Figure 5. Proportion of road-stream crossing fill eroded where streamflow overtopped the road. From: Furniss et al. (1996).

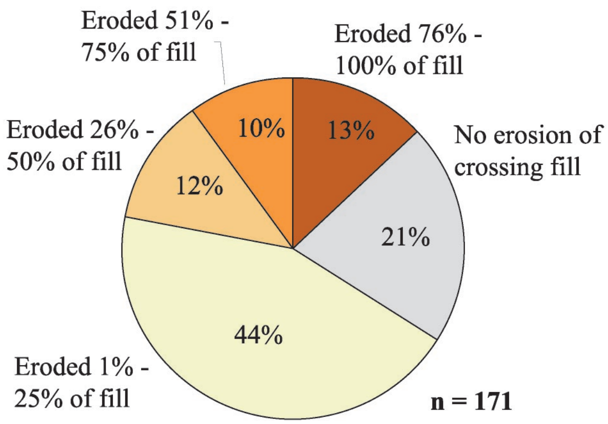


Photo 5: Typical large size restored stream crossing - 5N13B.

Photo 6: Typical small to moderate size stream crossing excavation - Road 2N14H.

Restoration of stream crossings must be carefully planned and executed, but even the best-designed projects have some post-treatment channel erosion. Some of these erosional features can be avoided while others are unpredictable and probably unavoidable. During site excavation, unforeseen conditions may occur and best guesses are made of original channel bottom depths and configurations, only to find out the next year that the channel has downcut, indicating that the original channel was clearly not reached during the initial excavation.

A relatively small proportion of the decommissioned roads (8%) were identified as warranting further monitoring for future channel adjustments and erosion pending the next large storm event. The majority of the decommissioned roads were determined to be in a stable condition and did not pose a significant future sedimentation risk. In others, the short-term impact had largely abated. Sites that warranted future monitoring were mostly associated with roads located in steep inner gorges and large perennial streams (typically 3rd-order or larger) where post-treatment channel erosion had varied between 1 to 15% of the total fill excavated. In these sites, roughly 229 to 459 m^3 (300 to 600 yd^3) of erosion occurred. In general, it is more difficult to minimize post-treatment erosion at decommissioned crossings with deeper channels and higher stream power within the inner gorge. A very small percentage of the sites warranted continued monitoring because of poor contract implementation.

Roadbed

Few surface erosional features attributable to road decommissioning were found on the remaining roadbed between stream crossings. The total volume of all erosional features associated with the 117 km (73 miles) of inventoried roadbed was 2,646 m^3 (3,460 yd^3) (total erosion and associated sediment from restored stream crossings was 9,213 m^3 (12,050 yd^3) or approximately 78% of total post treatment erosion). Roadbed fillslope failures occurred on two roads located in inherently unstable Franciscan mélange terrain (less than 1% of total miles of roads treated). Approximately 2,263 m^3 (2960 yd^3) of fill were associated with post-treatment fillslope failure on mélange terrain and 5% of this material was delivered to adjacent watercourses. The erosional features that produced the greatest erosion were associated with fillslope failures (2,523 m3 or 95%), followed by gullies (76 m^3 or 3%) and cutslope failures (42 m^3 or 1%).

The decision early on in the road-decommissioning program to minimize obliteration and recontouring of the road prism between stream crossings was validated by the relatively small proportion of sedimentation generated from post-treatment roadbed slumps and fillslope failures and by those few failures that occurred being limited to inherently unstable terrain. However, this conclusion should be re-evaluated after a major storm event, such as following a 50-year or greater recurrence interval storm.

Photo 7: Untreated roadbed on decommissioned road.

Photo 8: Outsloping associated with unstable roadbed.

Photo 7 shows a typical untreated roadbed left between restored stream crossings. Photo 8 is an example of road prism outsloping where slope stability was a concern.

Small gullies were the most common erosional feature on the roadbed between stream crossings, but did not account for a large amount of erosion (76 m^3 or 100 yd^3 total). Unlike fillslope failures however, gully erosion resulted in almost 100% sediment delivery to adjacent watercourses. Gully erosion was largely attributable to poor road drainage due to either faulty contract design or incomplete implementation of contract specifications.

Roadbeds between stream crossings were generally not ripped. Rolling dips and waterbars were installed between stream crossings to improve drainage of springs and seeps from road cutslopes. Limited post-treatment erosion was evident as a result of these practices.

Other Post-Treatment Variables

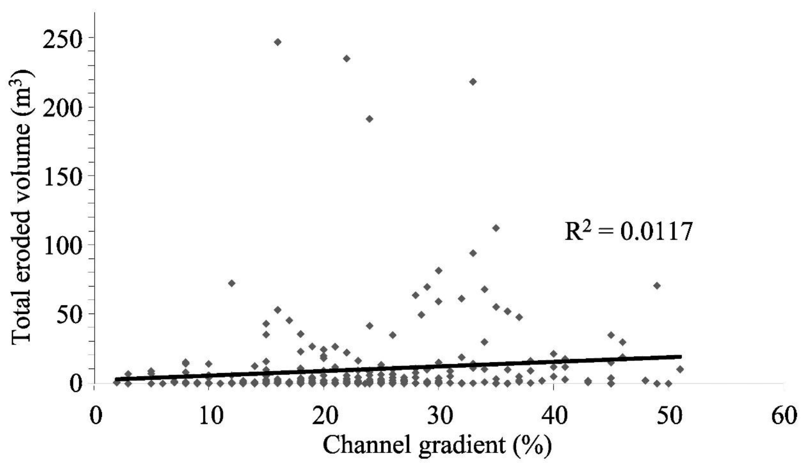
Independent variables such as geology, hillslope gradient, channel gradient, location in the inner gorge, storm history, drainage area, stream power, contract design and contract implementation were assessed to determine whether they influenced post-treatment erosion on decommissioned roads. Due to the high variability of post-treatment erosion within stream crossings, statistical relationships with the variables listed above were not significant. Storm history, geology, drainage area and location in the inner gorge appear to be useful predictors of increased erosion.

The influence of channel gradient on post-treatment adjustments was examined, but no statistical relationships were evident (Figures 6 and 7). We hypothesized that steeper channel gradients would result in more erosion, but this was not supported by the data.

Geology and post-treatment erosion were also evaluated, and some generalizations can be made. All treated sites were classified into five types of parent material: diorite rock, metasedimentary rock, mica schist, sedimentary and metasedimentary rock, and sheared metasedimentary rock. A means test was conducted and diorite and mica schist parent materials showed statistically significant lower post-treatment erosion rates than those sites located in sedimentary and metasedimentary rock (95% confidence interval) (Figure 8).

This finding is counter-intuitive because diorite parent material is generally non-cohesive and highly erodible. Further examination of the data reveals that all of the

Figure 6. Channel gradient regressed against total erosion.



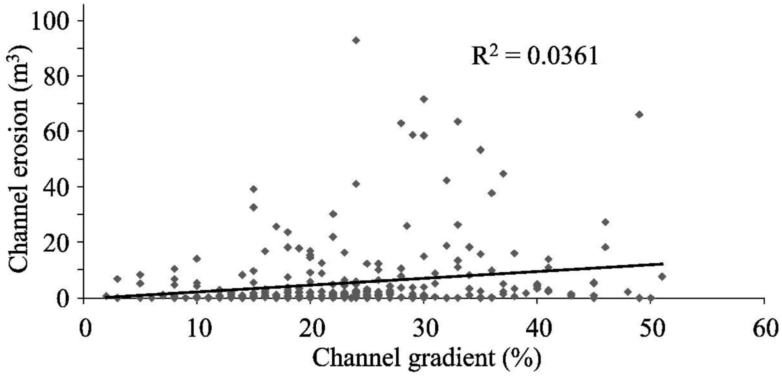
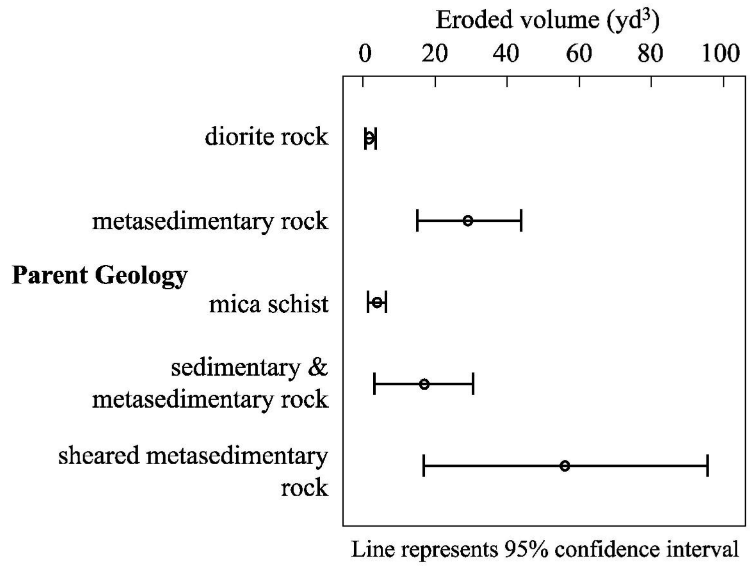


Figure 7. Channel gradient regressed against channel erosion.

Figure 8. Means test between eroded volume and parent material.



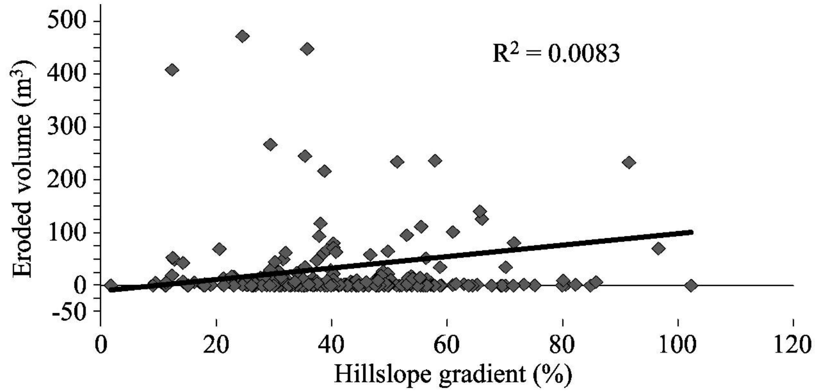
treated stream crossing sites within dioritic parent material are above 1,220 m (4,000 feet) in elevation and may be protected from winter storms due to presence of a seasonal snow pack. Treatment sites located in lower elevation diorite parent material are likely still highly susceptible to post-treatment erosion. (Qualitative observations of post-treatment erosion on low elevation sites in diorite parent material support this hypothesis; however, insufficient time was available to include these sites in this study).

