EROSION AND TURBIDITY MONITORING REPORT
SANCTUARY FOREST STREAM CROSSING EXCAVATIONS
IN THE UPPER MATTOLE RIVER BASIN, 2002-2003

REVISED

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I also than Dr. William Weaver and Todd Kraemer of Pacific Watershed Associates for providing comments that helped improve the revised report that follows.

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BACKGROUND AND PROJECT OBJECTIVES

The Sanctuary Forest, Inc., (SFI) has undertaken an erosion control and prevention program to reduce long-term sediment yield from lands in the upper Mattole River watershed. The primary focus of the erosion control and prevention program is to remove ('decommission') forest roads that are not needed for transportation and pose sedimentation risks to downstream resources (aquatic habitat for salmonids and other species). Due to concerns expressed by the local community, SFI decided to perform post-project monitoring with the following objectives: 1) determine effects on water quality and the volumes of erosion and sediment delivery following excavation stream crossings, and 2) determine the need for and nature of any modifications to the style or rate of excavations that may be warranted to reduce and/or spread impacts over a longer time period.

In the fall of 2002, I developed a monitoring plan for SFI to be implemented by staff and local volunteers with technical training and oversight provided by myself. Methods and materials chosen were low-tech and combined qualitative and quantitative approaches designed to be implemented by non-technical observers but still provide useful, repeatable information. Regarding the first objective, effects on water quality was quantified by measuring turbidity increases in streamflow passing through excavations and erosion/sediment delivery was evaluated by quantifying net seasonal erosion from within a sample of stream crossings treated in 2002. Regarding the second objective, suggestions for modifications to treatments are provided in the 'Discussion and Recommendations' section near the end of this report. The ultimate decision for whether or not to modify the nature of treatments or the rate at which sites are treated will be made by SFI staff and will include input from stakeholders.

While road removal vastly reduces the long-term erosional risks from forest roads, short-term erosional responses from stream crossing excavations can occur in the form of surface erosion, rilling, and gullying, channel scour, and minor slumping within excavations. Typically, most erosional responses occur within the first several years following road removal and greatly diminish as vegetation grows on excavation sideslopes and channels find stable grades and armor themselves with rock and woody debris (Madej, 2001).

We know from studies of erosional responses to road removal work elsewhere in the region (Klein, 1984; Madej, 2001) that most sites will likely experience minimal erosion and a few may experience relatively large volumes of erosion, and that causative factors cannot always be anticipated or mitigated. However, some instances of large erosional response can be anticipated. For example, placing loose, unstable fill near the channel or creating conditions promoting post-excavation headcutting can often be anticipated and avoided. Some level of post-treatment erosion must be viewed as a beneficial trade-off between smaller short-term impacts and larger long-term impacts that would result without treatment. However, the trade-off is less beneficial when a large volume of post-treatment erosion occurs that could have been anticipated and feasibly avoided.

PROJECT SCOPE

In preparation for the road removal program, 24 miles of roads were inventoried to assess their erosional risk and treatment needs (PWA, 2001). Road decommissioning was recommended on 19 of those 24 miles, while the remaining 5 miles were recommended for upgrading ('stormproofing'). Potential road-related erosion sites were prioritized for treatment based on risk as a function of both likelihood and volume of probable sediment delivery. The inventory identified 174 stream crossings to be decommissioned (fill excavated) or upgraded, and estimated that those stream crossings could yield about 19,000 cubic yards of future sediment delivery.

About one-third (65) of the total number of stream crossings identified for removal were decommissioned or upgraded in 2002. Water quality sampling during winter storms and post-winter erosion estimates were made at 18 of the stream crossings excavated in 2002 (about 28% of the 65 stream crossings treated in 2002; see maps in PWA, 2001). These elements of the monitoring project are referred to as 'onsite' monitoring.

In addition to onsite monitoring, water quality sampling was done at five locations on larger streams in the vicinity. The distribution of offsite sampling locations (see Fig. 1) was selected to evaluate effects on downstream water quality. Two of the five sites ('UMR', or Upper Mattole River, and 'HBA', or Lower Helen Barnum Creek) are short distances downstream of areas treated in 2002. The other three sites ('MCN', or McNasty Creek, 'ANC', or Ancestor Creek, and 'HBB', or Upper Helen Barnum Creek, see Fig. 1) drain areas in which no work by SFI was conducted.

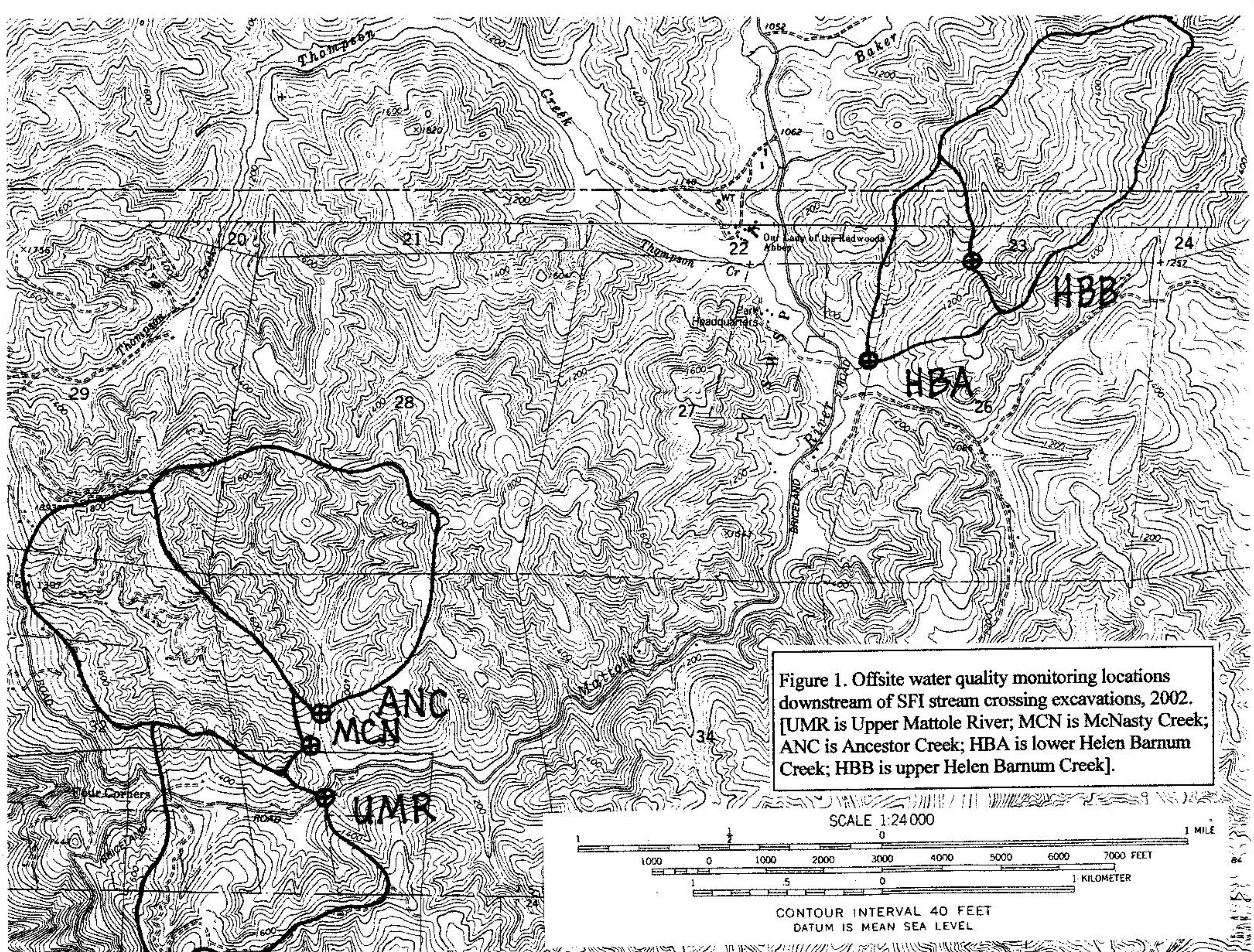


Figure 1. Offsite water quality monitoring locations downstream of SFI stream crossing excavations, 2002. [UMR is Upper Mattole River; MCN is McNasty Creek; ANC is Ancestor Creek; HBA is lower Helen Barnum Creek; HBB is upper Helen Barnum Creek].

MONITORING AND ESTIMATION PROTOCOLS

Onsite Monitoring

Onsite monitoring of stream crossing excavations consisted of two main elements:

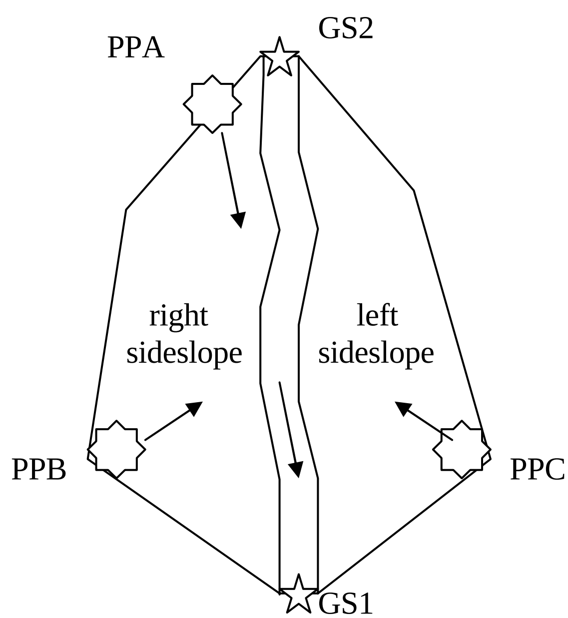
- photopoints were established at all stream crossings excavated in 2002;
- net seasonal erosion: measurement of erosion volumes at 18 of the stream crossings excavated in 2002;
- winter storm sampling: storm visits for water quality sampling were also made at 14 of the 18 excavations where erosion estimates were made.

These elements of onsite monitoring are described below.

Photopoints: Photopoints are monumented locations where repeated photographs taken are of the same location over time to document changes (e.g., erosion, vegetation growth). The first set of photos taken in fall, 2002, document the initial conditions for qualitative comparison with follow-up spring photos taken from the same locations and with the same framing. Spring photos were taken in April, 2003.

A minimum of three (3) photopoints was established within each stream crossing excavation (see Fig. 2, below for typical layout). Atypical stream crossing excavations required slight repositioning or additional photopoints. One photopoint was established immediately adjacent to the channel at the upstream end of the excavation with a view looking downstream, and others were established on the excavation sideslopes (left and right sideslopes) with views looking at the opposite sideslope and including the channel (see Fig. 2). Volunteer team members were positioned be within the field of view for all photos to serve as an approximate reference scale. Photopoint monuments consisted of 5 foot lengths ½"diameter rebar driven 2 feet deep with a 3-foot length of ½" diameter or larger PVC pipe slipped over the rebar. Stream crossing and photopoint identification numbers were permanently marked on the monuments to aid in photo retakes.

Figure 2. Typical layout of photopoint and grab sample locations at typical stream crossing excavations (PP = photopoint (arrow indicates direction of photo); GS = grab sample location). Note that left and right sideslopes are determined while facing downstream.



Net seasonal erosional and sediment yield estimates: Near the end of the winter rainy season, a field training session was held to train volunteers in quantifying erosion and sediment delivery at 18 stream crossings excavated in 2002. Methods for quantifying the volume of erosion consisted of taking a few simple measurements (e.g., width, length, depth) of the voids, or cavities, of discrete erosional features (channel scour, bank slumps) and calculating the volumes using appropriate formulae. Diagrams in Figure 3 show the layout of measurements for quantifying channel scour and bank slump erosional voids with reasonable accuracy. Measurements were recorded on field forms (example in Appendix A) and then entered into a spreadsheet database for calculation of erosion yield by these two processes. [Ultimately, measurements of post-winter erosion yields done by the volunteers proved unreliable due to the limited time for training and the considerable professional judgement required in measuring erosional voids. Consequently, measurements were re-done by experienced personnel at all sites initially done by volunteers so that greater confidence could be placed on the results.]

Not all the material eroded gets delivered to streams, depending on the time period considered and site characteristics. As mentioned above, the study was limited in scope to stream crossing excavations, and with respect to stream crossing excavations, erosion and sediment delivery are virtually equal, at least with the fullness of time. Excavation side slopes are typically steep and planar, and when slump materials accumulate on these slopes (rather than immediately entering the channel), they cannot be considered 'stable', and have a high likelihood of 'delivering' at some future time, especially where it impinges on the channel margins, as is often the case.

Channel Scour: Channel scour (fluvial erosion) was estimated by inputting field measurements of erosional scarp heights ('d1' and 'd2', Fig. 3A) and top widths ('w', Fig. 3A) made at geometric transitions within the excavations ('X#', Fig. 3B). To estimate the area of erosion at each transition, it was necessary to develop a method for reducing the gross area that would be calculated by simply multiplying average scarp height by top width, as only a portion of this gross area represents actual erosional losses (i.e., the finished grade upon completion of crossing excavation would have projected into the gross scour area). Use of gross area would have over-estimated true erosional area at individual transition points and for the crossing as a whole.

A calculation method was developed from cross section survey data at stream crossings excavated in 1979 at Redwood National and State Parks (data on file at RNSP). Scarp heights and top widths were measured on graphical plots of cross sections showing pre-erosion and post-erosion surveys to extract data analogous to the type of measurements taken at the SFI stream crossings. Calculated scour areas from the surveys done by RNSP were then compared with gross area calculated by simply multiplying top width by average scarp height to search for a mathematical means to reduce gross area to approximate true erosion cross sectional area.

