feeding in that it is difficult for fishes to see due to lack of light and suspended particles and also because macroinvertebrates pick up off the bottom and drift to escape turbidities over 60 ntu. The hours spent over 30 ntu are non-growth periods, perhaps because the energy it takes to capture food balances the nutrition provided by that food. Our analysis followed the procedure used by Klein, 2003 in that the hours over any one turbidity threshold are total but not consecutive hours.

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