Bedrock geology might also be an influence in post-treatment erosion associated with roadbed fillslope failures. Field data indicated however, that post treatment slope failures on roadbeds were extremely limited and located only in the Franciscan mélange terrain. The slope failures on these sites were not clearly attributable to the road decommissioning and could have resulted from the unstable geologic and geomorphic terrain. Overall, a relationship between post-treatment erosion and differing bedrock geology was not evident in the analysis.

The amount of in-channel erosion observed was compared to excavated volume, drainage area, and hillslope gradient as well as stream power. Hillslope gradient was defined as the average gradient of hillslope through which stream channel dissects and stream power was defined as drainage area times channel slope. No correlation was observed between either hillslope gradient (Figure 9) or stream power (Figure 10) and the amount of observed erosion. This was surprising, especially in the case of stream power which had been found to be a good predictor of erosion in the Franciscan terrain of Redwood Creek by Madej (2001). A multiple regression was conducted on post-treatment erosion, excavated volume, and drainage area on decommissioned stream crossings in Six Rivers. These variables were significantly related ($n = 52$, $r^2 = 0.55$, $p = 0.0001$)

Contract design appeared to influence the amount of erosion at some stream crossings, primarily where excavation did not reach the original channel grade, or where post-treatment channel sideslopes were overly steep. These were generally some of the earliest decommissioning project sites with inadequate pre-project surveys. Standard procedure currently is to survey all but the smallest crossings to ensure good contract design. Therefore, faulty contract design should not be a cause for significant erosion in the future.

Figure 9. Hillslope gradient regressed against eroded volume.



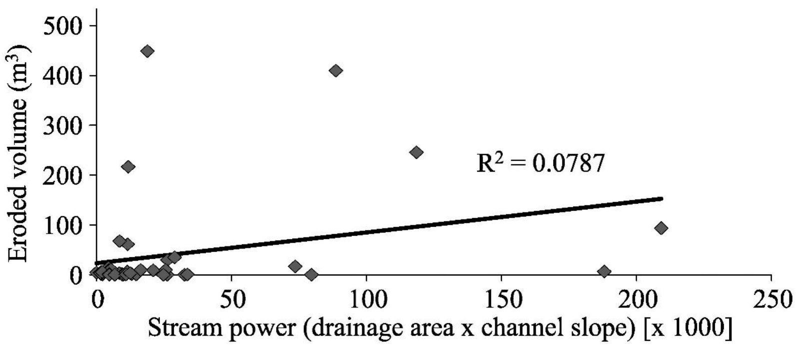
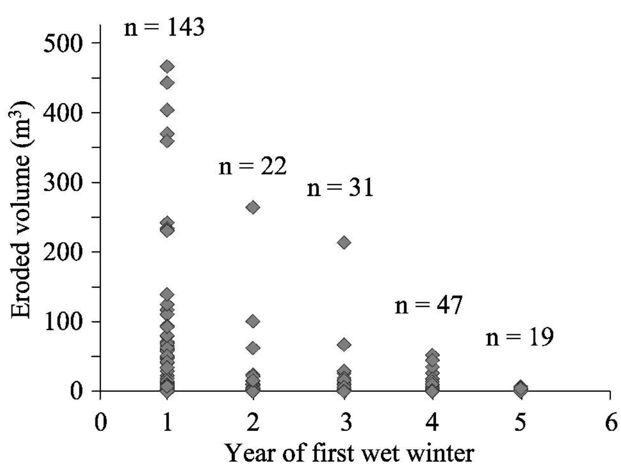


Figure 10. Stream power regressed against eroded volume.

Figure 11. Erosion related to the year of the first wet winter after decommissioning.



Quality of contract implementation did not consistently relate to the amount of post-treatment erosion. In fact, some of the largest erosion was associated with the best-implemented contracts, as determined by the level of on-site inspection during treatments. The large amounts of post-treatment erosion primarily occurred at large or sensitive crossing sites that experienced an unusually wet first winter.

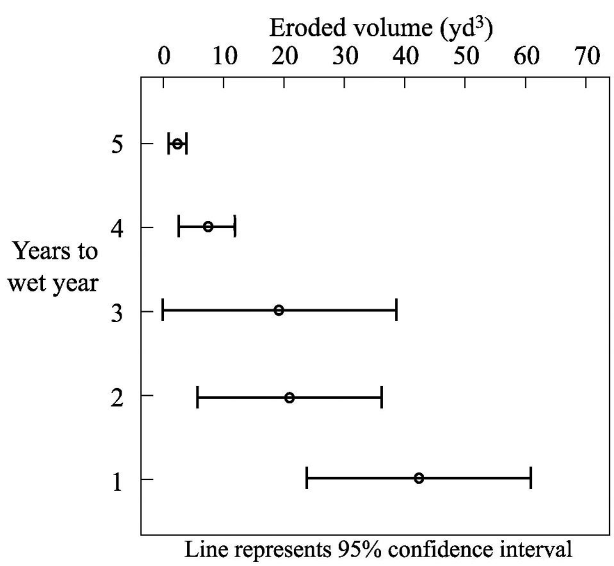
The amount of rainfall, particularly during the first winter, was found to be a good predictor of erosion. Each treatment site was classified into one of five categories reflecting the number of years since the site had experienced a wet winter. For purposes of this analysis, a wet winter was defined as the wettest monthly rainfall occurring with a recurrence interval of 5 or more years. In some cases (such as Bluff Creek), just weeks after completing the decommissioning, a 50-year storm event occurred. This storm produced some of the greatest observed post-treatment erosion, even though the project was well designed and implemented.

Relatively dry winters allow treated sites to revegetate and increase stability to the point where they can withstand a large storm with little erosion. Comparing the post-treatment erosion volumes in relation to time between storm events indicates that after four dry years, erosion from a wet year is minimal (Figure 11). There also appears to be a substantial reduction in erosion after only one dry winter (Figure 11).

While the relationship between time since storm events and post-treatment erosion is clearly visible in Figure 11, statistical analysis of the data show large variability. Comparing post-treatment erosion and years since first wet winter indicated that there was a high variability of erosion in sites that had a greater than 5-year storm event the first year following treatment (r^2 = 0.35, p = 0.001). This variability is due to lack of data on rainfall intensities of the storms, or knowing whether these storms were associated with rain-on-snow events, or the timing of the storms. Seasonal timing of large storms is important because if they occur in the late fall just after the completion of the decommissioning treatments, the recently treated channel slopes are highly vulnerable due to the unconsolidated nature of the disturbed soils; these disturbed soils become progressively more consolidated as the winter progresses due to the settling and compaction associated with raindrop impact. Despite the weak statistical significance between post-treatment erosion and years between large storms (r^2 = 0.35), a means test revealed there was a significant difference in post-treatment erosion between the sites that experienced a greater than 5-year recurrence interval storm the first year after treatment when compared to sites that had not experienced a storm greater than 5-year recurrence interval four and five years after treatment (95% confidence interval) (Figure 12). Further examination of the sites that experienced a greater than 5-year storm recurrence interval the first year after treatment revealed a significant relationship between the amount of excavated volume and post-treatment erosion (r^2 = 0.59). Sites that are exposed to large storm events close to completion of the treatment have a greater likelihood of experiencing post-treatment erosion than sites that have had at least four to five years to stabilize under milder winter conditions.

The amount of erosion was also correlated to whether the stream crossing was located in the inner gorge or not. Inner gorge was defined as any slope greater than 65% and adjacent to a stream channel. Crossings in the inner gorge produced about 4.5 times as much erosion as crossings not in the inner gorge. The 34 sites located in the inner gorge averaged 89 yd^3 (68 m^3) of erosion per year, where as the 226 sites outside the inner gorge yielded an average of only 20 yd^3 (15.3 m^3) of erosion per year. A means test was conducted and the observed differences between post-treatment erosion within the inner gorge were statistically different (95% confidence interval, $p < 0.001$) from those

Figure 12: Means test between eroded volume and years to first wet year.



outside the inner gorge and the observed differences were not a function of sample size. Greater post-treatment erosion within the inner gorge occurred because crossings in the inner gorge tend to be larger, on steeper slopes, and have more water. Faulty contract design or implementation at these inner gorge sites will generally have more severe consequences on post-treatment erosion than at sites with smaller stream crossings in more gentle terrain. In extremely incised and narrow inner gorge stream crossings, the natural topography can severely hamper the creation of stable channel side slopes. In these instances, it must be recognized that the ability to fully reconstruct the stream crossing close to its original morphology without risk of some sedimentation and post-treatment erosion is limited. However, the volume of material saved will likely be much larger than the amount lost due to post-treatment adjustments. Data indicate that in inner gorge areas, where the risk is highest, opportunities need to be explored to reduce the risk of post-treatment adjustment by minimizing overly steepened stream channel sideslopes where possible. While more costly, designing stream crossings so that the fill removal extends to and mimics the gradient of the surrounding valley walls will reduce the risk of post-treatment sideslope failure.

The duration of post-treatment erosion was not assessed in this study, however qualitative observations over many years indicate that the bulk of post-treatment erosion and channel adjustments occurs the first year after treatment and rapidly diminishes over subsequent winters. Klein (2003) conducted a post-treatment erosion and turbidity study on decommissioned stream crossings in the Mattole River watershed, coastal northern California, and found that peak turbidity levels downstream of treated sites occurred as a result of the first few winter storms during the first year but that, by and large, erosional response in the sampling sites diminished considerably over the winter sampling period.

CONCLUSIONS

Total erosion from decommissioned roads was found to be relatively minor and not likely to persist. Average post-treatment erosion on stream crossings was 21 m^3 (28 yd^3), which is 4.5% of the fill excavated. This amount is much smaller than the amount of erosion that could occur if the culverts failed during large storm events. Larger crossings produced greater amounts of erosion, but a smaller proportion of the excavated fill. Approximately 40% of erosion was from channel adjustment (primarily downcutting with some widening) and 60% was due to sideslope failures (usually from over-steepened slopes that resulted in shallow soil slumps). Over-steepened slopes in many restored stream crossings were due to inadequate contract design or implementation, but in other sites the over-steepened slopes were due to natural topographic constraints. Leaving the roadbed between stream crossings intact and only outsloping visibly unstable portions of the roadbed was shown to be a viable option in designing road decommissioning projects with limited risk of post-treatment erosion. Erosion from the roadbed between stream crossings was very small and occurred only in unstable mélange terrain. Analysis of data indicated that hillslope gradient, channel gradient, channel sideslope gradient, and stream power were not good predictors of post-treatment erosion. The amount of post-treatment erosion was best predicted by the storm history following treatment. When large storm events occur during the first winter after decommissioning, post-treatment erosion is above average and the amount of post-treatment erosion is influenced by the volume of material excavated. The risk of post-treatment erosion will be considerably less if the site does not experience a large winter storm until 4 or 5 years after treatment.