After trying several approaches, it was found that excavation side slope steepness provided a reasonably accurate means to reduce gross area, i.e., the steeper the side slopes, the less true erosion area is a percentage of gross area. Figure 4 shows a plot of the RNSP data used to develop the equation for reducing gross area and the equation itself. Although derived from only eight data points, it was felt that this equation provided a reasonable means to estimate channel scour from the field data.

Figure 3. Cross sectional (A) and overhead (B) schematic views of erosional void dimensions measured at stream crossing excavations.

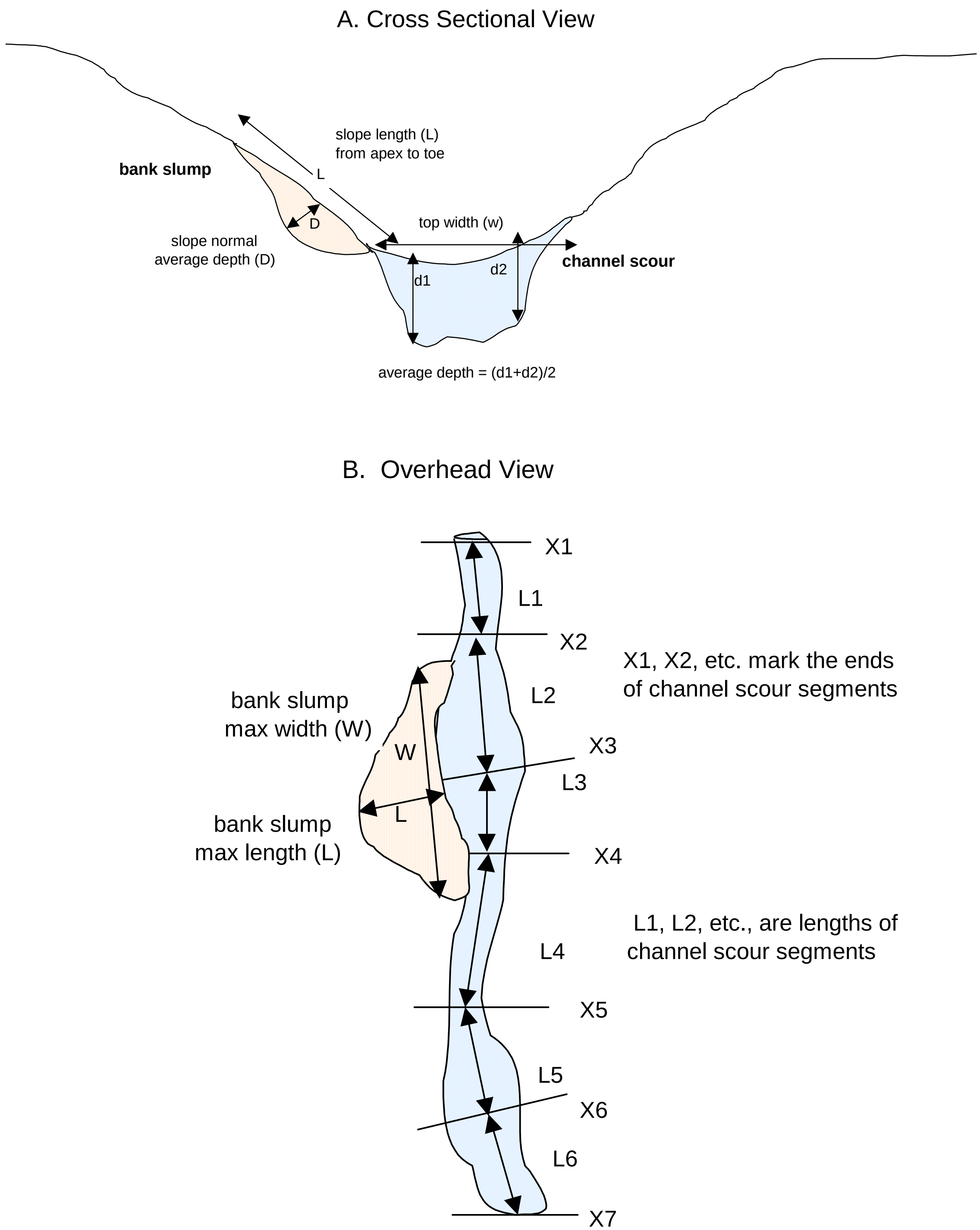
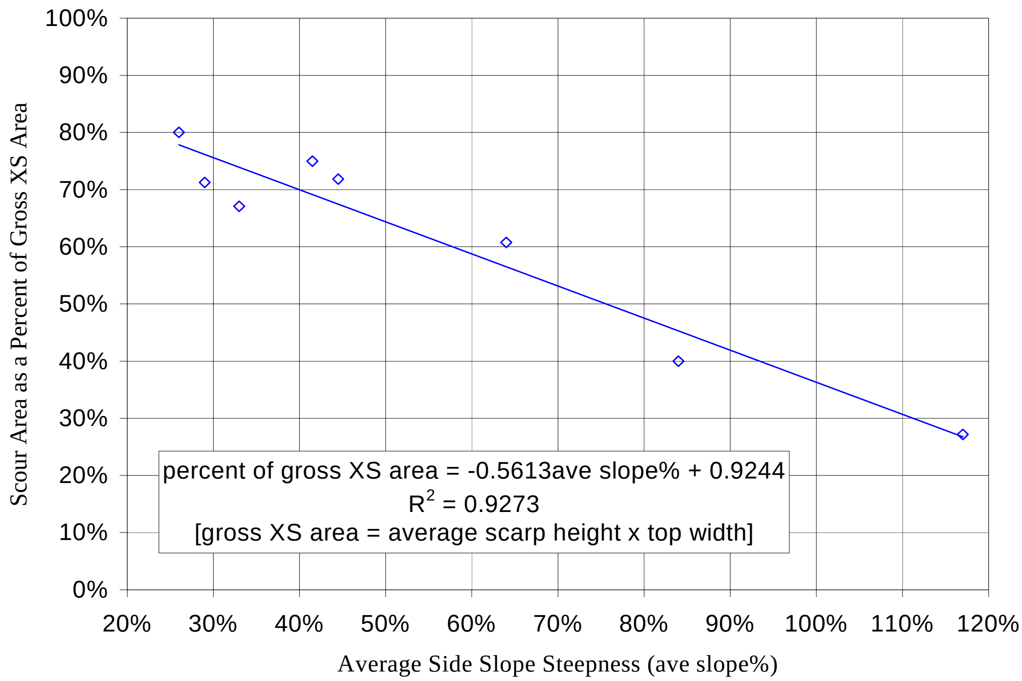


Figure 4. Average stream crossing side slope steepness vs true channel scour area as a percent of gross area (data on file at RNSP).



Bank Slumps: Erosional voids of bank slumps in stream crossing excavations were quantified by using the field measurements of width, length, and depth (as shown in Fig. 3) and applying a formula consistent with the parabolic shape typical of these features. The surface area was calculated by the formula:

$$A = 2/3XY$$

where: A = surface area in square feet,
X = maximum width along channel ('W' in Fig. 3B, feet),
Y = maximum length up from channel ('L' in Fig. 3B, feet)

Volume of bank slumps was calculated by multiplying area ('A', above) by average depth ('D' in Fig. 3A, feet). Average depth was estimated in the field by visually estimating the depth of the erosional void perpendicular to the adjacent slopes ('slope normal'). Volume is reported here in cubic yards (cy). Where slump shape was more rectangular than parabolic, this formula likely under-estimated volume. The percentage of slump volume not yet delivered to the channel (if any) was also estimated to allow reduction of total volume to account for only that which was delivered.

Surface Erosion: For surface erosion on excavation sideslopes, erosional severity was qualitatively evaluated by visually estimating the surface area of bare ground (not mulched) and characterizing erosional processes at work (sheet wash, rilling, gullying) and their severity class (e.g., minor or heavy). Surfaces covered by mulch were assumed to have experienced no surface erosion. Although the method did not provide volume estimates, surface erosion typically represents a small proportion of total erosion at excavated stream crossings. Thus, a qualitative approach was considered sufficient, and the technique was applied by volunteers with relative confidence following field training.

Winter Storm Sampling

Rainfall

Storage rain gages were placed at two locations within the project area to assess erosional stresses experienced over the winter monitoring period. Storage rain gages were installed near the Ancestor Creek (ANC) and Lower Helen Barnum Creek (HBA) offsite water sampling stations. Rainfall depths were recorded periodically throughout the winter. In additional, data from a continuous recording rain gage conveniently located near the study area (in Thompson Creek) was obtained for comparison with the storage gage data and for determining rainfall intensities. Ultimately, only the recorded (continuous) rainfall data were used.

Onsite Water Sampling

Grab samples of water were taken at a representative sample of about 25% (14) of the 65 stream crossing excavations done in 2002. Two grab samples were taken at each sampled crossing: water flowing out from each crossing was sampled first (GS1, Fig. 2) and then water flowing into each crossing (GS2, Fig. 2) was sampled. Procedures for taking grab samples were demonstrated to the volunteers during the pre-winter training session. The downstream sample (GS1) was taken first to avoid contamination from sediment that might be generated by walking within the crossing, although this was avoided to the extent possible. Wide mouth sample bottles were used for most sampling as these allow rapid water entry without submerging the bottle's mouth, a condition that could cause contamination by re-circulation of stream water within the bottle. Care was taken not to contaminate the sample with streambed sediment by selecting locations with sufficient water depth.

Attempts were made to obtain grab samples during significant rainstorms; times when erosional activity and turbidity generation within the stream crossing excavations would be expected. However, some storms, including the largest of the season, were not sampled due to dangerous weather conditions, lack of daylight, and limited availability of observers. Consequently, onsite water quality data consist of samples from a combination of several small to moderate storms and several between-storm (late-recessional or baseflow) periods.

Because of its ease of measurement and strong correlation with erosion and sedimentation, turbidity was selected as the sole water quality monitoring parameter. Turbidity of early-season samples was determined using a HF Scientific DRT-15CE turbidimeter by SFI volunteers. Some of the samples were later re-run for turbidity by me using a HACH 2100P turbidimeter and results between the two meters were compared. In most cases, turbidities obtained by the SFI volunteers with the HF Scientific DRT-15CE meter agreed well with those obtained by me using the HACH 2100P meter. However, some did not, particularly the more turbid samples.

The data indicate that the primary source of disagreement was due not so much to the use of two different meters, but rather by the method for extracting a sub sample from the sample collection bottle (typically about 400 ml) to fill the small cuvet (about 20 ml) for use in the meters. During turbidity testing, I refined a technique for sub-sample extraction that gave highly repeatable results. The technique consisted of vigorous sample agitation followed by immediate filling of the cuvet used in the HACH meter. This was repeated until consistent turbidity readings were obtained (typically three to four times). Consistency among repeated readings was taken as an indicator of representative sub-sampling. Later-season samples were all run by me using the HACH 2100P meter.

Offsite Water Sampling

As described above, the offsite water quality sampling strategy was designed to assess water quality effects on larger streams draining treatment areas. Sample collection followed the same procedures as discussed above for onsite sampling. Because offsite (downstream) water quality responses are delayed behind onsite (upstream) responses, sampling offsite is less time sensitive, providing a larger window of opportunity for effective sampling.

Selection of offsite sampling locations was guided by a ‘treatment/control’ sampling strategy, as described below:

Upper Mattole River (UMR): In the southwestern part of the project area, the upper Mattole River was sampled downstream of areas of road removal in 2002. Drainage area upstream from UMR is about 247 acres. The area above UMR has been extensively treated in 2002 (16 stream crossing excavations plus a number of other types of treatments), thus served as a ‘treatment’ site in a paired-basin type of sampling strategy for the 2002/2003 winter.

McNasty Creek (MNC): This site is downstream of an area not within the Sanctuary Forest and not slated for road removal activities. Drainage area upstream from MNC is about 277 acres. Land use activities are similar to other areas of the Upper Mattole, thus it served as a ‘control’ basin for contrasting with UMR.

Ancestor Creek (ANC): This site is an area where road removal hasn’t yet begun, but is planned in the near future. Thus, it served as a second control basin for contrasting with UMR until road removal work begins there and will become a treatment basin once work does begin. Drainage area upstream from ANC is about 347 acres.