Post-treatment road decommissioning monitoring indicates that while there is a short-term risk of increased erosion and sedimentation, the amount of erosion is minor when compared to the volume of material removed, and that road-decommissioning treatments are effective in reducing long-term sedimentation risks. Recommendations for future work include assessing the extent and duration of sedimentation effects from decommissioning treatments on local aquatic fauna (e.g., macro-invertebrates), as well as assessing the magnitude of changes to the local hydrology of affected streams.

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TI: Effectiveness of Three Rehabilitation Treatments for Unpaved Forest Roads

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AB: Up to $1 million per year is being spent to reduce sediment production and delivery from unpaved roads and protect the remaining Chinook salmon habitat on the Lassen National Forest in northeastern California, but little is known about the effectiveness of these treatments. The goal of this study is to estimate the reduction in road sediment production and road-stream connectivity due to three road rehabilitation treatments: 1) rocking and out-sloping, 2) road closures, and 3) road decommissioning. Sediment production was estimated for 4.6 km of untreated roads and 27 km of treated roads by measuring the volumes of erosion features. Road-stream connectivity was assessed by following the rills and sediment plumes emanating from each road segment. The mean volume of erosion features from the untreated roads was 16 m^3 km^{-1} (s.d. = 15 m^3 km^{-1}). The measured mean volume for 26 rocked and out-sloped road sections was 5.9 m^3 km^{-1} (s.d.= 16 m^3 km^{-1}), which was 37% of the mean for the untreated roads. However, just three of the 26 treated sections accounted for 88% of the total volume. The closed roads had a similar mean volume of erosional features as the rocked and out-sloped roads, and three of the 11 sections accounted for 97% of the total volume. The mean erosion volume for the decommissioned roads was an order of magnitude higher at 41 m^3 km^{-1} (s.d.= 92 m^3 km^{-1}). Again the distribution was highly skewed with three of the 22 sections accounting for 83% of the total, while 11 sections had no significant erosion features. Road-stream connectivity was less than 10% of the surveyed length for the untreated roads, the rocked and out-sloped roads, and the closed roads. In contrast, 28% of the surveyed length of the decommissioned roads was connected to the stream channel network. The highly skewed distributions of erosion volumes show that most of the road-related sediment is coming from a few 'bad' roads. This indicates that detailed road surveys are needed to identify which roads should be treated, and which roads need additional work to adequately protect fish habitat.

DE: 0481 Restoration
DE: 1803 Anthropogenic effects (4802, 4902)
DE: 1815 Erosion
DE: 1834 Human impacts
DE: 1880 Water management (6334)
SC: Hydrology [H]
MN: 2008 Fall Meeting

The Effectiveness of Road Rehabilitation Treatments at Reducing Sediment Production on Unpaved Forested Roads

H51D-0856

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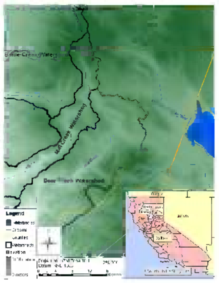
Introduction

Unpaved roads have been identified as a major source of sediment in our nation's forests. In Lassen National Forest (Figure 1) $500,000- $1,000,000 per year has been devoted to road surface treatments in order to improve stream habitat for the remaining anadromous chinook salmon. The goal of this study is to quantify the effectiveness of ten different treatments (Table 1) for reducing sediment production and road-stream connectivity.

Figure 1. Study area in the Lassen National Forest, California



Methods

Detail surveys were conducted in summer 2007 and 2008 of a random sample of treated and untreated road sections (listed in order of increasing cost and disturbance in Table 1). Sediment production was estimated by measuring the dimensions of the following erosion features that were greater than 5 cm deep: 1) incised ditches (Figure 2); 2) surface rills (Figure 3); 3) fill-slope rills (Figure 3), and 4) drainage rills or gullies created by road runoff. Road-stream connectivity was determined by following each drainage rill or sediment plume and assigning each road segment to a connectivity class (Table 2).

Figure 2. Example of incised ditch on native surface road with cross drain in the lower left hand corner.

Figure 3. Catastrophic fill-slope rill and surface rill.

Table 1. Number of sampled road sections, sampled length, number of segments, and mean eroded volume by treatment.

Treatment	Number of road sections	Total road length (km)	Number of road segments	Mean eroded volume (m^3 km^{-1})
Untreated	67	32.8	290	18.5
Closed	13	9.1	77	3.2
Rocking	12	2.8	23	6.3
Cross Drains	7	3	12	25.9
Rocking and Cross Drains	8	2.4	46	44.2
Dips	6	1.8	23	5
Rocking and Dips	11	3.2	41	51.9
Out-sloped	5	1.9	14	0
Rocking and Out-sloping	14	16.5	41	13.3
Decommissioned	21	10.9	*NA*	16.3
Paved	3	2.1	7	0.1
Total	167	74.5	564	184

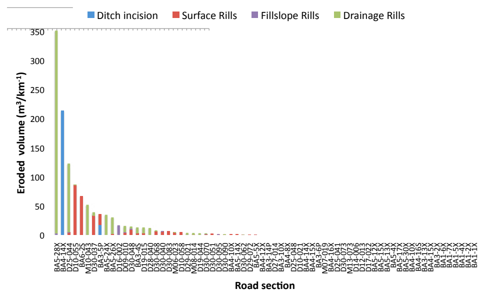
Table 3. Description of connectivity classes.

Connectivity Class	Drainage feature
1	No feature
2	Feature length is less than 20 m in length and terminates more than 10 m from nearest stream
3	Feature length is more than 20 m in length and terminates more than 10 m from the nearest stream
4	Feature terminates less than 5 m from nearest stream

Results

In general, the volume of sediment produced from different road sections for a given treatment was highly skewed, with only a small fraction of the surveyed sections producing sediment (Figures 4 and 5). The mean eroded volume for untreated roads was 19 m^3 km^{-1} (Table 1), although two sections accounted for 48% of the estimated eroded volume (Figure 4). Two of the treatments had higher mean erosion volumes than the untreated roads, and these were rocking with additional dip installation and rocking with additional cross drain installation. Three of the treatments had similar erosion volumes, and these were additional cross drain installation, road decommissioning, and rocking with out-sloping (Figure 6). The other treatments had lower eroded volumes than the untreated roads (Figure 6).

Figure 4. Eroded volume by road section for untreated roads.



Drainage rills accounted for 61% of the total eroded volume. Surface rilling was the next most important erosion process that accounted for 34% of the total eroded volume and was the sole source decommissioned roads. Ditch incision was only important for some untreated road a small component of the eroded volume on some of the untreated roads (Figure 4 and 6) and roads with additional cross drain installation (Figure 6). Fill-slope rills were rare and contributed very little to the total eroded volume (Figure 6).

Only 5.3% of the 33 km of untreated roads surveyed had a rill or sediment plume that extended to a stream channel (connectivity class 4 on Figure 7). The decommissioned roads had the highest road-stream connectivity (28% of the surveyed length).

For the untreated roads the mean volume of delivered sediment was 1.6 m^3 km^{-1} (Figure 8). One road section that was rocked with additional cross drain installation caused this treatment to have the greatest delivery of 43.6 m^3 km^{-1} (Figure 8). Roads with additional dip installation had an estimated mean sediment delivery of 16 m^3 km^{-1} (Figure 8), although this was only found on 2 road sections. Treatments with moderate sediment delivery were additional cross drain installation, rocking with additional dip installation, and road decommissioning (Figure 8). The other treatments had little or no sediment delivery (Figure 8).

Figure 5: Box plots of eroded volume for each surveyed road section by treatment.

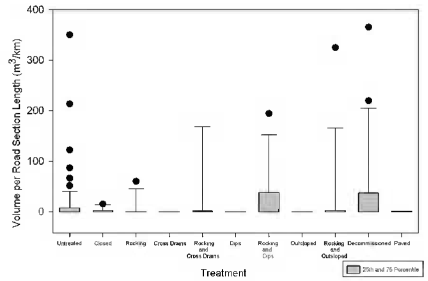


Figure 6. Eroded volume by source for each treatment (n is the number of sections surveyed).

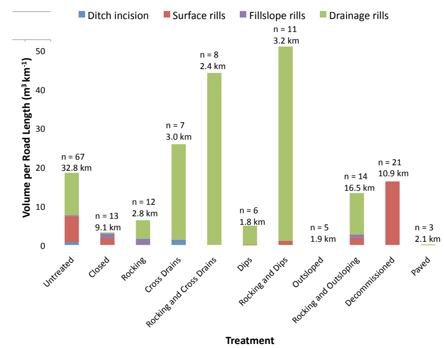


Figure 7. Percentage of each connectivity class for each treatment.

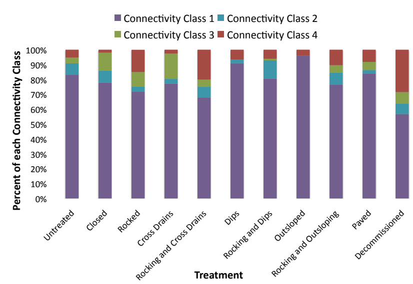
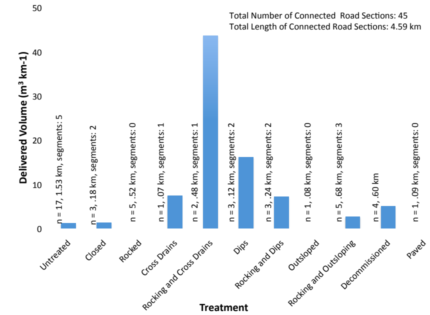


Figure 8. Sediment delivered to connected streams per surveyed length for each treatment (n = the number of producing and connected road sections)



Discussion

It is important to note that the eroded volumes being measured in this study are a total over time rather than a rate. Most of the road treatments date from 1999, 2001, 2003 or 2007, while the eroded volumes for untreated roads may have developed over a potentially much longer period.

An additional caveat is the extent to which the data are biased. Since the goal was to reduce sediment delivery to streams, the most costly and intensive treatments (e.g., decommissioning) were done on the most severely eroding roads in closest proximity to streams. This means that the remaining untreated roads should have a lower eroded volumes and less connectivity.

Another factor that needs consideration is that incised ditches, fill-slope rills and drainage rills surveyed in this study may have developed on roads before treatments were implemented. This native surface, in-sloped and cross-drained configuration is vulnerable to surface erosion and more effectively delivers concentrated runoff from the road prism. Drainage rills were found to be the primary erosion mechanism, and since none of the treatments alter these features and their associated connectivity these features may be inherited from the pre-treatment road configuration (Figure 6). This may have resulted in roads that received rocking and additional cross drain installation, rocking and additional dip installation, and rocking with out-sloping having eroded volumes greater than the roads with only those constituent treatments (Figure 6).

When decommissioned roads are initially implemented the surface is typically greatly disturbed and left bare. Because of this, these roads are highly susceptible to surface erosion for the first few years after treatment, before revegetation can protect the surface. The greater eroded volume from surface rilling on decommissioned roads may reflect this tendency (Figure 6). Roads that have native surface are also unprotected from surface erosion, this may have resulted in the instances of surface rilling on untreated and closed roads (Figure 6).

Conclusions

This study out-sloped roads have the lowest eroded volumes and least connectivity, and that rocking also was an effective means of decreasing sediment production. For these reasons rocking and out-sloping should be implemented in conjunction, to reduce sediment production and disconnect road segments from streams. Road decommissioning is expensive and some treated sections still produce and deliver sediment. Additional flow barriers or surface treatments (e.g., mulching, surface roughening) may be needed to minimize surface erosion.

Road closure is a low cost and effective means of reducing sediment production and delivery. With time these roads will naturally recover and revegetate, becoming more protected from erosion processes. Roads that received either additional cross drain installation or additional dip installation retain the efficient hydrologic pathways of in-sloped roads, leaving them susceptible to ditch incision and drainage rilling. More intensive treatments may be necessary to reduce sediment production and connectivity on these road sections. Most of the untreated roads have low potential for producing and delivering sediment to the stream network.

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The Effectiveness of Surface Rehabilitation Treatments for Unpaved Forest Roads

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Abstract. Up to $1 million per year is being spent to reduce sediment production and delivery from unpaved roads on the Lassen National Forest in northeastern California. The purpose is to protect the remaining Chinook salmon habitat, but little is known about the effectiveness of the various treatments. In this study we measured the volumes of erosion features and assessed road-stream connectivity for 10 road surface treatments on 44 km of roads. The following treatments were considered in order of increasing cost and disturbance: 1) road closure, 2) installation of additional dips, 3) installation of additional cross drains, 4) rocking, 5) rocking and installation of additional dips, 6) rocking and installation of additional cross drains, 7) out-sloping, 8) rocking and out-sloping, 9) paving, and 10) road decommissioning. The measured erosion features included incised ditches, road surface rills, fill-slope rills, and drainage rills. Each drainage feature was followed to assess connectivity to the nearest stream. Erosion volumes and road sediment delivery were normalized by length to facilitate comparisons among treatments, but the data are inherently biased because of the tendency to implement the most intensive treatments on the worst roads with the highest road-stream connectivity.

The treatments with the greatest mean erosion volumes were 52 $m^3 km^{-1}$ for rocking and additional dip installation, 42 $m^3 km^{-1}$ for rocking and additional cross drain installation, and 35 $m^3 km^{-1}$ for additional cross drain installation. Decommissioned roads had estimated road erosion volumes of 20 $m^3 km^{-1}$, while the mean erosion volumes were progressively lower for roads with additional dips (14 $m^3 km^{-1}$), rocking and out-sloping (13 $m^3 km^{-1}$), rocking (8.0 $m^3 km^{-1}$), and closed roads (6.5 $m^3 km^{-1}$). Out-sloped and paved roads had no significant surface or drainage erosion features.

Decommissioned, paved and rocked roads had the highest road-stream connectivity with about 30% of the surveyed length connected to a channel. The high connectivity can be attributed to the tendency to implement these treatments on roads adjacent to streams. The combination of these data showed that rocked roads with additional cross drains had the highest estimated sediment delivery of 42 $m^3 km^{-1}$, followed by 14 $m^3 km^{-1}$ for roads with additional dips, and 9.6 $m^3 km^{-1}$ for roads with additional cross drains. The estimated sediment delivery for the other treatments was less than 7.0 $m^3 km^{-1}$. These results indicate that road design, particularly insloping, and road location are the two most important controls on estimated road sediment delivery. The highly skewed distributions of erosion and delivery volumes mean that most of the road-related sediment is coming from a few “bad” road sections or segments. Detailed road surveys are critical for identifying which roads should be treated, and which roads may need additional work to adequately protect fish habitat.

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Erosion rates over millennial and decadal timescales at Caspar Creek and Redwood Creek, Northern California Coast Ranges

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Abstract

Comparing millennial-scale denudation rates from cosmogenic nuclides with decadal-scale sediment yields can shed light on erosional processes and on the effects of land use on sediment delivery to streams. Detailed measurements of sediment fluxes in the Northern California Coast Ranges at Caspar Creek and Redwood Creek have provided estimates of physical erosion rates since 1963 and 1971, respectively. We used cosmogenic ^{10}Be to measure millennial-scale denudation rates averaged over 1400–8700 years at six catchments in Caspar Creek and four catchments in Redwood Creek. Our ^{10}Be measurements at Caspar Creek imply denudation rates that are nearly spatially uniform across the entire catchment and average $0{\cdot}09 \pm 0{\cdot}02$ mm a^{-1}. These millennial-scale rates implied by cosmogenic ^{10}Be are faster than physical erosion rates of $0{\cdot}005 \pm 0{\cdot}001$ mm a^{-1} to $0{\cdot}046 \pm 0{\cdot}007$ mm a^{-1} inferred from sediment flux measurements over the past few decades in the same catchments. At Redwood Creek, our cosmogenic ^{10}Be measurements imply millennial-scale denudation rates that vary across the catchment from $0{\cdot}14 \pm 0{\cdot}03$ mm a^{-1} to $0{\cdot}44 \pm 0{\cdot}09$ mm a^{-1}, in contrast to physical erosion rates ranging from $0{\cdot}038 \pm 0{\cdot}011$ mm a^{-1} to $0{\cdot}48 \pm 0{\cdot}09$ mm a^{-1} derived from sediment flux measurements made over the past few decades at the same catchments. The decadal-scale and millennial-scale measurements tend to differ most at the smallest tributaries, but differ by less than a factor of three for the Caspar Creek and Redwood Creek catchments as a whole. These measurements suggest that denudation rates at Caspar Creek are slower than rock uplift rates of 0·3–0·4 mm a^{-1}, implying that Caspar Creek is not in topographic steady state. Copyright © 2005 John Wiley & Sons, Ltd.

Keywords: erosion rate; cosmogenic ^{10}Be; Northern California Coast Ranges

Introduction

Erosion rate measurements are essential for modelling landscape evolution, quantifying soil formation rates (e.g. Heimsath *et al*., 1997), determining patterns of chemical weathering (e.g. Riebe *et al*., 2003), and understanding how sediment loading affects stream ecosystems. Comparing recent sediment yields to long-term 'background' rates of erosion can shed light on erosional processes and on the effects of land use on sediment delivery to streams. Cosmogenic nuclides such as ^{10}Be in stream sediments can be used to estimate whole-catchment denudation rates averaged over thousands of years, a timescale that is unobservable by conventional methods. These millennial-scale denudation rates can provide useful reference points for quantifying the effects of land use practices on sediment yields (e.g. Brown *et al*., 1998; Hewawasam *et al*., 2003).

In this study we focus on two catchments in the Northern California Coast Ranges, Caspar Creek and Redwood Creek (Figure 1), where stream sediment fluxes have been measured for several decades. The Northern California Coast Ranges are a rapidly evolving mountain range, undergoing rapid erosion under moderate-to-high rates of uplift associated with migration of the Mendocino Triple Junction (e.g. Merritts and Vincent, 1989). The old-growth coastal redwood (*Sequoia sempervirens*) forests in the Coast Ranges have largely been harvested over the past two centuries, and much research has been done at Caspar Creek and Redwood Creek to assess the effects of timber harvesting on stream ecology and stream sediment loading (e.g. Lewis, 1998; Nolan and Janda, 1995; Marron *et al*., 1995; Madej, 2001).

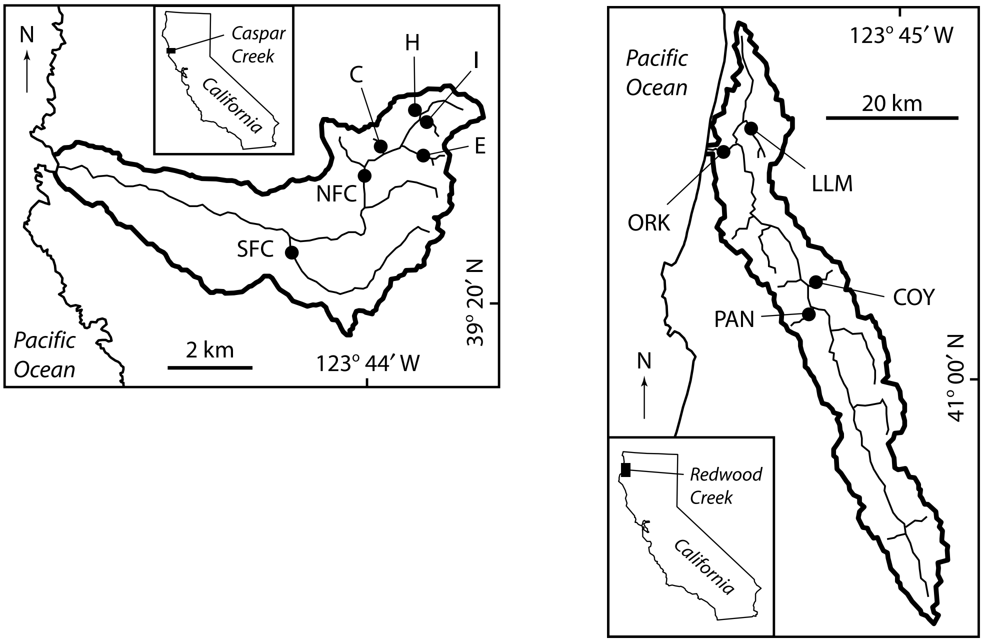

Figure 1. Sample sites for ^{10}Be in alluvial stream sediment at Caspar Creek and Redwood Creek, Northern California. Caspar Creek site labels: NFC, North Fork Caspar Creek; SFC, South Fork Caspar Creek; C, Carlson; E, Eagle; H, Henningson; I, Iverson. Redwood Creek site labels: COY, Coyote Creek; LLM, Little Lost Man Creek; ORK, Redwood Creek at Orick; PAN, Panther Creek. The Grogan Fault closely follows the main stem of Redwood Creek, and separates the Redwood Creek Schist to the west from weak Franciscan sandstones and mudstones to the east (Harden *et al.*, 1981). Note different map scales.