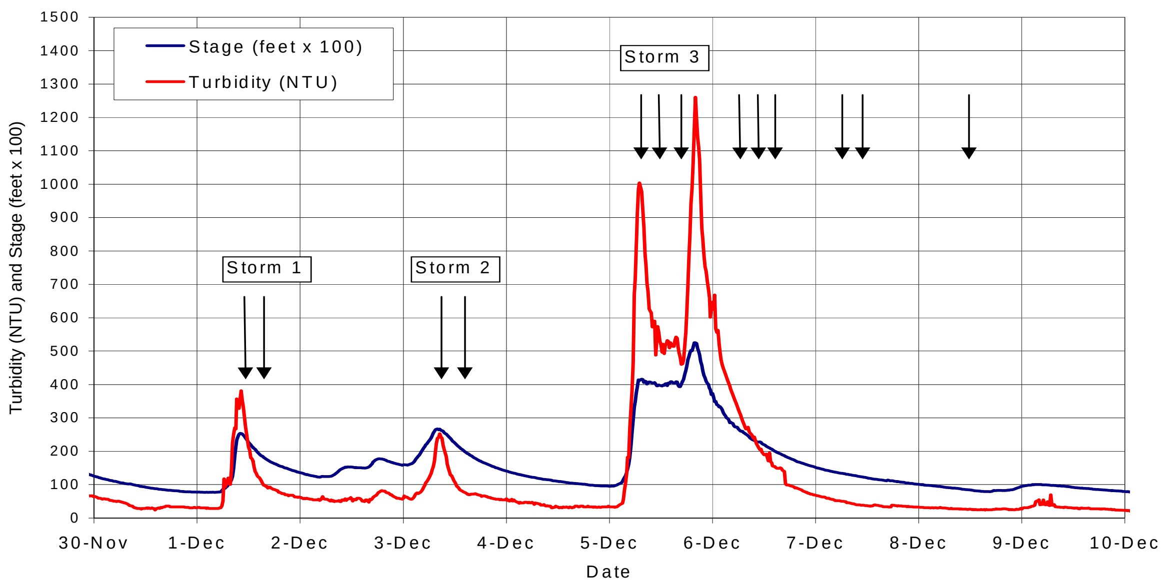
Helen Barnum Creek (HBA and HBB): In the northwestern part of the project area, the layout of the treated sites in Helen Barnum Creek afforded an opportunity for an upstream-downstream type of sampling strategy. The treated road segment follows the creek for about 3500 feet and has 5 stream crossing excavations; no roadwork has been done or is proposed for the area upstream of the treatment site. Sampling was be done at both the downstream (HBA) and upstream (HBB) ends of the treated road segment, with onsite sampling also occurring at several of the stream crossing excavations. Drainage area upstream from HBA is about 377 acres and drainage area upstream from HBB is about 281 acres..

Data collected at UMR was compared with that from the adjacent MCN and ANC watersheds of similar size, rock type, and rainfall, but lacking road removal activities. Alternatively, the Helen Barnum sampling sites lent themselves to an 'upstream/downstream' sampling strategy (HBB is immediately upstream of treated tributaries and HBA is immediately downstream). While not a true 'paired watershed' approach due to the lack of a pre-treatment calibration period, the combination of onsite monitoring with the offsite sampling provided a fairly robust means to evaluate offsite effects. If sampling is continued at these sites during future years, ANC, presently a control watershed, will become a treatment watershed as road removal begins therein. Consequently, data collected in 2002/2003 will become valuable pre-treatment data for evaluating future work.

Uncertainty in interpreting results may be introduced by lack of knowledge of the sources of suspended sediment contributing to offsite turbidity, i.e., whether turbidity differences are due to road removal treatments or other upstream turbidity sources. This uncertainty was unavoidable, but was likely minimal in the Helen Barnum Creek setting because of the upstream/downstream setup. However, the UMR/MCN/ANC trio may be more subject to confounding sediment sources unrelated to SFI restoration work.

Figure 5 shows stream stage and turbidity during a fairly typical winter storm sequence occurring in a northcoast stream. Ideal sampling times, shown as arrows, target storm peaks and stormflow recession. In reality, however, dangerous weather, lack of daylight, or unavailability of volunteers caused sampling to be less than ideal.

Figure 5. Typical winter storm hydrograph and turbidigraph for a northcoast stream showing ideal times for manual turbidity sampling at offsite stations.



QUALITY CONTROL AND QUALITY ASSURANCE

Quality control and quality assurance was achieved by employing several methods. Pre- and post-winter training was conducted to provide all field personnel with the tools, information and hands-on experience needed to conduct the work properly and obtain reliable information. Data were provided to the oversight hydrologist soon after its collection to check for possible errors, missing information, and other potential problems so they could be quickly corrected.

Feedback was given to volunteer coordinators at various times throughout the winter data collection period. This feedback consisted chiefly of emphasizing the need for complete water quality sample sets (all monitoring sites) from storm monitoring sessions, assisting with decisions on when to sample at both onsite and offsite stations, and answering the inevitable questions that arose during the post-winter erosion inventory.

During the first storm monitoring session (Nov. 7-8, 2002), only about half of the onsite stations was sampled, and the sampling occurred over two days instead of one. The incomplete data set from this storm presented difficulties for analysis and interpretation of results. Later sampling sessions were, for the most part, sampled completely (all stations on a single day), although several sessions occurred on light rainfall (low erosional stress) days and were of limited value.

I re-analyzed a subset of water samples from both onsite and offsite locations for turbidity. Although I used a different turbidity meter than was used by SFI staff and volunteers (discussed above), most samples had very similar turbidities [note that different types of turbidity meters will give different results, but usually not by a large amount]. As discussed earlier, a method for sub-sample extraction for filling the turbidity meter cuvet was developed that provided repeatable results. This method was employed for most samples collected during the 2002-2003 rainy season.

A total of 204 samples was taken over the winter at onsite stations and 45 at offsite stations. I re-analyzed 32 of the 99 samples initially analyzed by SFI volunteers, or about one-third. Of these, 7 samples (or 22% of those re-analyzed) had widely divergent results between the initial readings taken by SFI staff and volunteers and my re-analysis. All 7 of these samples were quite turbid (>500 NTU). As discussed earlier, I suspect that the procedure used in obtaining a sub-sample for use in the turbidity meter was the culprit for the divergent results between SFI volunteers and myself. For samples run by both SFI volunteers and myself, I used my values in all data representations and analyses.

Finally, I performed erosion measurements on a subset of the stream crossing excavations inventoried by the volunteers to evaluate the quality of information collected. While some amount of disagreement in erosion inventories is to be expected among even the most well trained observers, the check was designed to identify and correct errors resulting from lack of correct identification of erosion features and their spatial dimensions and errors arising from mis-recorded data. As mentioned earlier, large disagreement was found in the subset re-sampled, so all sites were subsequently re-done with experienced personnel and those results are included herein.

RESULTS

Onsite Water Quality

Figures 6-11 show turbidities from individual onsite water quality monitoring events over the 2002-2003 winter period. Figures 12-17 present these data as increases in turbidity from the upstream sampling location (GS2) to the downstream location (GS1). In 14 out of the total of 76 upstream/downstream sample pairs, water sampled at the upstream end of an excavation was more turbid than that sampled at the downstream location. In ten of those cases, turbidity values and their percent differences were fairly low. This probably reflected real but minor differences in samples or subsample extraction procedures (discussed above), and such differences were not considered significant.

However, for four of the upstream/downstream sample pairs, both the turbidity values and the percent differences were large. This seems a physical impossibility: how could a large part of the suspended sediment load settle out of the water column within the short, steep channel characteristic of a stream crossing excavation? In these four cases, it is suspected that the samples were mis-labeled and that the more turbid sample of the pair was actually from the downstream sampling location. Although this could not be verified, this was assumed to be the case in data analysis and plotting the results. In Figures 6-8 and 12-15 (the sampling periods when mis-labeling was assumed to have occurred), the affected data points are clearly marked for these four cases. Note the changes in vertical scale when viewing Figures 6-17.

Figure 6. Sanctuary Forest onsite water quality results for Nov. 7-8, 2002.

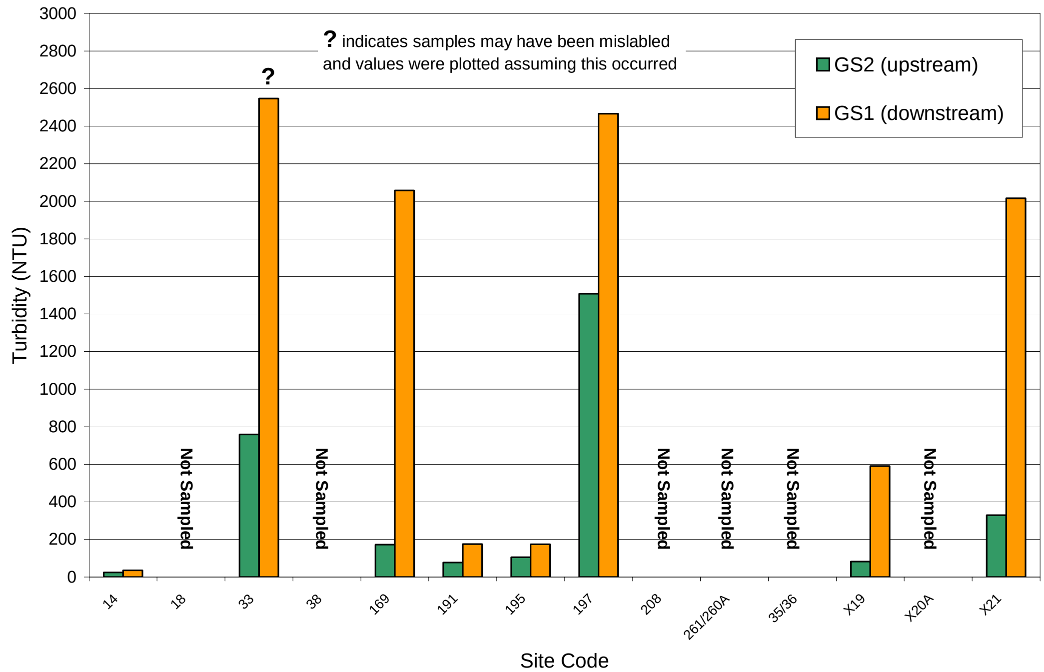


Figure 7. Sanctuary Forest onsite water quality results for Dec. 14, 2002.

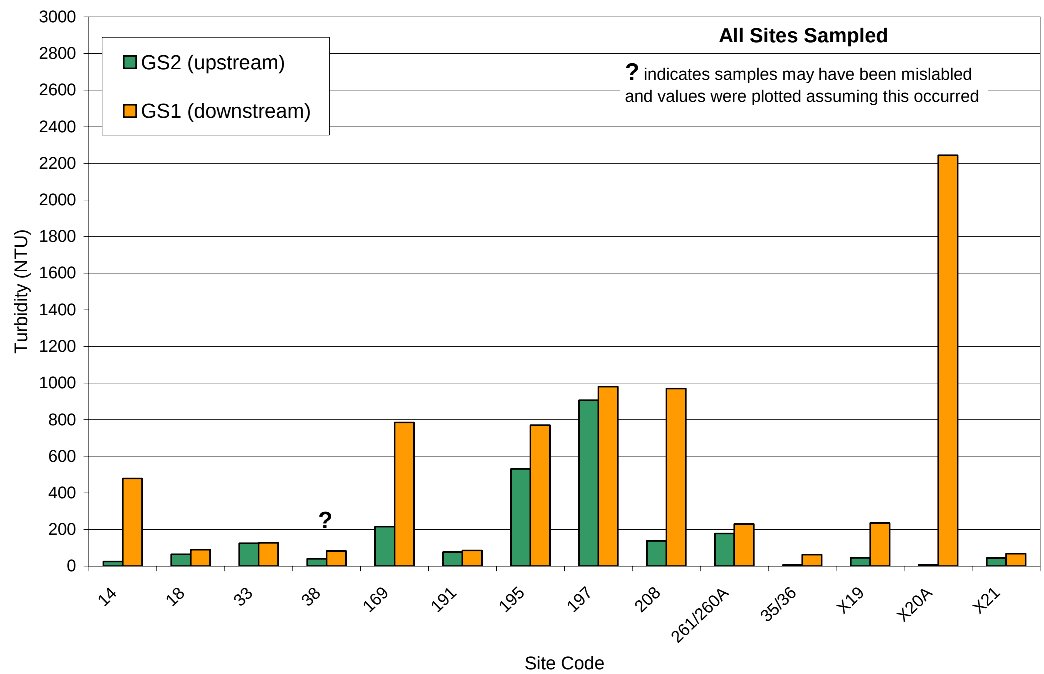


Figure 8. Sanctuary Forest onsite water quality results for Dec. 16, 2002.

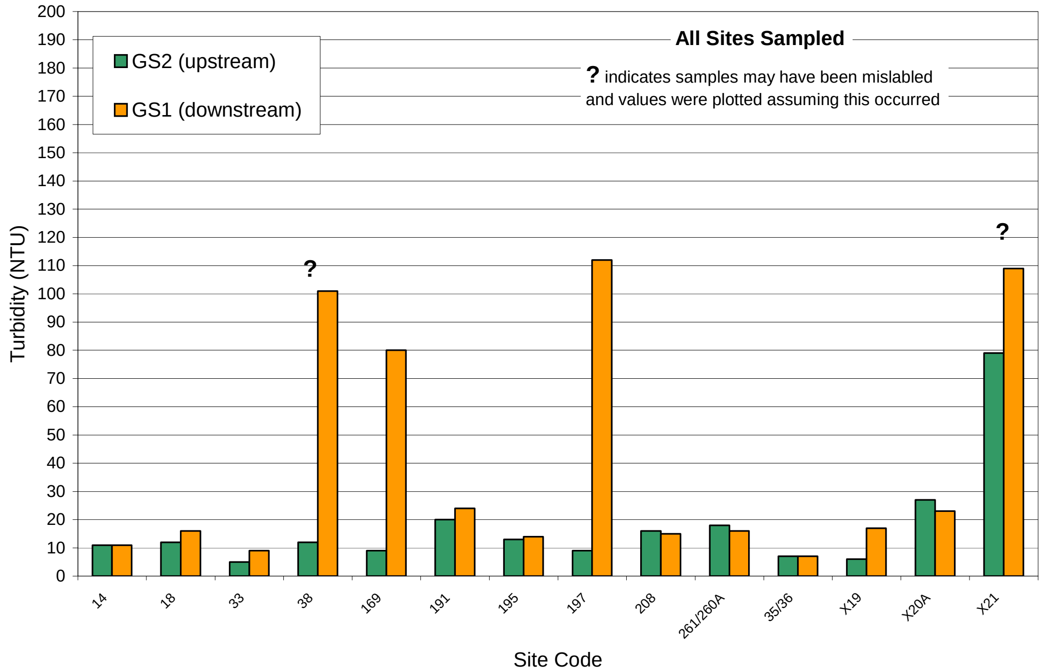


Figure 9. Sanctuary Forest onsite water quality results for Dec. 20, 2002.