Ongoing measurements of stream sediment fluxes at Caspar Creek and Redwood Creek since 1962 and 1971, respectively, have provided some of the longest and most detailed sediment yield records in the Pacific Northwest. Using our measurements of cosmogenic ^{10}Be in stream sediment, we calculated denudation rates averaged over the past several thousand years at ten locations within these catchments, and compared these rates to sediment yields measured over the past few decades. Our results imply that, at individual subcatchments, decadal-scale sediment yields at Caspar Creek are as much as 16 times lower than millennial-scale denudation rates, and at Redwood Creek, sediment yields over the past few decades differ from millennial-scale average rates of sediment production by less than a factor of four. However, for Caspar Creek and Redwood Creek as a whole, sediment yields over the past few decades are generally consistent, within a factor of three, with millennial-scale rates of sediment production estimated from cosmogenic ^{10}Be.

Field Sites

Caspar Creek

Caspar Creek is a small (*c*. 9 km^2) experimental catchment in Northern California (39°21′ N, 123°44′ W; Figure 1) that drains into the Pacific Ocean through a series of incised, uplifted marine terraces. Steep, soil-mantled hillslopes within the catchment reach a maximum elevation of 320 m, and are underlain by the Coastal Belt Franciscan formation (Jennings and Strand, 1960), a lithology composed of greywacke and feldspathic sandstone, with lesser amounts of siltstone, mudstone and conglomerate. Soils are highly permeable clay loams 1–2 m in depth (Henry, 1998), allowing rapid subsurface storm flow. The climate is Mediterranean, with mild fluctuations around a mean annual temperature of 12 °C, and 90 per cent of the mean annual precipitation of *c*. 1200 mm falling between November and May (RSL website, 2004). Stream sediment has been monitored intensively at Caspar Creek since 1962 under the California Department of Forestry and Fire Protection and the USDA Forest Service (Henry, 1998).

Redwood Creek

Redwood Creek flows roughly northwest in a steep narrow catchment 720 km^2 in size, discharging into the Pacific Ocean at about 41°18′ N, 124°6′ W (Figure 1). The main stem of Redwood Creek closely follows the Grogan Fault, which separates the Redwood Creek Schist to the west from weak, unmetamorphosed Franciscan sandstones and mudstones to the east (Harden *et al*., 1981). Like Caspar Creek, the climate in the Redwood Creek basin is Mediterranean, with *c*. 90 per cent of the precipitation falling from October to April. Mean annual precipitation is *c*. 1700 mm near the mouth of Redwood Creek at Prairie Creek Park in Orick (WRCC website, 2004) and may be as high as 2540 mm in the headwaters (Iwatsubo *et al*., 1975). The maximum elevation within the basin is 1615 m, and at higher elevations some of the winter precipitation falls as snow. Sediment monitoring began at Orick near the mouth of Redwood Creek under the USGS in 1971, and has since expanded to include suspended sediment measurements at many gauging stations within the catchment. Suspended sediment monitoring is now under the supervision of Redwood National Park and Redwood State Park.

Methodology

Beryllium-10-derived denudation rates and assumptions

Concentrations of ^{10}Be in quartz grains in stream sediment can be used to calculate spatially averaged denudation rates over the upstream basin, if it can be assumed that the sampled sediment is representative of all sediment delivered to the stream, and if the mean residence time of sediment in storage and transport is much shorter than the erosional timescale $\Lambda\ \rho_{rock}^{-1}\ \varepsilon^{-1}$, where ρ_{rock} is the bedrock density, ε is the erosion rate, and Λ is the mean penetration depth of cosmogenic neutrons expressed as mass per unit area, in order to be invariant for materials of differing densities (Brown *et al*., 1995; Bierman and Steig, 1996; Granger *et al*., 1996). In order to obtain samples that are representative of sediment delivered to the stream, we collected well-mixed, recently mobilized sediment in stream channels. We do not know the storage history of the sediment in our samples, but the small volumes of sediment stored in the river networks suggest that mean storage and transport timescales are much shorter than the erosional timescale. Channel-stored sediment was estimated to be $1{\cdot}6 \times 10^3$ tons at the North Fork of Caspar Creek (Napolitano, 1998), $4{\cdot}3 \times 10^7$ tons at Redwood Creek (Madej, 1995), and $2{\cdot}2 \times 10^4$ tons at Coyote Creek, a tributary of Redwood Creek (Pitlick, 1995). At the denudation rates measured in our study, the mean residence times of sediment in storage at these sites are 1–52 years. This would add <350 atoms of $^{10}Be\ g^{-1}$ to the samples, which is far less than our measured ^{10}Be concentrations (Table I).

Table I. Sample basin characteristics, measured ^{10}Be concentrations, and calculated denudation rates

Catchment	**Gauging station latitude, longitude (deg N, deg W)**	**Basin area (km^2)**	**Mean altitude (m)***	**Mean hillslope gradient***	**^{10}Be conc. (10^5 at g^{-1}) (mean ± s.e.)**	**Cosmogenic denudation rate (mm a^{-1}) (mean ± s.e.)**	**Time scale (a)†**
Caspar Creek							
North Fork	39·36, 123·73	4·73	211	0·36	0·316 ± 0·020	0·107 ± 0·020	5540
South Fork	39·34, 123·75	4·24	170	0·33	0·449 ± 0·036	0·068 ± 0·013	8700
Carlson	39·37, 123·73	0·26	229	0·37	0·339 ± 0·022	0·101 ± 0·019	5856
Eagle	39·37, 123·72	0·27	242	0·38	0·487 ± 0·031	0·072 ± 0·014	8178
Henningson	39·36, 123·72	0·39	232	0·35	0·334 ± 0·021	0·103 ± 0·020	5737
Iverson	39·36, 123·72	0·21	226	0·34	0·439 ± 0·048	0·080 ± 0·017	7436
Redwood Creek							
Redwood Creek at Orick	41·30, 124·05	720	567	0·35	0·106 ± 0·008	0·438 ± 0·088	1353
Coyote Creek	41·12, 123·91	20·18	596	0·34	0·251 ± 0·025	0·184 ± 0·040	3216
Little Lost Man Creek	41·32, 124·02	8·96	391	0·29	0·294 ± 0·023	0·138 ± 0·028	4308
Panther Creek	41·09, 123·91	15·7	489	0·34	0·190 ± 0·012	0·225 ± 0·044	2639

* Mean altitudes and mean hillslope gradients were determined from 10 m SDTS (Spatial Data Transfer Standard) digital elevation data.
† Erosional timescales are calculated as $\Lambda\ \rho_{rock}^{-1}\ \varepsilon^{-1}$, where Λ is the mean penetration depth of cosmogenic neutrons (160 g cm^{-2}), ρ_{rock} is the bedrock density (2·7 g cm^{-3}), and ε is the cosmogenic denudation rate.

Table II. Summary of parameters used to calculate denudation rate ε in Equation 1

Parameter	Value	Description	Source
In Equation 1			
τ	$2{\cdot}18 \pm 0{\cdot}09$ Ma	Meanlife of ^{10}Be	Middleton *et al.* (1993)
ρ	$2{\cdot}7$ g cm^{-3}	Bedrock density	Assumed
Λ	160 ± 10 g cm^{-2}	Neutron penetration depth	Masarik and Reedy (1995)
L_1	$738{\cdot}6$ g cm^{-2}	Muon penetration depth	Granger and Smith (2000)
L_2	2688 g cm^{-2}	Muon penetration depth	Granger and Smith (2000)
L_3	4360 g cm^{-2}	Fast muon penetration depth	Granger and Smith (2000)
P_n	$5{\cdot}1$ atoms ^{10}Be g^{-1} a^{-1}	Nucleonic ^{10}Be production rate	Lal (1991), Stone (2000)
A_1	$170{\cdot}6$ μ^- g^{-1} a^{-1}	Muon production rate	Granger and Smith (2000)
A_2	$36{\cdot}75$ μ^- g^{-1} a^{-1}	Muon production rate	Granger and Smith (2000)
Y	$5{\cdot}6 \times 10^{-4}$ atoms ^{10}Be/μ^-	^{10}Be yield per negative muon	Heisinger (1998)
B	$0{\cdot}026$ atoms ^{10}Be g^{-1} a^{-1}	Fast muon ^{10}Be production rate	Granger and Smith (2000)
Other parameters			
d	$1{\cdot}5 \pm 0{\cdot}5$ m	Soil depth	Assumed
ρ_s	$1{\cdot}5 \pm 0{\cdot}25$ g cm^{-3}	Soil density	Assumed
f_s/f_r	$1{\cdot}04 \pm 0{\cdot}01$	Soil quartz enrichment	Assumed*

Values listed for production constants P_n, Y, A_1, A_2, B are for sea level and high latitude, and are modified for the characteristics of each field site. Values for P_n are modified for latitude and altitude according to Lal (1991); P_n and Λ are modified for topographic shielding according to Masarik *et al.* (2000); YA_1, YA_2, and B are modified for altitude according to Stone *et al.* (1998); and P_n, YA_1, YA_2, B are modified to account for vegetative shielding as described in the text.

* Quartz enrichment in Redwood Creek soil is calculated as $W/D + 1$, where W is the chemical weathering rate (49·7 t km^{-2} a^{-1}; Dethier, 1986) and D is the total denudation rate (chemical weathering rate + physical erosion rate). We use the average 1971–2000 sediment yield at Redwood Creek at Orick (1304 ± 231 t km^{-2} a^{-1}) as the physical erosion rate. In the absence of chemical weathering rate data for Caspar Creek, we assume that quartz enrichment in Caspar Creek soil is the same as in Redwood Creek soil.

After determining ^{10}Be concentrations, we calculated denudation rates by iteratively solving Equation 1 (Granger *et al.*, 2001), which says that the total ^{10}Be concentration (N) is the sum of ^{10}Be concentrations due to nucleon spallation (the first term) and muogenic production (the last three terms):

$$N = \frac{P_n}{\tau^{-1} + \rho\varepsilon(\Lambda^{-1})} + \frac{YA_1}{\tau^{-1} + \rho\varepsilon(L_1^{-1})} + \frac{YA_2}{\tau^{-1} + \rho\varepsilon(L_2^{-1})} + \frac{B}{\tau^{-1} + \rho\varepsilon(L_3^{-1})} \tag{1}$$

where P_n is the production rate of ^{10}Be at the surface due to nucleon spallation, τ is the radioactive meanlife of ^{10}Be, ε is the denudation rate, ρ is the density of the quartz-bearing material (i.e. rock or soil), Λ is the penetration depth for nucleons, and L_1, L_2, and L_3 are the penetration depths for muon reactions. A_1 and A_2 are the production rates of negative muons in quartz, Y is the yield of ^{10}Be per negative muon, and B is the production rate of ^{10}Be due to fast (i.e. high energy) muons. For each sample site, we scaled P_n for latitude and altitude according to Lal (1991), P_n and Λ for topographic shielding according to Masarik *et al.* (2000), and muogenic production rates for altitude according to Stone *et al.* (1998). Values for the above parameters at sea level and high latitude are listed in Table II. In order to determine the mean production rate of ^{10}Be at each sample site, we calculated production rates across the range of elevations at each catchment and computed an areally weighted average production rate based on basin hypsometry. At our study catchments, production rates calculated in this manner differed from production rates at the mean basin elevation by at most 3 per cent. We scaled denudation rates to account for preferential weathering of minerals other than quartz, which increases the residence time of quartz in soil, and hence increases the exposure time of quartz grains to cosmogenic radiation (Small *et al.*, 1999; Riebe *et al.*, 2001). Denudation rates determined from Equation 1 are averaged over a characteristic timescale of $\Lambda\ \rho_{rock}^{-1}\ \varepsilon^{-1}$, the time required to erode a layer of rock *c*. 60 cm thick; the characteristic erosional timescale for each site is listed in Table I.

Accounting for vegetative shielding

Materials such as snow, ice and vegetation shield the Earth's surface from cosmic radiation and reduce the production rate of cosmogenic nuclides in the underlying soil and rock (e.g. Lal, 1991). In many regions, shielding due to vegetation is minimal (e.g. Brown *et al*., 1995), but above-ground biomass densities in the Northern California redwood forests are among the highest in the world (Waring and Franklin, 1979), so the ^{10}Be production rate P_n in Equation 1 must be modified accordingly. In order to estimate biomass density, we averaged six measurements of biomass volume from old-growth *Sequoia sempervirens* forests in the Northern California Coast Ranges (Westman and Whittaker, 1975; Fujimori, 1977), and assumed a live redwood bulk density of 800 kg m^{-3} (USDA, 1987). These estimates produce a vegetative mass density of 51 ± 13 g cm^{-2} (mean ± s.e.).

Pollen studies from an offshore sediment core (ODP Site 1019; 41·682° N, 124·930° W) suggest that Coast Range forests reached their current composition about 4000 years ago, and that *Sequoia sempervirens* was roughly half as common during the mid-Holocene (Barron *et al*., 2003). Assuming that this pollen record accurately reflects the vegetative history of our field sites, we estimate that the biomass density was 51 ± 13 g cm^{-2} from 4 ka to present, and half that prior to 4 ka. At Caspar Creek, the original forests were dominated by coast redwood, Douglas fir and grand fir (Reid and Hilton, 1998), while at Redwood Creek, 82 per cent of the basin is dominated by coast redwood and Douglas fir, and the remaining 18 per cent is split evenly between oak woodlands and grasslands (Best, 1995). We assume that the biomass density of 51 ± 13 g cm^{-2} is relevant to the entire Caspar Creek catchment, and that the spatially averaged biomass density at Redwood Creek is 82 per cent of that calculated above. These assumptions yield average biomass densities ranging from 38 to 45 g cm^{-2} at Caspar Creek and 41 to 42 g cm^{-2} at Redwood Creek. These biomass densities reduce the production rate of ^{10}Be to 75–79 per cent of its unshielded rate, and we applied these correction factors to our calculations for each field site.

Beryllium-10 sample preparation

Sample preparation followed the procedures outlined in Riebe (2000). We collected stream sediment samples from active bars in the stream channel away from obvious landslide deposits. Because of the low abundance of quartz at these field sites, we needed to process 5–6 kg of stream sediment in order to obtain the necessary 50–100 g of quartz for each sample. After crushing the sediment to a grain size of 0·25–0·5 mm, we isolated quartz via magnetic separation and chemical dissolution in hydrochloric, phosphoric, nitric, and hydrofluoric acids (Kohl and Nishiizumi, 1992). After verifying the purity of the quartz by measuring aluminium concentrations with inductively coupled plasma spectrophotometry, we spiked quartz samples with ^{9}Be carrier and dissolved the quartz in HF and HNO_3. The dissolved samples were then dried down in platinum crucibles, redissolved and dried down in H_2SO_4, raised to 1 N HCl solution, and passed through cation exchange columns. We then precipitated out titanium hydroxide by raising the solution to pH 5 and centrifuging the samples, and then extracted beryllium hydroxide from the remaining solution by raising the solution to pH 8 and centrifuging again. We then transferred the beryllium hydroxide to quartz crucibles and oxidized the samples at 750 °C. Lastly, we mixed the beryllium oxide samples with niobium powder, and packed the mixtures in target holders to be run at the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory.

Sediment monitoring

Caspar Creek. Streamflow and suspended sediment concentration have been measured at the North Fork and South Fork of Caspar Creek since 1962 and at the North Fork tributaries since 1986 (Henry, 1998). Bedload accumulation is surveyed annually in the ponds behind the North Fork and South Fork weirs, and this volume is converted to mass based on a density of 1185 kg m^{-3} (Lewis, 1998). Approximately 40 per cent of the total sediment load settles in these weir ponds.

Suspended sediment sampling methods have changed since monitoring began, which is of concern because early sampling procedures may have produced biased estimates of sediment flux. Prior to 1975, suspended sediment fluxes may have been overestimated by a factor of two to three (Lewis, 1998), because calculations of suspended sediment load were based on empirical relationships between suspended sediment concentration and discharge, and most suspended sediment samples were collected on the rising limb of the hydrograph. Measurements during storms at Caspar Creek have since shown that suspended sediment concentrations are higher on the rising limb of the hydrograph than at equivalent discharges on the falling limb (Lewis, 1998). Calculated sediment loads, therefore, were overestimated to the degree that suspended sediment concentrations on the rising limb exceeded the mean suspended sediment concentration at equivalent discharges. Because 1963–1975 sediment loads were probably overestimated by a factor of two to three (Lewis, 1998), we arbitrarily scaled down Caspar Creek suspended sediment fluxes from 1963–1975 to 40 per cent of their originally documented values.

At the North Fork tributaries Carlson, Eagle, Henningson and Iverson, suspended sediment concentrations have been measured since 1986, but bedload fluxes have not. To calculate total sediment yields for these tributaries, we

Table III. Regression equations used to estimate suspended sediment loads at Caspar Creek tributaries Carlson, Eagle, Henningson and Iverson, based on 1986–2003 storm sediment loads at the North Fork and South Fork of Caspar Creek

Catchment	Regression equations used to estimate suspended load (tons)	R^2	n*
Carlson	$\log(CAR) = -0.1280 + 0.9006 \times \log(NFC)$	0·83	83
	$\log(CAR) = -0.2119 + 0.8636 \times \log(SFC)$	0·70	80
Eagle	$\log(EAG) = -0.0407 + 1.0481 \times \log(NFC)$	0·81	87
	$\log(EAG) = -0.1156 + 1.0257 \times \log(SFC)$	0·67	86
Henningson	$\log(HEN) = -0.4016 + 1.0912 \times \log(NFC)$	0·89	82
	$\log(HEN) = -0.6627 + 1.1320 \times \log(SFC)$	0·82	79
Iverson	$\log(IVE) = -0.5610 + 0.9025 \times \log(NFC)$	0·79	78
	$\log(IVE) = -0.6953 + 0.8852 \times \log(SFC)$	0·73	74

Because Carlson, Eagle, Henningson and Iverson are tributaries of the North Fork, we applied a regression of tributary sediment load against North Fork load wherever possible. For storms without North Fork data, we applied a regression of tributary sediment load against South Fork load. Abbreviations stand for suspended sediment loads (in tons) at the following stations: NFC, North Fork Caspar Creek; SFC, South Fork Caspar Creek; CAR, Carlson; EAG, Eagle; HEN, Henningson; IVE, Iverson.
* Number of data points used to create the regression.

Table IV. Linear regression equations used to estimate bedload at Redwood Creek sites. Regressions are based upon annual suspended load and bedload measurements at each site

Catchment	Regression equation used to estimate bedload (tons)	R^2	n*
Redwood Creek at Orick	bedload = 60 043 + 0·1275 × suspended load	0·52	19
Coyote Creek	bedload = 909 + 0·2906 × suspended load	0·85	8
Little Lost Man Creek	bedload = 49 + 0·2269 × suspended load	0·92	5
Panther Creek	bedload = 139 + 0·4596 × suspended load	0·62	11

* Number of years with both bedload and suspended load data, and also the number of data points used to create the regression equations.

assumed that the bedload fraction was the same as the 1989–1995 bedload fraction measured at the North Fork, i.e. 0·31 (J. Lewis, personal communication, October 2004). This is not an unreasonable assumption; grain size distributions probably do not change much in the short distance (<2·5 km) between the tributaries and the North Fork weir.

The suspended sediment yield records at these tributaries have many gaps. Suspended sediment yield data are tabulated by storm, where a ‘storm’ is defined as an event in which water levels exceed 2 feet (0·61 m) at the South Fork weir. In each tributary dataset, between 24 and 35 (out of 116) storms lack good quality suspended sediment data. Where possible, we estimated suspended sediment yields for ‘missing’ data using log-linear regressions of tributary suspended sediment yields against North Fork and South Fork suspended sediment yields. These regressions are listed in Table III. Suspended sediment yields could not be estimated in this manner for three storms because every gauging station lacked good quality data. However, these three storms were probably small (J. Lewis, personal communication, 2004), and we assume they did not significantly contribute to the total sediment flux over the 18 years of record.

Redwood Creek. At Orick, near the mouth of Redwood Creek, stream sediment fluxes have been measured since 1971, first under the USGS and later under Redwood National Park and Redwood State Park. The tributaries of Redwood Creek considered in this study have between 13 and 20 years of suspended sediment data. The sediment yield records are not continuous: between 1 and 3 years of data are missing from each of the tributary records, and bedload was not recorded later than 1992. For years without bedload data, we estimated bedload as a function of suspended load by creating linear regressions of bedload against suspended load for each station. These regression equations are listed in Table IV.

Results

Beryllium-10 measurements and calculated denudation rates

Table I lists all ^{10}Be concentrations and calculated denudation rates for Caspar Creek and Redwood Creek. At Caspar Creek, millennial-scale denudation rates at each basin nearly agree within error, and average $0{\cdot}09 \pm 0{\cdot}02$ mm a^{-1}. Millennial-scale denudation rates at Redwood Creek vary by a factor of 3, from $0{\cdot}14 \pm 0{\cdot}03$ mm a^{-1} at Little Lost Man Creek to $0{\cdot}44 \pm 0{\cdot}09$ mm a^{-1} at Redwood Creek at Orick.