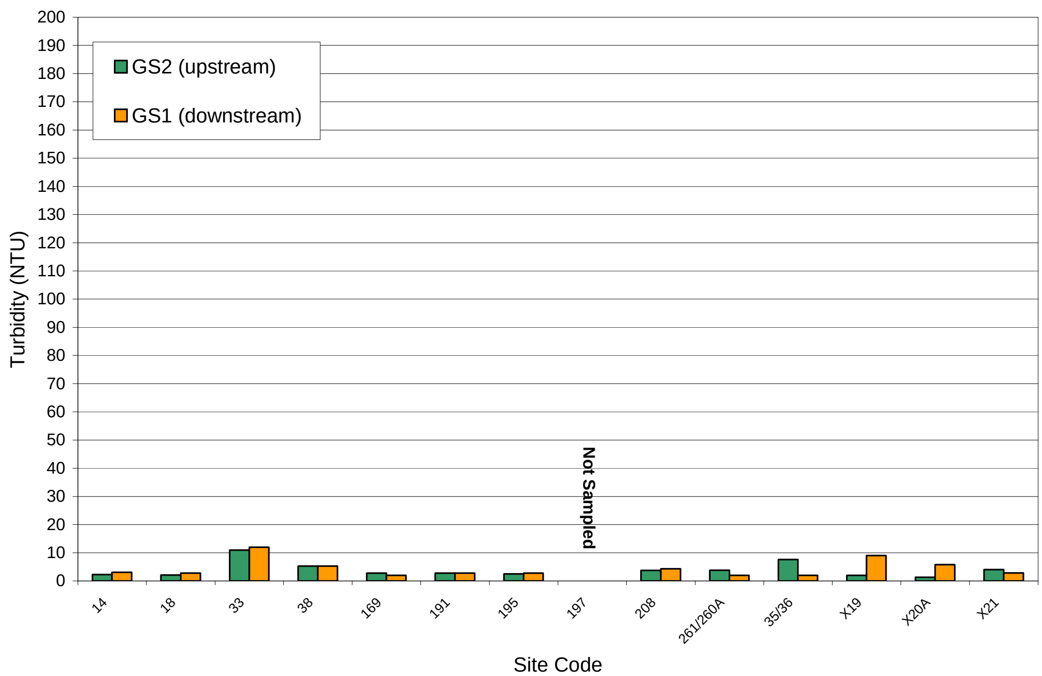


Figure 10. Sanctuary Forest onsite water quality results for Jan. 14, 2003.

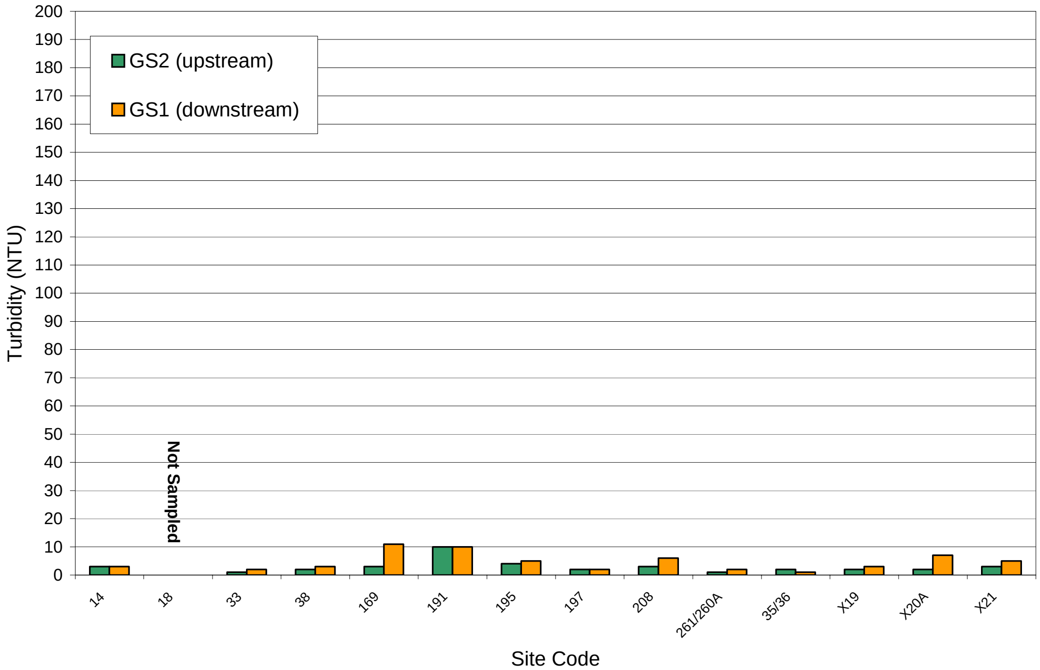


Figure 11. Sanctuary Forest onsite water quality results for Mar. 14, 2003.

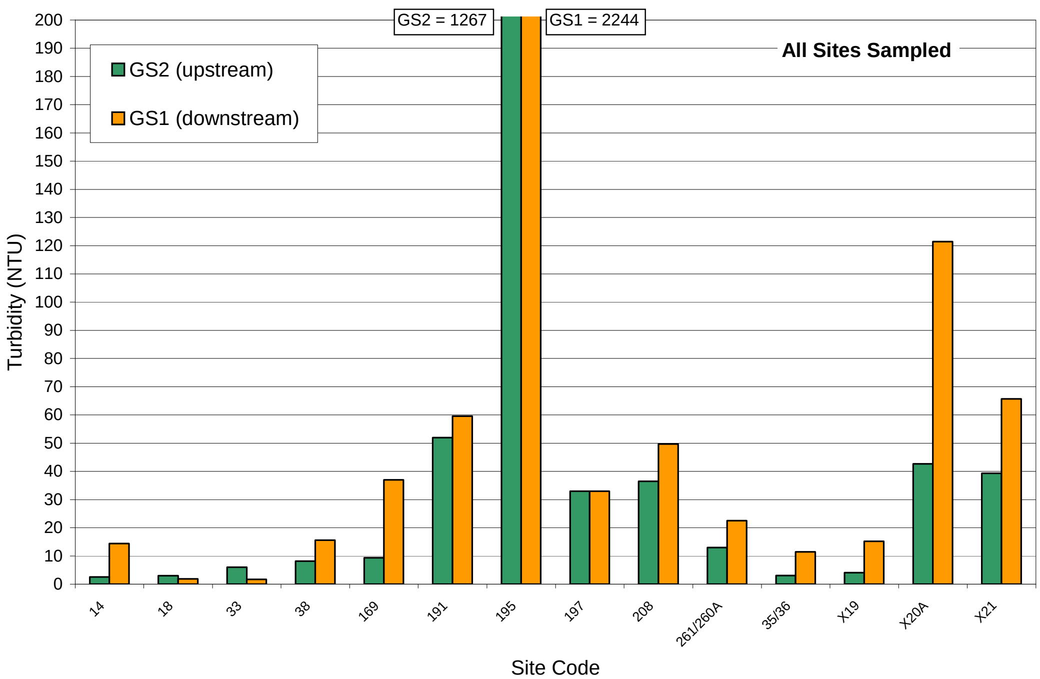


Figure 12. Turbidity increases within stream crossing excavations, 7-8 Nov. 2002.

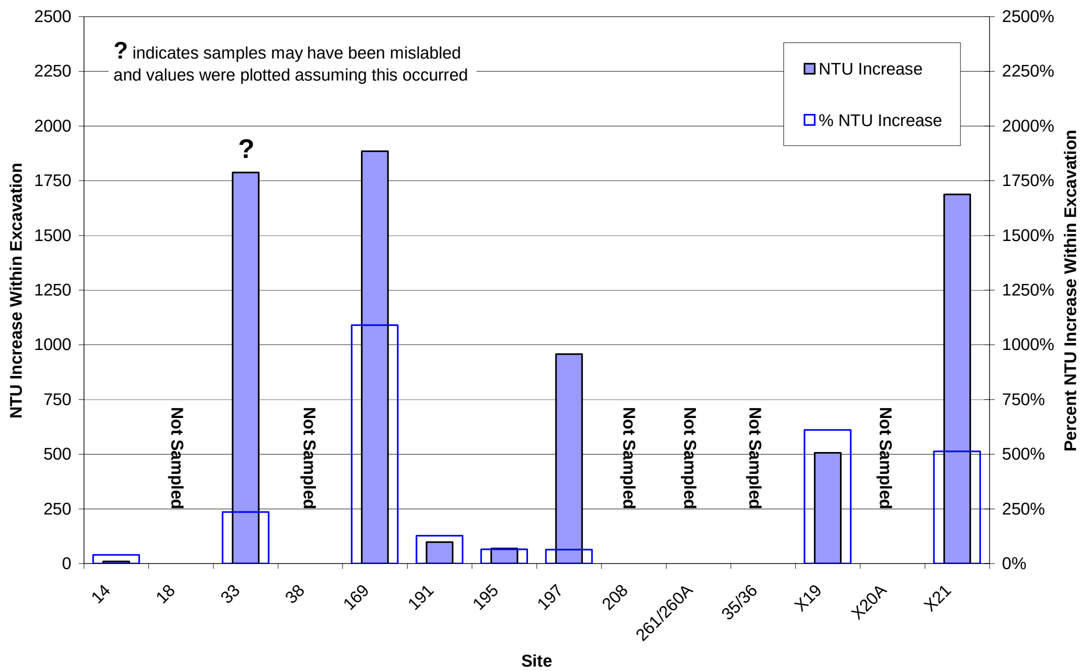


Figure 13. Turbidity increases within stream crossing excavations, 14 Dec. 2002.

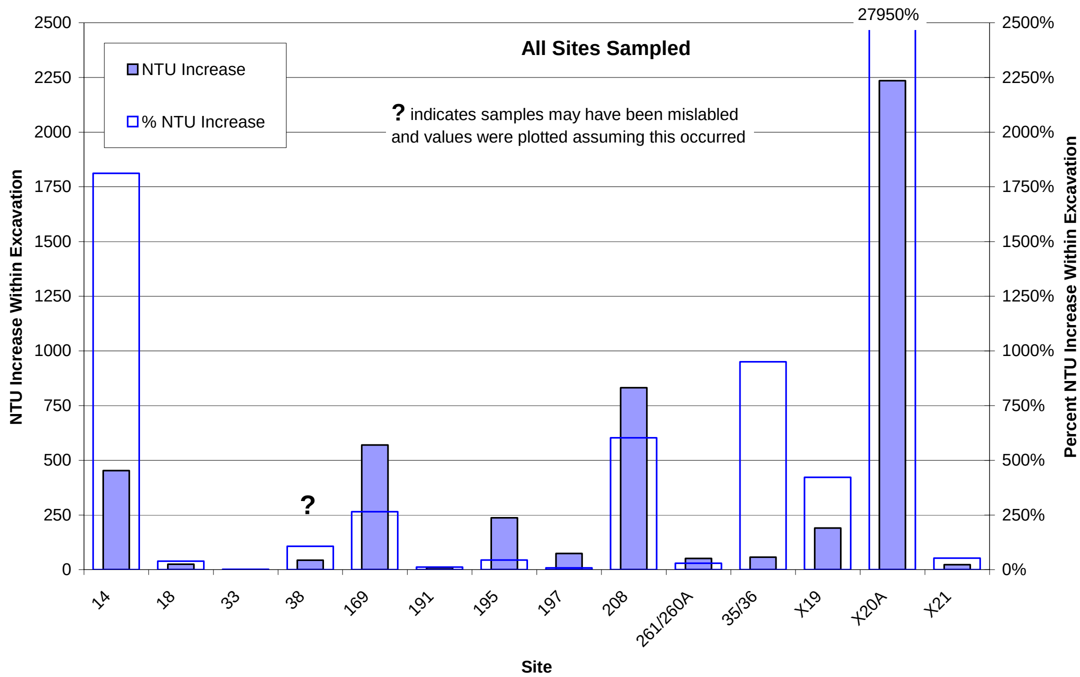


Figure 14. Turbidity increases within stream crossing excavations, 16 Dec. 2002.

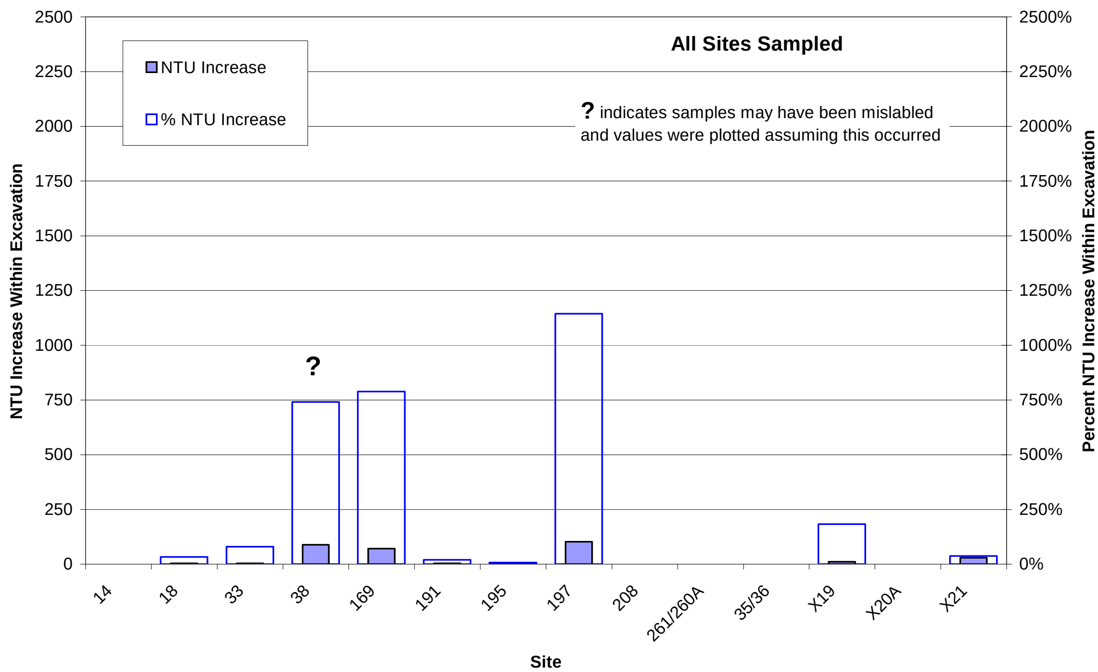


Figure 15. Turbidity increases within stream crossing excavations, 20 Dec. 2002.