Decadal-scale sediment yields

Caspar Creek. By summing annual suspended sediment yields and bedload yields (RSL website, 2004), and scaling sediment yields by an assumed bedrock density of 2700 kg m^{-3}, we calculated total 1963–2002 erosion rates for the North Fork and South Fork of Caspar Creek to be $0{\cdot}057 \pm 0{\cdot}015$ mm a^{-1} and $0{\cdot}064 \pm 0{\cdot}012$ mm a^{-1} (mean ± s.e.), respectively. Multiplying the 1963–1975 suspended sediment yields by a factor of 0·4 to account for sampling bias, as described above, reduces the total erosion rates for the North Fork and South Fork of Caspar Creek to $0{\cdot}044 \pm 0{\cdot}009$ mm a^{-1} and $0{\cdot}046 \pm 0{\cdot}007$ mm a^{-1} (mean ± s.e.), respectively. We assume that these rescaled estimates more closely represent actual 1963–2002 erosion rates. At the tributaries Carlson, Eagle, Henningson and Iverson, assuming that the storm records capture 100 per cent of the suspended sediment flux, and that the bedload flux at these tributaries is 0·31 of the total sediment flux, erosion rates range from $0{\cdot}005 \pm 0{\cdot}001$ mm a^{-1} to $0{\cdot}037 \pm 0{\cdot}011$ mm a^{-1} (Table V).

Redwood Creek. We calculated Redwood Creek sediment yields as the sum of suspended sediment yield and bedload yield. Mean annual sediment yields over the past few decades are generally higher than decadal-scale Caspar Creek sediment yields, and are highly variable from basin to basin. The mean 1971–2000 sediment yield for Redwood Creek at Orick, for example, is 12 times higher than the mean 1985–2000 sediment yield at Little Lost Man Creek (Table V).

Table V. Summary of sediment monitoring results at Caspar Creek and Redwood Creek

Catchment	Years of record: Suspended load	Years of record: Bedload	Sediment yield (t km^{-2} a^{-1}) (mean ± s.e.)*	Erosion rate (mm a^{-1}) (mean ± s.e.)†	Ratio of rates‡
Caspar Creek					
North Fork	1963–2002	1963–2002	119 ± 25	0·044 ± 0·009	2·4
South Fork	1963–2002	1963–2002	125 ± 18	0·046 ± 0·007	1·5
Carlson	1986–2003	–	27 ± 6	0·010 ± 0·002	10·1
Eagle	1986–2003	–	99 ± 31	0·037 ± 0·011	1·9
Henningson	1986–2003	–	45 ± 12	0·017 ± 0·004	6·1
Iverson	1986–2003	–	12 ± 3	0·005 ± 0·001	16·0
Redwood Creek					
Redwood Creek at Orick	1971–2000	1974–1992	1304 ± 231	0·48 ± 0·09	0·9
Coyote Creek	1980–1982, 1984–1988, 1992–1995	1980–1988	1112 ± 414	0·41 ± 0·15	0·4
Little Lost Man Creek	1985–1989, 1993–2000	1985–1989	103 ± 29	0·038 ± 0·011	3·6
Panther Creek	1980–1990, 1992–2000	1980–1990	383 ± 160	0·14 ± 0·06	1·6

Sediment yield measurements at Caspar Creek were collected by Pacific Southwest Research Station, Redwood Sciences Laboratory and the California Department of Fire and Forestry Protection. Sediment yield measurements at Redwood Creek were collected by the US Geological Survey, Redwood National Park and Redwood State Park.

* Sediment yields include assumed bedload fractions for years lacking bedload measurements.

† Erosion rates are calculated from sediment yields based on an assumed bedrock density of 2700 kg m^{-3}.

‡ 'Ratio of rates' is the millennial-scale denudation rate (derived from ^{10}Be measurements; see Table I) divided by the decadal-scale erosion rate derived from measurements of stream sediment flux over the past several decades.

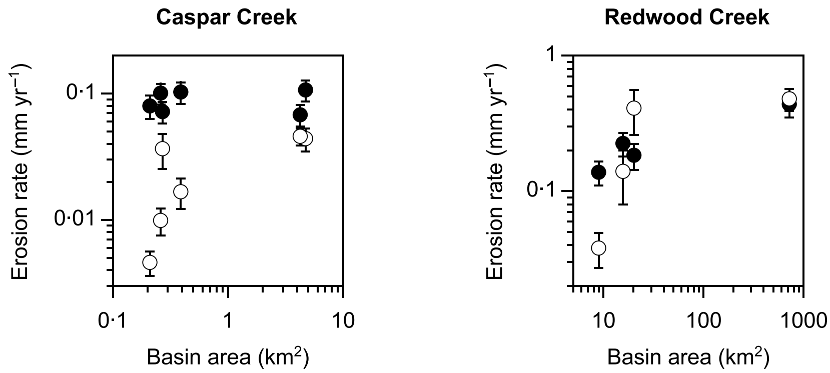

Figure 2. Erosion rates at Caspar Creek and Redwood Creek, averaged over millennial timescales (filled circles) and over decadal timescales (open circles). Uncertainties are one standard error.

Assuming a bedrock density of 2700 kg m^{-3}, Redwood Creek sediment yields translate to erosion rates ranging between $0{\cdot}038 \pm 0{\cdot}011$ mm a^{-1} and $0{\cdot}48 \pm 0{\cdot}09$ mm a^{-1}.

Discussion

Comparison of millennial-scale and decadal-scale erosion rates

The denudation rates we measured over millennial timescales by cosmogenic ^{10}Be are less spatially variable, and have smaller uncertainties, than erosion rates inferred from sediment yield measurements over decadal timescales. Our ^{10}Be measurements imply that over the past *c*. 5500–8700 years (Table I), Caspar Creek has experienced denudation rates that are nearly spatially uniform across the entire catchment, and average $0{\cdot}09 \pm 0{\cdot}02$ mm a^{-1} (Figure 2). By comparison, erosion rates derived from post-1962 sediment yields are slower than millennial-scale denudation rates, and show more spatial variability, ranging from *c*. 0·005 mm a^{-1} up to *c*. 0·05 mm a^{-1}. In general, the smallest basins show the greatest discrepancy between decadal-scale and millennial-scale measurements (Figure 2).

At Redwood Creek, denudation rates implied by ^{10}Be vary by a factor of three from basin to basin, ranging from $0{\cdot}14 \pm 0{\cdot}03$ mm a^{-1} to $0{\cdot}44 \pm 0{\cdot}09$ mm a^{-1} over the past *c*. 1400–4300 years (Table I). Erosion rates inferred from decadal-scale sediment yields range from *c*. 0·04 mm a^{-1} to *c*. 0·48 mm a^{-1} and agree with millennial-scale denudation rates within error at Panther Creek and Redwood Creek at Orick, but the decadal-scale rate is about twice a fast as the millennial-scale rate at Coyote Creek and 3·6 times slower at Little Lost Man Creek (Figure 2).

Could the calculated rates be wrong?

Is it possible that the decadal-scale sediment yield measurements are too low or the ^{10}Be-derived denudation rates are too high? The fact that ^{10}Be measurements reflect total denudation (physical erosion + chemical weathering fluxes) while sediment gauging records reflect only physical erosion should not cause a large difference between the millennial-scale and decadal-scale rates documented here. Previous measurements at Redwood Creek indicate that chemical denudation rates (49·7 t km^{-2} a^{-1}; Dethier, 1986) constitute a small fraction of the total denudation rates measured in this study (1149 ± 226 t km^{-2} a^{-1}). Cosmogenic rates could also be too high if the parameters used in the calculations are wrong. For example, at each site we assumed the soil had an average density of $1{\cdot}5 \pm 0{\cdot}25$ g cm^{-3} and an average depth of $1{\cdot}5 \pm 0{\cdot}5$ m. Changing each of these parameters by a factor of two, however, changes calculated denudation rates by less than 5 per cent. We also assumed that quartz enrichment in the soil relative to bedrock (e.g. Small *et al*., 1999; Riebe *et al*., 2001) is 4 per cent; decreasing this enrichment to 0 per cent reduces millennial-scale denudation rates by only 2 per cent. It is also important to consider potential biases due to grain size effects, since some studies (e.g. Brown *et al*., 1995) have found a correlation between grain size and ^{10}Be concentrations, where larger grains, delivered to the stream by landslides, have lower concentrations of ^{10}Be. Most of our stream sediment samples were dominated by relatively large grains; at Caspar Creek, grains larger than 2 mm constituted 72–88 per cent of our sediment sample, and at Redwood Creek, grains larger than 2 mm constituted 18–69 per cent of our sediment samples. This should bias our calculated denudation rates if grain size is correlated with exposure to cosmogenic radiation at our field sites, and if the grain size distribution of our sediment samples deviates from the average distribution of grain sizes in stream sediment at our field sites. If our sediment samples have abnormally large grains with abnormally low ^{10}Be concentrations, then actual denudation rates would be lower than our calculated denudation rates.

Decadal-scale erosion rates could be too low if the sediment gauging stations missed part of the sediment flux. However, it seems unlikely that gauging inefficiency could account for the discrepancy between the decadal-scale and millennial-scale measurements (J. Lewis, personal communication, 2004). At Caspar Creek, gauging stations would have to miss 37–94 per cent of the sediment flux in order to match millennial-scale rates. Decadal-scale sediment yields at tributaries Carlson, Eagle, Henningson and Iverson might also be too low if the assumed bedload fraction were too low. At these tributaries, however, bedload would have to constitute 66–96 per cent of the total load in order to account for the discrepancy, which is inconsistent with the observation that only *c*. 30 per cent of the total yield accumulates as bedload in the weir ponds.

How has logging affected ^{10}Be concentrations in our stream sediment samples?

Clear-cut logging at Caspar Creek from 1860 to 1906 (Henry, 1998) probably led to rapid erosion, which implies that ^{10}Be concentrations in our sediment samples might be lower than they would have been if the study catchments had never been logged. If this is the case, then our calculated denudation rates would be faster than actual millennial-scale denudation rates. Unfortunately, since we are not aware of estimates of erosion rates during the 19th century, it is not possible to properly account for this in the denudation rate calculation. Nonetheless, we suspect that our calculated denudation rates are not far from actual millennial-scale denudation rates, since ^{10}Be concentrations are fairly insensitive to recent changes in denudation rates. For example, if clear-cut logging during the years 1860–1906 had uniformly eroded 100 cm of soil (that is, if erosion rates had been *c*. 500 times faster than 1963–2002 erosion rates at the North Fork of Caspar Creek), then our calculated denudation rates would overestimate the pre-logging denudation rate by only about a factor of two. As a rough comparison, Lewis (1998) calculated that erosion rates were elevated by less than a factor of three at the South Fork of Caspar Creek during 1972–1978, the period which immediately followed removal of *c*. 65 per cent of the South Fork stand volume. Thus 1860–1906 erosion rates would have to have been very high in order to drastically alter the ^{10}Be concentrations in our sediment samples.