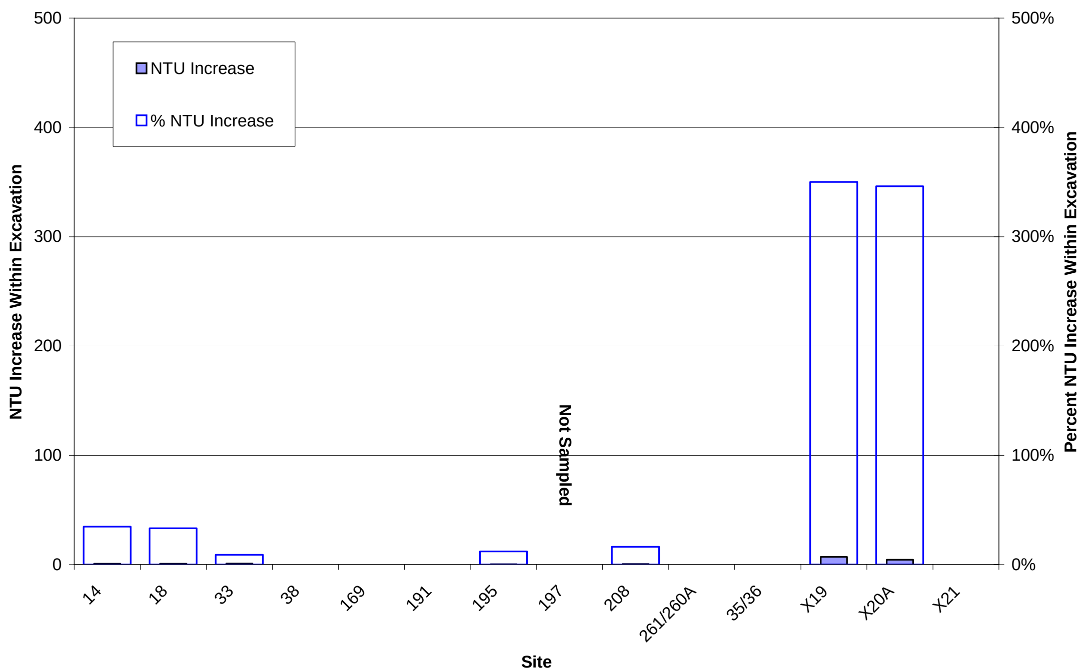


Figure 16. Turbidity increases within stream crossing excavations, 14 Jan. 2003.

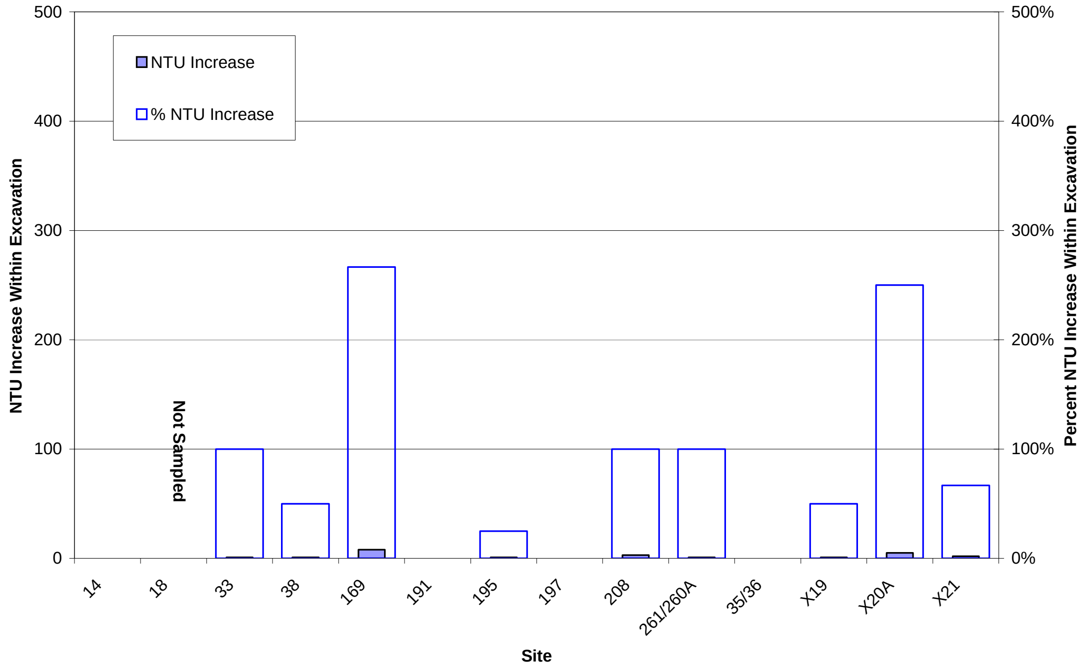
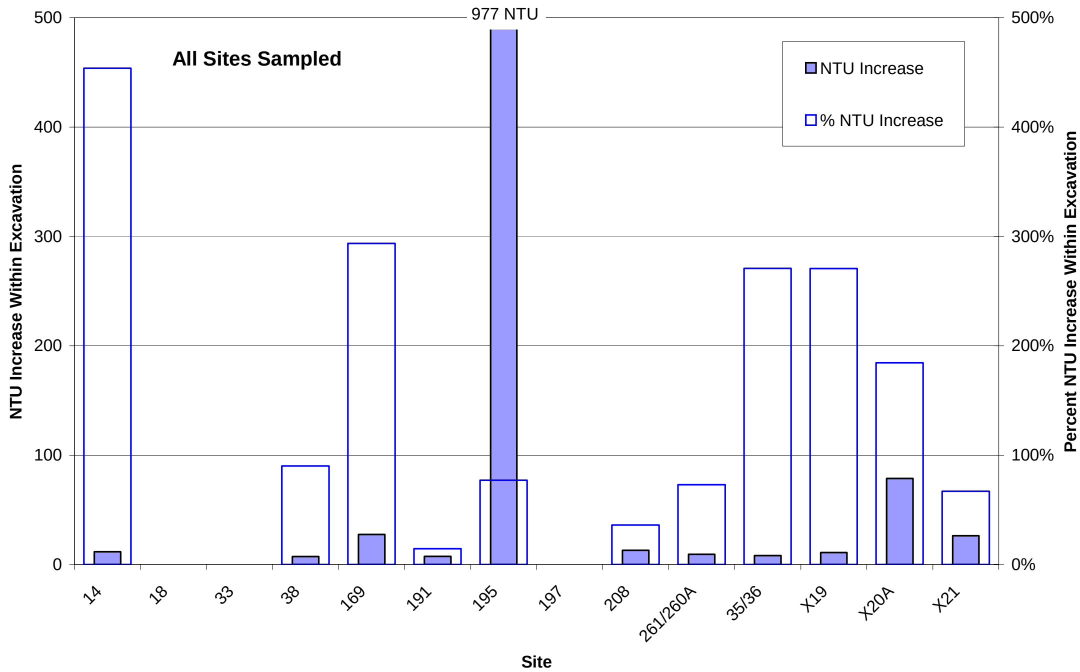
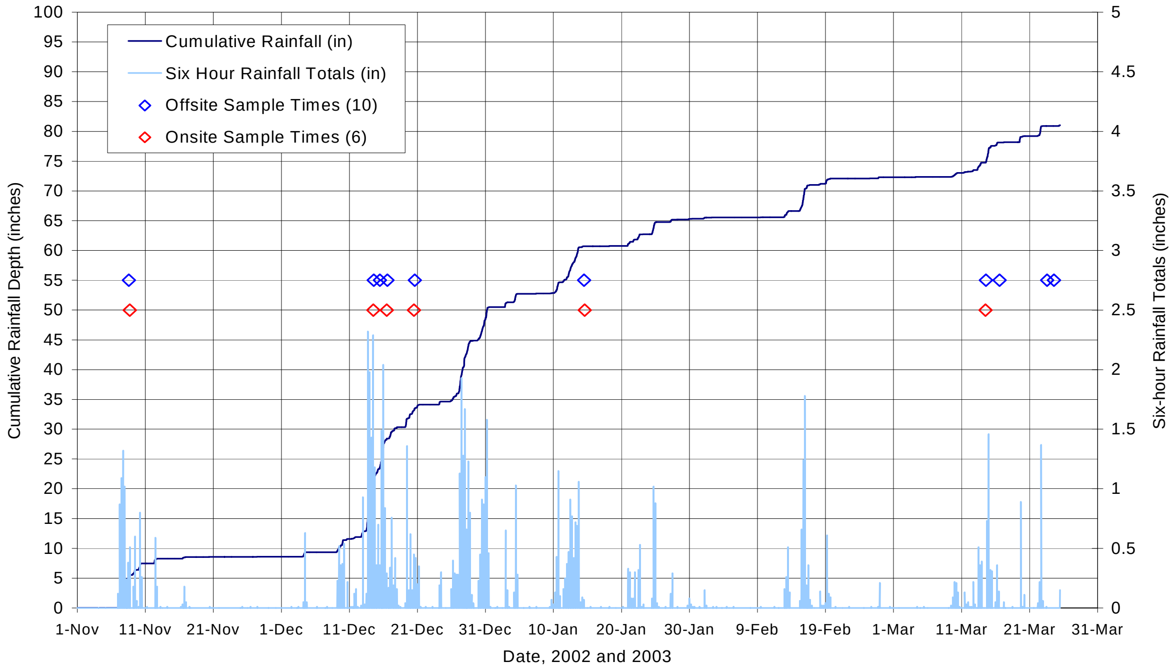


Figure 17. Turbidity increases within stream crossing excavations, 14 Mar. 2003.



It is important to view the data in Figures 6-17 in terms of the hydrological stresses imposed by rainfall during the sampling times. Figure 18 shows both cumulative and short-term (6-hour) rainfall depths recorded at a National Weather Service rain gage in Thompson Creek, less than a mile from the project area. Sampling times are shown for both onsite and offsite samples. As indicated, rain was falling during most sampling times, but the heaviest rainfall for those storms usually preceded the sampling times by several hours.

Figure 18. Upper Mattole rainfall (Thompson Creek raingage) and Sanctuary Forest water sampling, Nov. 2002 through Mar. 2003



The first round of sampling occurred over a 2-day period (Nov. 7-8, 2002), but only eight of the fourteen sites were visited. Of those sites, five exhibited large erosional responses, as indicated by much greater turbidity in water flowing out of the site compared to that flowing in (see Figs. 6 and 12). Three sets of samples (Dec. 14, 16, and 20) were obtained during the intense storm period of mid- to late December, 2002. Only the first of these three sets (Dec. 14) occurred while heavy rain was falling, and this is reflected in the higher turbidities shown in Figures 7 and 13 relative to those from Dec. 16 and 20. Several significant storm periods were not sampled during the winter period: two in late December and one in mid-February.

The final round of sampling occurred during a moderate rainfall event in mid-March (March 14, 2003, see Figs. 11 and 17). Most sites exhibited small or no turbidity responses, but four of the 14 sites had relatively large responses during this late-season storm. These were sites 169, 195, X20A, and X21. This storm provided closure on the winter onsite sampling period and indicated that, by and large, erosional responses in the sampling sites had considerably diminished over the winter sampling period.

Table 1 lists sites where large upstream/downstream turbidity differences were observed. Four sites stand out as 'repeat offenders', or sites where large turbidity responses were observed on more than one occasion: 169, 197, X20A, and X21. Note that on sampling events where one of the listed sites was not sampled ('NS'), it is unknown whether or not a large turbidity response occurred, thus sites 38 and 208 may also be repeat offenders and sites 197 and X20A may actually have had an additional occurrence of large turbidity response among the sampling events.

Table 1. Turbidity response at those sites where a large response was observed at any time during the study period ['N' = no large response; 'Y' = large response; 'NS' = not sampled] ['repeat offenders' shown in **bold** font].

Storm Sampling Date	Turbidity Responses by Sampling Date at Sites Exhibiting Large Responses During Any Sampling Date									
	14	33	38	**169**	195	**197**	208	X19	**X20A**	**X21**
11/7-8/02	N	Y	NS	**Y**	N	**Y**	NS	Y	**NS**	**Y**
12/14/02	Y	N	N	**Y**	N	**N**	Y	N	**Y**	**N**
12/16/02	N	N	Y	**Y**	N	**Y**	N	N	**N**	**Y**
12/20/02	N	N	N	**N**	N	**NS**	N	N	**N**	**N**
1/14/03	N	N	N	**N**	N	**N**	N	N	**N**	**N**
3/14/03	N	N	N	**Y**	Y	**N**	N	N	**Y**	**Y**

Offsite Water Quality

Offsite samples were taken during ten rounds of sampling between early November, 2002, and late March, 2003. Table 2 shows turbidity results from these events. To assess downstream effects on water quality, UMR (treatment site) is best compared against ANC and MCN (adjacent control sites), and HBA (treatment site) is best compared against HBB (upstream control site).

Table 2. Results of grab sampling at offsite location, winter 2002-2003. Treatment sites (those draining areas where road removal work occurred in summer, 2002) are shown in *red italic* font and control sites (no road removal work done) are shown in green non-italic font. ['NS' indicates no sample was obtained].

Site	Sampling Date									
	11/08/02	12/14/02	12/15/02	12/16/02	12/20/02	01/14/03	03/14/03	03/16/03	03/23/03	03/24/03
ANC	8	58	11	27	2	4	10.2	2.3	1.6	1.8
MCN	4	86	8	14	1	12	23.7	2.4	1.8	1.4
UMR	*20*	*107*	*15*	*28*	*3*	*12*	*19.8*	*3.5*	*3.6*	*1.6*
HBB	5	130	NS	55	NS	NS	13.7	3.4	2.2	0.9
HBA	*6*	*328*	*16*	*63*	*NS*	*NS*	*5.8*	*3.6*	*2.1*	*1.9*

Figure 19 shows turbidity results by site, while Figures 20 and 21 show results by sampling date for the UMR/MCN/ANC offsite group and the HBA/HBB offsite group, respectively.

Figure 19. Sanctuary Forest Offsite Monitoring Results by Site for WY2003

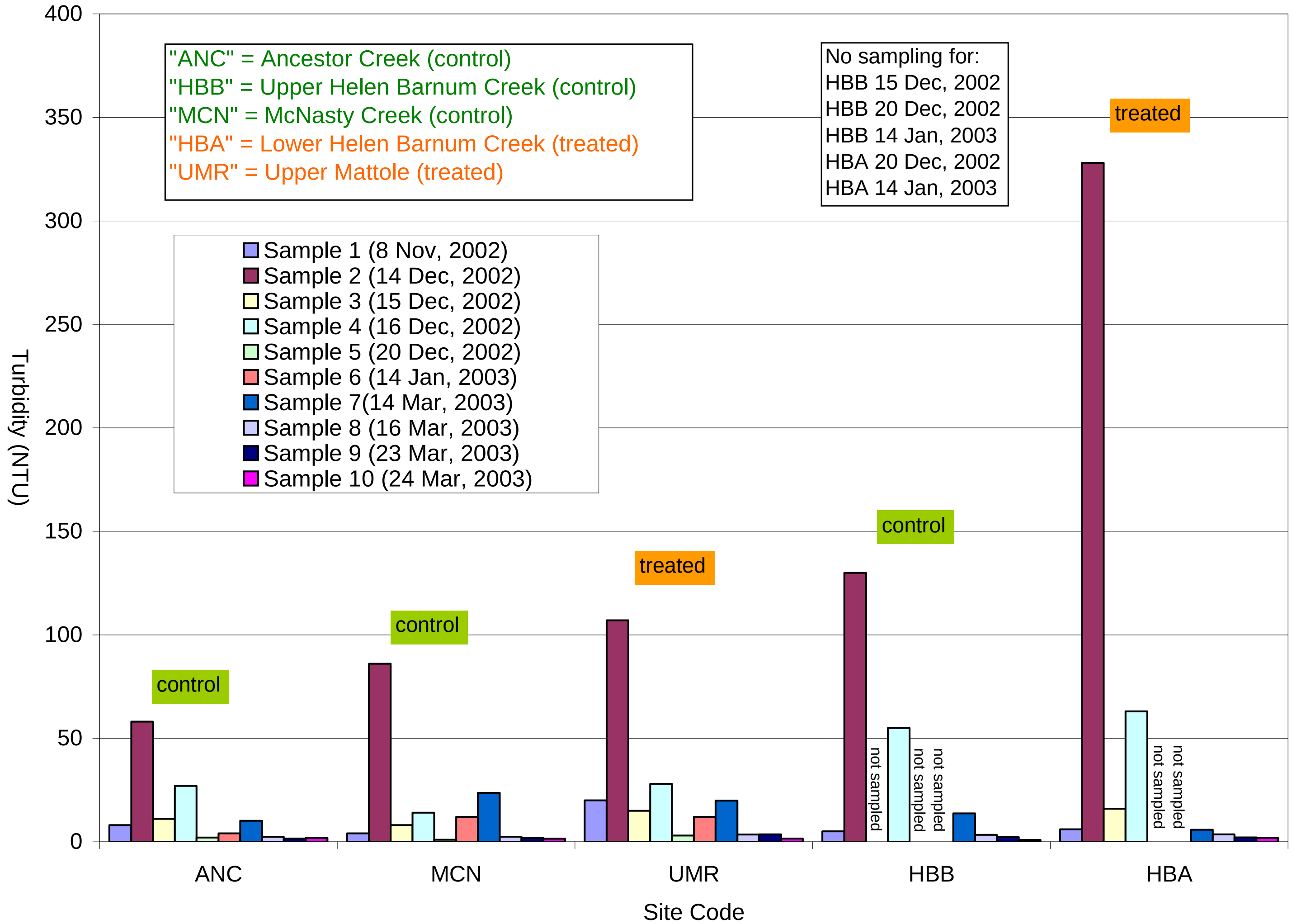


Figure 20. Turbidity results at offsite locations UMR, MCN, and ANC by sampling date.

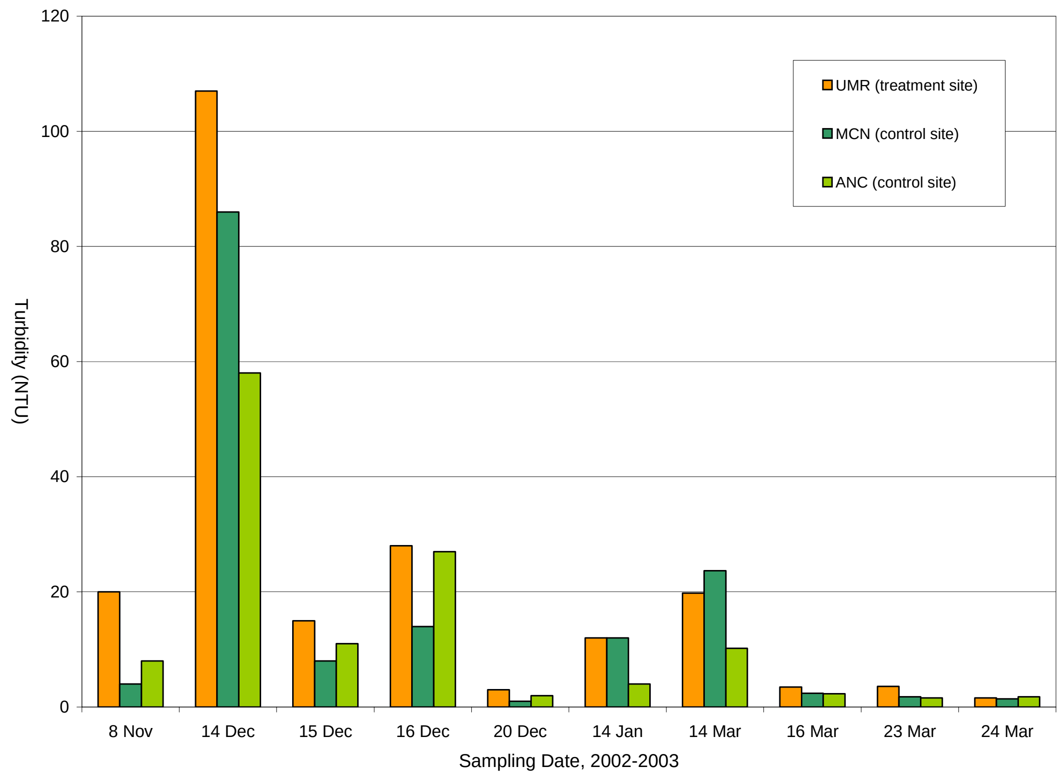
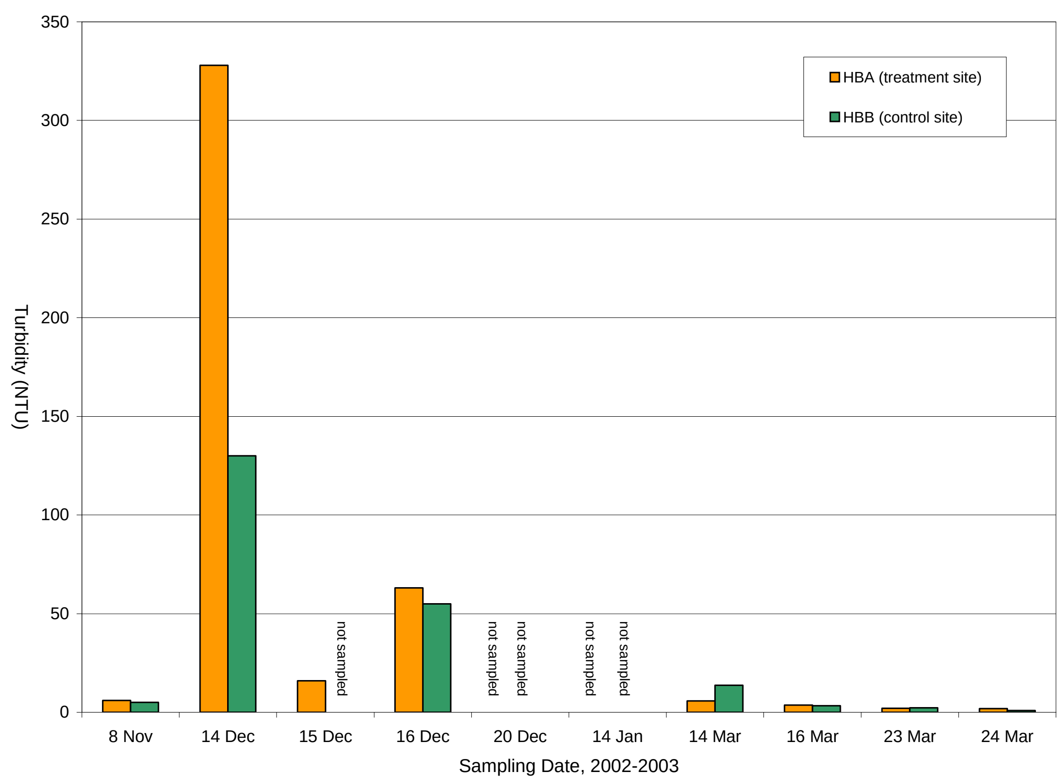


Figure 21. Turbidity results at offsite locations HBA and HBB by sampling date.



As indicated in Table 2 and Figures 19-21, turbidity at all offsite locations generally declined over the sampling period. This is due to the occurrence of larger storms in December than later in the winter period. Although a large storm (second largest of the winter, judging by peak rainfall intensities shown in Fig. 18) on Dec. 27, 2002, was not sampled, turbidities would be expected to be lower than those measured during the largest storm that occurred two weeks earlier on Dec. 14.

In Figure 20, the treatment site (UMR) was higher than one or both control sites (MCN and ANC) during the first four sampling events (early Nov. through mid-Dec., 2002), after which differences were minimal. For the HBA/HBB offsite sampling group (see Fig. 21), the treatment site (HBA) was substantially greater than the control site (HBB) during only a single sampling event, however, missed samples (5 between the two sites) limits the number of sampling events to only seven of the ten events samples at the UMR/MCN/ANC group. For the seven sampling events common to both groups (including the largest storm of the season), results were nearly identical in a relative sense (virtually the same relationships between turbidity magnitudes at control and treatment sites).

Net Seasonal Erosion and Sediment Delivery

Table 3 show net seasonal erosion and sediment delivery results from the erosional void ("cavity") measurements made at the 18 stream crossing excavations, along with additional data collected at each crossing. Both within-crossing and above-crossing (upstream headcutting) sediment delivery values are given, as well as the total attributable to crossing excavation. Figures 22 and 23 show these data graphically, arranged in order of largest to smallest volumes. Figure 22 expresses volumes both as total sediment delivery and delivery volume per lineal yard of excavated channel to allow comparison of excavations of different size. Figure 23 expresses volumes by the two dominant erosion processes; channel scour and bank slumping.

Table 3. Net seasonal erosion and other characteristics at SFI stream crossing excavations.

	Within Crossing Sediment Delivery							Within and Upstream of Crossing			
Site No.	Channel Scour (cy)	Bank Slumps (cy)	Xing Deliv. (cy)	Channel Length (y)	Ave. Side Slope (%)	Channel Slope (%)	Unit Deliv. (cy/y)	Headcut Vol (cy)	Total Deliv. (cy)	Total Length (yd)	Total Unit Deliv. (cy/y)
X20	10.3	20.8	31.1	58	89%	30%	0.53	0	31.1	58	0.53
191	7.0	0	7	29	54%	1%	0.24	44.5	51.5	96	0.54
38	40.2	0	40.2	36	112%	5%	1.12	0	40.2	36	1.12
169	13.7	3.6	17.3	71	37%	14%	0.24	0	17.3	71	0.24
261a	21.7	2.2	23.9	56	46%	3%	0.42	0	23.9	56	0.42
12	15.4	3.2	18.6	27	80%	26%	0.68	0	18.6	27	0.68
261	16.6	0.4	17	45	13%	5%	0.38	0	17	136	0.13
X21	11.2	2.9	14.1	52	11%	9%	0.27	0	14.1	155	0.09
14	12.8	0	12.8	53	24%	4%	0.24	1.5	14.3	59	0.24
249	13.7	0	13.7	44	31%	30%	0.31	0	13.7	44	0.31
195	11.6	0	11.6	57	20%	6%	0.20	0	11.6	57	0.20
18	6.0	0	6	27	22%	9%	0.22	0	6	27	0.22
35/36	5.7	0	5.7	65	9%	10%	0.09	0	5.7	65	0.09
X19	2.9	1.2	4.1	49	11%	37%	0.08	0	4.1	49	0.08
208	2.2	1.3	3.5	45	10%	38%	0.08	0	3.5	45	0.08
33	2.7	0	2.7	32	9%	1%	0.09	0	2.7	32	0.09
197	2.1	0	2.1	36	6%	28%	0.06	0	2.1	36	0.06
297	1.6	0	1.6	33	5%	26%	0.05	0	1.6	33	0.05
Total =	197.4	35.6	233	815	---	---	---	46	279	1082	---
Ave =	11.0	2.0	12.9	45	33%	16%	0.29	2.6	15.5	60	0.29

Figure 22. Sediment yields from SFI stream crossing excavations, 2002.

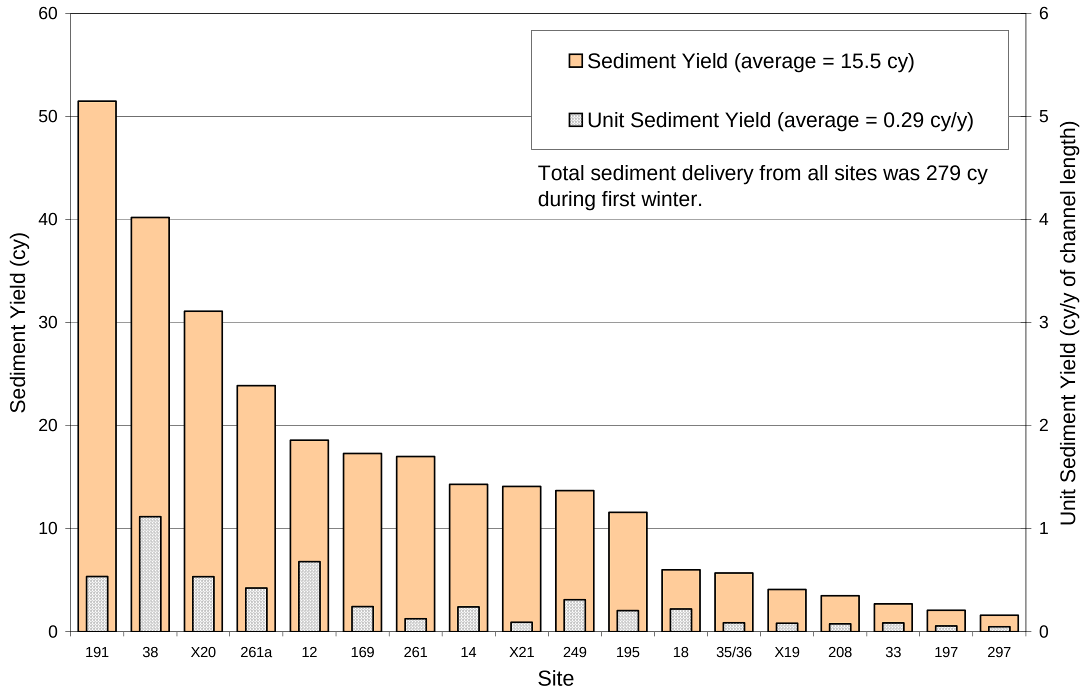
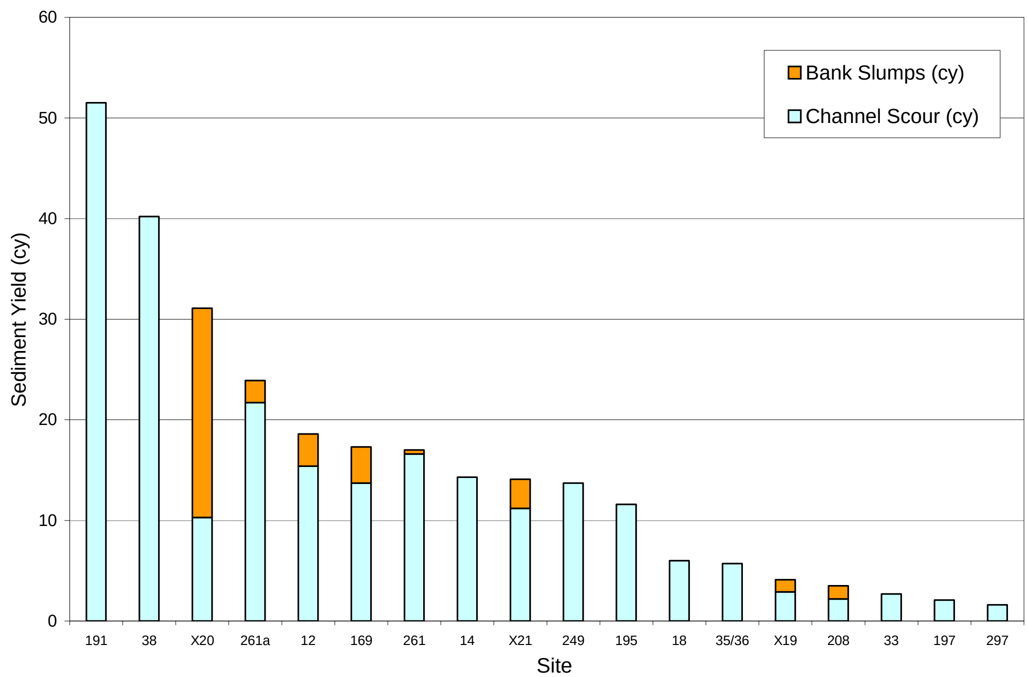


Figure 23. Sediment yields by process from SFI stream crossing excavations, 2002.



As shown in Table 3, average sediment delivery from the sample of stream crossing excavations was 15.5 cubic yards (cy), with channel scour (including upstream headcutting) accounting for the majority (88%) of the total. Headcutting occurred upstream of two of the inventoried crossings (Site 191 was 44.5 cy, Site 14 was 1.5 cy), accounting for about 16% of the total delivery measured. Volumes due to banks slumps were overshadowed by channel scour, accounting for only 13% of total erosion.. Unit erosion, expressed as cubic yards of erosion per lineal yard of channel length, averaged 0.29 cy/y for the 18 sites, ranging from 0.05 to 1.12 cy/y (see Table 3). As mentioned earlier, unit erosion allows comparison of stream crossing excavations of different size in terms of channel length (the longer the channel excavation, the greater the exposure to erosive forces).

Channel scour should also vary directly with channel slope, as slope is a major determinant of erosive force ('streampower'), along with flow rate. However, as shown in Table 2, several of the steepest channels experienced relatively low erosion, while some of the gentlest channels had high erosion. This is likely explained by differences in peak flow rates, which were not quantified in this study, headcutting upstream of the gentlest crossing (site 191), and the existence of bedrock in some steep channels. Drainage areas upstream of the sites could serve as a surrogate for peak flow rate, but were not determined. Typically, steeper channels are associated with smaller drainage areas found near headwaters. Thus as drainage area increases, channel slope should decrease, however this is a broad generalization to which exceptions will occur.

Comparison of water quality and net seasonal erosion

With perfect sampling, one would expect good correlation between storm water quality sampling and sediment yields at stream crossing excavation sites. However, perfect sampling requires continuous recording of streamflow and turbidity at the sites during all storms, quite infeasible for the type of study conducted here. Without continuous recording of streamflow and turbidity, parts of storm hydrographs (rising limb, peak, recessional limb) will be unsampled, and some storms will be missed altogether. This was the case here, despite a considerable winter storm monitoring effort by SFI staff and volunteers. Consequently, the water quality (turbidity) sampling done here merely provides snapshots at discrete points in time of erosion and sedimentation processes occurring at excavations. Net seasonal erosion measurements, however, provide data on the sum total of erosional responses that occurred during the entire winter runoff period, but provide no information on exactly when they occurred. This disparity was inescapable and limited the ability to relate erosion and water quality responses in this study.

Table 4 lists the sites that exhibited large turbidity responses during one or more sampling events along with net seasonal erosion and sediment delivery volumes. While some sites fit the expected association of large turbidity responses at sites with large sediment delivery, several did not: sites 33, 197, 208 and X19 had relatively low delivery, all well below the average of 15.5 cy (0.29 cy/y), with site 197 being a repeat offender. The best explanation for this is that storm sampling is a 'hit or miss' endeavor on small, relatively flashy streams such as those sampled here, potentially leading to some sites being erroneously characterized as erosionally unstable, and others being erroneously characterized as stable. Thus, relying solely on grab sampling to evaluate erosional and/or water quality responses is not advisable.

Table 4. Sediment delivery volumes at sites that experienced one or more large turbidity responses [‘repeat offenders’ shown in **bold** font].

Sediment Delivery Volume	Sites Exhibiting Large Turbidity Responses During Any Sampling Date								
	14	33	38	**169**	**197**	208	**X21**	X19	**X20**
Total (cy)	14.3	2.7	40.2	**17.3**	**2.1**	3.5	**14.1**	4.1	**31.1**
Unit (cy/y)	0.24	0.09	1.12	**0.24**	**0.06**	0.08	**0.09**	0.08	**0.53**

DISCUSSION AND RECOMMENDATIONS

It is often assumed that the benefits of road decommissioning for reducing long term sediment yield to streams (‘sediment savings’) far outweigh the costs in terms of short term erosion and sedimentation responses, but this assumption is rarely tested by quantitative assessment of post-restoration erosion. Alternatively, the ‘eyeball’ method (visually judging the severity of erosion or estimating volume) is commonly relied upon, but can be misleading. This study provided quantitative information on post-treatment erosion and turbidity responses at stream crossing excavations that can and should be used for informing adaptive management. Insights from studies like this must be factored into management decisions about how far to go in terms of site-specific mitigations taken at individual stream crossing excavations and how many excavations to perform in any given year.

While reducing sedimentation threats from roads is an important component of watershed restoration, it is not without consequences. Short-term impacts to water quality downstream of stream crossing excavations are inevitable, and become obvious to those living and working near areas where road removal projects occur. The expansion of this type of work in recent years has made it more visible and thus more subject to public scrutiny in the Upper Mattole River basin and elsewhere. The following discussion presents several ways for putting the measured erosion and sediment delivery volumes from the SFI crossings in perspective.

Comparison with Other Studies

In a study of post-excavation erosion at 24 stream crossings excavated in 1982 at RNSP, Klein (1984) found the erosion averaged 35 cy (0.95 cy/y) per site after the first winter. The study period (1982/1983) was fairly wet, as with the 2002/2003 winter experienced by SFI sites. The average total erosion in the RNSP study was about twice that of the SFI stream crossings, and unit erosion was over three times that in the SFI study.

Madej (2001) evaluated longer-term erosion and sediment delivery from excavated stream crossings, also on road removal projects within RNSP. For the period 1980 to 1997 (including several large storms), she measured a total of about 13,733 cy of sediment delivery at 207 excavations, or about 66 cy per stream crossing excavation. Thus, it appears longer-term sediment delivery from stream crossing excavations may approach twice that of first year erosion, assuming similar climatic conditions (i.e., erosional stresses). Assuming this also applies to the SFI projects, then the near-term average sediment delivery may exceed 30 cy per site.

SFI Erosion and Sediment Delivery Volumes

Distinguishing between erosion (soil displacement) and sediment delivery (the movement of displaced soil into a stream channel) is important because impacts to aquatic ecosystems only arise from the latter. Both erosion and sediment delivery were measured in this study, and the difference between the two was quite small (about 36 cy out of 315 cy total erosion, or about 11%) and due to slump volumes not yet fully delivered to the channels. As discussed earlier, erosion is nearly equal to sediment delivery in stream crossing excavations owing to typically steep, planar side slopes, and I suspect the 36 cy of 'undelivered' slump volume, and more from new or enlarging erosion features, will be delivered in the not-to-distant future.

The 18 sites inventoried for net seasonal erosion and sediment delivery span a fairly broad range of characteristics in terms of channel length, channel slope, and side slope steepness (see Table 3) and were assumed to be representative of all stream crossings excavated in 2002. This assumption remains unverified, but if valid, then the total sediment delivery from the 65 sites can be approximated by multiplying the average from the inventoried sites (15.5 cy) by 65, or about 1,000 cy. Whether this is considered a large or small volume, or an acceptable cost of reducing long-term sediment delivery is, to some degree, a value judgement and will vary from person to person. Various methods have been used for evaluating whether a given volume of sediment delivery at excavated stream crossings is large or small, including:

1) Sediment delivery volume as a percentage of stream crossing excavation volume;
2) Sediment delivery volume as a percentage of pre-excavation sediment delivery potential volume;
3) Sediment delivery volume as a percentage of total watershed erosion and/or sediment yield.

Each method has its own set of assumptions and merits, as briefly discussed below.

Sediment delivery as compared to excavation volume: Unlike the other methods discussed below, reliable data are relatively easy to obtain for item 1, above. However, it assumes that the difference between excavation volume and sediment delivery volume represents "sediment savings", but rarely does the entire crossing fill erode and deliver upon failure. Moreover, only a small percentage of road crossings will actually fail during even large storms. Consequently, use of excavated volumes as the yardstick in a "sediment savings" approach heavily skews the evaluation in favor of aggressively performing road decommissioning and inflates the true benefits of its use as mitigation in offsetting other land use impacts.

Excavation volumes for the SFI stream crossings are not yet available, so the following is offered for comparison. The total sediment delivery estimated above for the 65 stream crossings excavated by SFI in 2002 (1,000 cy) would be approximately equivalent to two small-sized or one moderately-sized stream crossing excavation. If one assumes that one or two of the 65 excavated stream crossings would have failed completely (all the fill went downstream, an unlikely scenario) this past winter if they hadn't been treated, then the sediment savings from the project would be on par with the sediment delivery caused by project implementation. It is impossible to know for sure if any of the crossings would have failed, but failure of one or two of the 65 stream crossings during the wet winter of 2002-2003 is not an unreasonable assumption.

Sediment delivery as compared to delivery potential: Item 2, above, seems more valid because it compares potential with actual sediment delivery, but estimating delivery potential at a stream crossing is subject to large observer bias. However, if we assume the estimate of sediment delivery potential made by PWA (19,000 cy) is a reasonable one, and divide this by the number of stream crossings inventoried (174), then the average pre-treatment sediment delivery potential is about 110 cy (note that the time period for this delivery is unknown). Thus, the average post-treatment sediment delivery measured in this study (15.5 cy) is about 14% of the estimated pre-treatment sediment delivery potential. If we also assume that the near-term (the initial several years following treatment) volume of sediment delivery at excavations is twice that of the first-year volume (after Madej, 2001), then post-treatment sediment delivery may approach 28% of pre-treatment sediment delivery potential. Thus, using sediment delivery potential as the yardstick (a more valid one than excavated volume), one would characterize the near-term impacts as more substantial than if excavated volumes were used.

Sediment delivery as a percentage of total watershed erosion and/or sediment yield: Item 3, above, is more consistent with water quality standards and basin plans, but unless rigorously investigated, watershed sediment yield estimates can have substantial uncertainty and may be unavailable for specific areas where road removal is conducted. Conducting a basin-wide erosion inventory and measuring sediment yield (primary components in a sediment budget) are expensive and logistically difficult tasks, especially where access for field inventories is limited. However, the approach is superior to the other two because it places road removal in a broader context; one that considers the myriad of erosion sources, both natural and human-caused, operating within a watershed. This approach becomes more feasible (and more relevant in evaluating a specific project) when limited in geographic scope to the primary sub-watershed(s) where the project is located, such as the Upper Mattole, rather than an entire river basin.

So how much is too much? As mentioned above, this not entirely a technical or scientific issue, but one that should be made considering input from stakeholders and using, among other criteria, the results and discussion provided herein. Some may consider sedimentation from SFI work in 2002 too great to conduct the remaining work at the pace presently scheduled, while others won’t. In my opinion, considering the high erosional stress of the study period, the erosion and sediment delivery experienced in 2002/2003 was not so extraordinary as to reduce the pace of work, but relatively minor adjustments in how the work is done are warranted. Several cost-efficient methods to reduce post-restoration erosion while keeping the overall program on schedule are discussed below.

Adaptive Management

Adaptive management consists of a three-step sequence: 1) quantifying and critically reviewing the erosional response of treatment sites and the results of monitoring, 2) seeking explanations for why some sites performed well (i.e., experienced minor erosion and sediment delivery) and others did not, and then, 3) modifying treatments at future sites accordingly. For example, if excessive channel scour occurred in an excavation, it might be explained by a mis-aligned excavation (the original channel was to one side or the other of the excavation), an excavation left above original channel grade (the original channel was below the excavated channel), lack of erosion-resistant features in the excavated channel (rocks, boulders, bedrock, woody debris), or any combination of these factors. Adaptive management could consist of improving pre-treatment channel surveys, improving grade control during excavation, or placing rocks or woody debris in excavated channels to resist erosional forces.

This study provided information for step 1, above, but step 2 requires qualitative assessments to determine explanations for observed erosion. For example, some sites with steep channels (high streampower) but had little erosion might have been stabilized by bedrock in the channel. Or some sites that had gentle channels (low streampower) but large erosion volumes might have triggered upstream headcutting by removing the grade control formerly provided by the stream crossing (as occurred at site 191 in this study). Much of this anecdotal information is already known by SFI staff, contractors that performed the excavations, and volunteers that conducted the monitoring. It is important to compile this type of information and fold it into adaptive management so that appropriate responses can be formulated for future work.

Klein (1984) found that erosive force (expressed as peak streampower during the study period), the coarse fragment content of streambank materials, and the amount of in-channel woody debris explained a high degree (92%) of the variation in channel scour along 24 excavated stream crossings in Redwood National and State Parks. Channel scour varied directly with streampower, and inversely with the other two variables (coarse fragment content of streambank materials and in-channel woody debris) because of their roles in providing erosional resistance. Due to the intensive fieldwork and the relatively high level of expertise required to quantify these variables, they were not collected for the SFI project, although they surely affected erosional responses within the SFI stream crossing excavations.

While little control can be exerted on the excavated channel gradient by restorationists, and none on the coarse fragment content of streambank soils, judicious application of channel stabilizing materials in excavations is feasible, as demonstrated elsewhere (RNSP). Imported rock (rip-rap) is typically cost-prohibitive, as well as being aesthetically undesirable. However, large woody debris (LWD) is usually abundant near stream crossing excavations due to earthmoving activities and is an important component of channel structure in stable streams. Thus, where bedrock or other stabilizing materials are not found in excavated channels, careful placement of LWD can provide an effective means to prevent or reduce channel scour, both within the excavation and upstream (headcutting). Additional benefits of woody debris placement include providing habitat for aquatic species (e.g., salamanders, salmon) and nutrients for primary production.

Proper placement of LWD is as much an art as it is a technical task; one that is difficult to convey with words. It is important to place logs in positions where they will remain relatively stable and not divert streamflow into channel banks. This may require slightly wider channel bottom excavations to accommodate woody debris. And LWD structures need not be designed as check dams; examples of ‘leaky’ LWD structures are abundant in natural streams, where they function to dissipate stream energy, store sediment, and control channel grade, and these structures can be replicated in stream crossing excavations by careful, selective LWD placement. Experience is the best teacher for woody debris placement, so it is recommended that restorationists experienced in woody debris placement be utilized included in design and placement of LWD.

Bank slumping is difficult to anticipate or avoid, but was not a major erosion process in this study. However, several lessons learned elsewhere are provided for consideration. First, placement of loose fill with direct access to channels should be avoided. Avoidance can be achieved through either compacting streamside fill or (preferably) by placing it on stable benches well away from channels. Second, excessively steep excavation side slopes should be avoided where possible, although excavating into native ground (deeper than the limit of fill material within a crossing) is not recommended.

Future Monitoring

Onsite Monitoring: Photopoints should be considered an essential component of any future monitoring done by SFI. They are relatively easy means to track changes at stream crossing excavations and provide a wealth of information, albeit qualitative.

Post-winter erosion and sediment delivery measurements at stream crossing excavations provided reliable data for evaluating erosional responses, although this task must be done by experienced professionals. Unlike other, less fortunate studies of erosion and sediment delivery, this study happened to be conducted during a wet winter when erosional stresses were relatively high. This provided a good test of erosional responses under stressful conditions. Consequently, the results of this study, contrary to those that would have been obtained if the winter had been below normal rainfall, probably answered the fundamental question ('how much erosion does road removal cause?') to a satisfactory degree. However, additional monitoring of erosion and sediment delivery volumes would certainly be instructive, both at the 2002 excavations (for tracking longer-term erosion) and those to be done in the future.

Onsite storm water grab sampling for turbidity, although somewhat instructive in this study, may not be worthwhile continuing. As discussed earlier, samples provide snapshots of erosion and sedimentation processes, but because of the flashy nature of runoff at stream crossing excavations and the difficulty of access during winter storms, it is difficult to obtain samples that give a complete picture of the winter's turbidity responses at excavations. For this reason, the onsite turbidity data collected this past winter was somewhat inconsistent with the erosion and sediment delivery numbers, so the turbidity results cannot be considered representative of the collective response to all the storms that occurred this past winter. Had it not been for erosion and sediment delivery measurements this spring, reliance on onsite turbidity monitoring would have led to erroneous conclusions. More intensive sampling, probably at a level of effort two to three times that made in 2002/2003, might have provide a sufficiently complete data set. This would be a lot to expect of a volunteer effort and would be extremely expensive to pay consultants to do.

Offsite Monitoring: Because the SFI restoration program will span several years, some future monitoring of post-excavation erosion and sedimentation would be beneficial. As mentioned earlier, offsite monitoring for turbidity was conducted in Ancestor Creek (ANC), which served as a control in this study. However, road removal work will soon begin in Ancestor Creek, changing its status to a treatment site. No work is planned for McNasty Creek (MCN), the second control site, and no additional work is planned for the Upper Mattole River (UMR; also known as Mercer and Well Spring creeks). Consequently, it is recommended that monitoring of stormflows for turbidity continue at these three sites. This would provide data to track trends in the expected reduction in post-excavation erosion in UMR and any increase arising from road removal in ANC. The upstream/downstream treatment/control sites Helen Barnum Creek (HBA and HBB, respectively) should also be considered for future turbidity monitoring to track temporal trends in the expected reduction in post-excavation erosion. Additional offsite grab sample locations might also be considered to provide more treatment and control sites at locations downstream of areas of future work. Monitoring protocols used this past winter should continue.

To strengthen the utility of offsite sampling, erosion inventories in the contributing areas (in addition to the stream crossing excavations) could provide data to help explain the differences between control and treatment basins. A reconnaissance level inventory should suffice for this.

In addition to the grab sample sites discussed above, installation of one or more strategically-located gaging stations to record continuous turbidity and stage data would provide important data on water quality. Data from such stations would allow better definition of hydrological conditions than that provided by rainfall data, as used here. It would provide a means to establish the conditions under which offsite grab samples were taken, for example, whether turbidity at those times was rising, falling, or at peak. It would also allow for comparison of turbidity magnitude and duration in the Upper Mattole with the growing network of similar gaging stations on the north coast of California. Finally, if grab sampling for suspended sediment concentration and occasional discharge measurements are also performed at these recording gaging stations (enough to define a stage-discharge rating curve), suspended sediment yield can be calculated. As mentioned above, this is an important component of a sediment budget.

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APPENDIX A: Example of erosion field data collection sheet

SITE:	DATE:	Initials:

Channel Scour

Cross Section	Scoured Width	Average Depth	Distance to next XS	Notes
XS1	3.2	0.9	12.2	above excav.
XS2	3.5	1.1	14.9	top of excavation
XS3	6.9	2.6	11.6	
XS4	2.7	1.2	16.1	
XS5	2.8	0.7	12.1	
XS6	5.8	1.1	15.1	
XS7	3.3	0.3	n/a	bottom of excav
XS8				
XS9				
XS10				

Bank Slumps

No.	MaxWidth	AveDepth	MaxLength	Notes
1	23.5	0.8	13.3	about 50% gone
2	14.2	1.3	8.7	fully gone
3				
4				
5				
6				
7				
8				
9				
10				

Surface Erosion

Right Bank: Mulch Coverage (% of surface area) = ***85*** %

Bare Ground Condition (circle all that apply):

No erosion | Minor Sheetwash (circled) | Heavy Sheetwash

Minor Rilling | Heavy Rilling

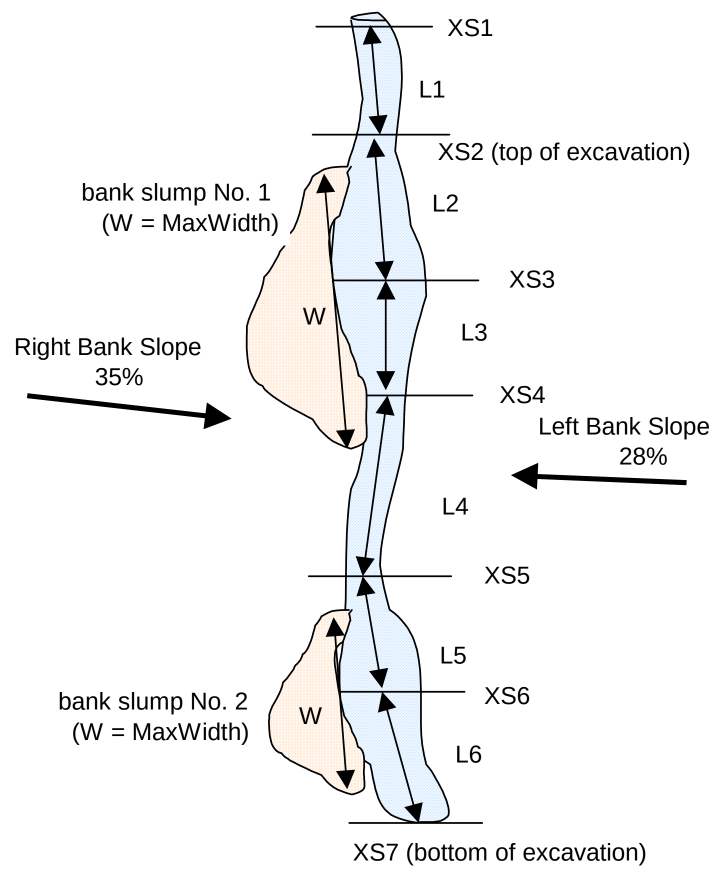
Left Bank: Mulch Coverage (% of surface area) = ***65*** %

Bare Ground Condition (circle all that apply):

No erosion | Minor Sheetwash | Heavy Sheetwash (circled)

Minor Rilling (circled) | Heavy Rilling

SKETCH



NOTE: L1, L2, etc., are lengths of channel reaches between XS ("Distance to Next XS")