What causes the observed spatial variation in erosion rates?

The spatial similarity in millennial-scale denudation rates across the Caspar Creek basin is not surprising, given that the underlying lithology varies little throughout the basin (Jennings and Strand, 1960), hillslope gradients are roughly the same in each tributary basin (Table I), and the small size (*c*. 9 km^2) of the study area makes for a roughly uniform climate. The small spatial variability in ^{10}Be concentrations suggests that erosion rates, when averaged over a sufficiently long time period, approach a single constant rate throughout the Caspar Creek catchment. This small spatial variability in ^{10}Be concentrations contrasts with the large spatial variability in the decadal-scale measurements, suggesting that erosional processes at Caspar Creek vary on timescales longer than decades and shorter than the cosmogenic erosional timescale, i.e. <5500 years (Table I).

According to our Redwood Creek ^{10}Be measurements, Coyote Creek, Panther Creek and Little Lost Man Creek are eroding more slowly than Redwood Creek basin as a whole, implying that the unsampled tributaries of Redwood Creek must be eroding more quickly, on average, than the three tributaries we sampled. It would not be surprising to find that the fastest erosion rates are concentrated farther south than the tributaries we sampled, since Redwood Creek is much steeper near its southernmost headwaters, and the higher elevations there may be subject to enhanced physical weathering due to more intense freeze–thaw cycles. Mean hillslope gradients vary little from site to site (Table I), and so are probably not the main cause of variation in denudation rates. Lithology has been shown to regulate bedrock river incision rates (e.g. Sklar and Dietrich, 2001), but its influence on hillslope denudation rate is not apparent in our ^{10}Be measurements. For example, Coyote Creek cuts through incoherent sandstone and mudstone, and Panther Creek incises the Redwood Creek Schist (Harden *et al*., 1981), yet their millennial-scale denudation rates agree with each other within error. This agreement in denudation rates at Panther Creek and Coyote Creek might be a result of main stem forcing, since these tributaries enter the main stem of Redwood Creek at about the same location (Figure 1). If the morphologies of Panther Creek and Coyote Creek are both adjusted to produce incision rates that match Redwood Creek's incision rate, then the steepness of these tributaries should reflect differences in bedrock strength – that is, the tributary in the stronger lithology should be steeper than the tributary in the weaker lithology. However, the mean channel gradient at Coyote Creek is *c*. 0·12, and at Panther Creek it is *c*. 0·08 (Figure 3). This would seem to suggest

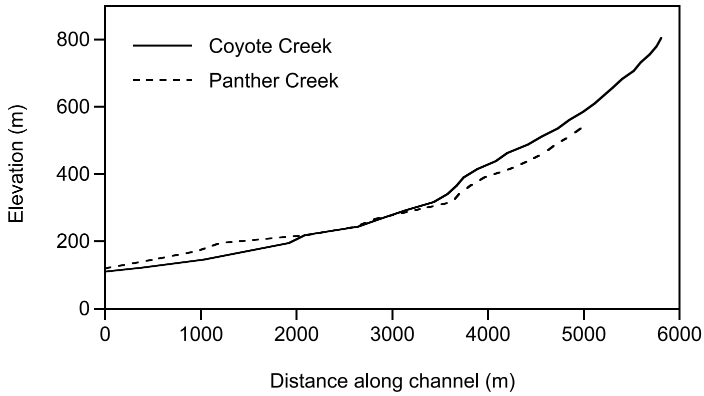

Figure 3. Longitudinal profiles of Coyote Creek and Panther Creek, determined from 1:24 000 USGS topographic maps. The horizontal axis is distance from the main stem of Redwood Creek, measured along the channel. Mean channel gradients are *c.* 0·12 at Coyote Creek and *c.* 0·08 at Panther Creek.

that, if the difference in channel gradient were purely a function of differences in lithologic strength, then the incoherent sandstone underlying Coyote Creek would be stronger than the Redwood Creek Schist underlying Panther Creek, which is implausible. Thus any influence of bedrock lithology on hillslope denudation rates is not evident in our cosmogenic ^{10}Be measurements. Measurements of bedrock tensile strength, as well as further ^{10}Be measurements from stream sediment in other tributaries, could help quantify the influence of lithology on erosion rates in the Redwood Creek basin.

In the decadal-scale measurements, the spatial differences in erosion rates appear to be partially attributable to the different measurement periods. At Caspar Creek, the records for tributaries Carlson, Eagle, Henningson and Iverson span 1986–2003, while the North Fork and South Fork records go back to 1963. The mean 1986–2002 erosion rates at the North Fork and South Fork are $0{\cdot}029 \pm 0{\cdot}008$ mm a^{-1} and $0{\cdot}039 \pm 0{\cdot}011$ mm a^{-1} (mean ± s.e.) respectively; this is slower than the mean 1963–2002 North Fork and South Fork erosion rates, but still faster than most of the 1986–2003 tributary erosion rates. Similarly, during the monitoring periods at Coyote Creek, Panther Creek and Little Lost Man Creek (Table V), the average physical erosion rate at Redwood Creek at Orick ranged from $0{\cdot}32 \pm 0{\cdot}07$ mm a^{-1} to $0{\cdot}36 \pm 0{\cdot}06$ mm a^{-1} (mean ± s.e.), which is slower than the 1971–2000 erosion rate of $0{\cdot}48 \pm 0{\cdot}09$ mm a^{-1} (mean ± s.e.) at Redwood Creek at Orick, but still faster than erosion rates at Panther Creek and Little Lost Man Creek. These calculations suggest that, within the Caspar Creek and Redwood Creek catchments, the site-to-site differences in the decadal-scale measurements are partially, but not entirely, due to the different measurement periods.

What causes the observed temporal variation in erosion rates?

Why are there discrepancies between the decadal-scale and millennial-scale erosion rates at some of the basins and not in others? It should be noted that at most of the study basins, the difference between decadal-scale and millennial-scale erosion rates is a factor of two to three, which is not particularly large. A similar study in Idaho (Kirchner *et al.*, 2001) found that millennial-scale denudation rates were, on average, 17 times faster than short-term erosion rates, most likely reflecting extremely episodic sediment delivery to streams. Another study in Sri Lanka (Hewawasam *et al.*, 2003) found the opposite: short-term erosion rates that were an order of magnitude faster than denudation rates averaged over the past *c.* 20 000 years, reflecting recent human disturbance. A potential explanation for the difference in erosion rates at Caspar Creek and Redwood Creek is that sediment delivery to streams is naturally episodic; it is possible that the past 40 years of sediment monitoring have seen relatively few of the large events that dominate long-term average erosion rates.

Why do the smallest catchments tend to have slower decadal-scale rates?

Especially at Caspar Creek, it appears that small catchments show greater disparity between millennial-scale and decadal-scale sediment yields than large catchments. This observation is consistent with the hypothesis that small catchments are dominated by episodic sediment delivery. That is, if sediment delivery from small catchments is usually slow, and is infrequently punctuated by large events (e.g. landslides, debris flows), then the decadal-scale sediment yield in small basins will usually be low and infrequently high. At the mouth of a large basin, on the other hand, the sediment yield is the average of all the sediment yields from the upstream tributaries. If the tributary basins are dominated by episodic sediment delivery, and if the timing of sediment delivery were uncorrelated from one tributary to another, then the decadal-scale sediment yield at a large basin would be the average of many low sediment yields and a few high sediment yields. This averaging could result in a sediment yield at a large basin that is higher than the low sediment yields experienced by most of the small tributary basins in any particular period, yet still lower than the long-term average sediment yield in the large basin. If millennial-scale erosion rates are dominated by episodic erosion, then over a short time period the spatial pattern of sediment yields could match the pattern of decadal-scale sediment yields observed at Caspar Creek (Figure 2).

How would the spatial pattern of erosion be interpreted if we only had the decadal-scale sediment yields?

The spatial patterns of erosion revealed by the decadal-scale and millennial-scale measurements are quite different, and highlight the value of using cosmogenic denudation rate measurements in landscape evolution models. Decadal-scale sediment fluxes suggest that erosion rates vary in space by a factor of 10 at Caspar Creek and a factor of 12 at Redwood Creek, while our cosmogenic ^{10}Be measurements suggest that erosion rates are nearly spatially uniform at Caspar Creek and vary by a factor of three at Redwood Creek. Because the decadal-scale sediment fluxes imply greater spatial variability in erosion rates than our cosmogenic ^{10}Be measurements imply, the decadal-scale rates would be interpreted as predicting greater variability in landscape morphology over time. However, because the cosmogenic denudation rates are averaged over longer timescales than the sediment flux measurements at Caspar Creek and Redwood Creek, denudation rates determined from measurements of cosmogenic ^{10}Be are more likely to be representative of the processes that dominate long-term landscape evolution.

How do these denudation rates compare with uplift rates?

Many researchers have posited that landscapes tend to approach topographic steady state, a condition in which a particular property of the landscape (e.g. mean elevation) remains constant over time (e.g. Hack, 1960; Willett and Brandon, 2002). In such a situation, if a region is undergoing spatially uniform uplift, erosion rates are also spatially uniform. Caspar Creek is an example of a landscape that is undergoing nearly spatially uniform erosion over millennial timescales, but which is not eroding as quickly as it is being uplifted. Ages and elevations of nearby marine terraces yield uplift rates of 0·3–0·4 mm a^{-1} (Kennedy *et al.*, 1982; Merritts and Bull, 1989), higher than both the millennial-scale and decadal-scale erosion rates at Caspar Creek. If this uplift rate is also the mean uplift rate over the timescale of our cosmogenic denudation rates, our ^{10}Be measurements indicate that the mean elevation of Caspar Creek has been increasing at an average rate of *c.* 0·2–0·3 mm a^{-1}.

The marine terrace ages also reveal that our catchment-averaged denudation rates do not agree with the rate of river incision through the terraces in lower Caspar Creek. The oldest marine terrace to which Merritts and Bull (1989) assigned an age is the *c.* 130 m terrace, which they correlated with the 330 ka sea-level highstand. Next to this terrace, Caspar Creek has an elevation of *c.* 10 m, which implies that Caspar Creek has incised through *c.* 120 m in 330 ka – an incision rate of 0·36 mm a^{-1}. There are several possible reasons why this river incision rate does not match the average denudation rate of 0·09 ± 0·02 mm a^{-1} implied by our ^{10}Be measurements. First, the 130 m terrace is downstream of our ^{10}Be sampling locations, so it is possible that erosion rates in lower Caspar Creek are faster than in upper Caspar Creek. Second, it is possible that the difference is due to the different timescales; the rate of river incision through the terrace is a 330 ka average, while the ^{10}Be-derived denudation rates are *c.* 5–9 ka averages (Table I). It might be that Caspar Creek has simply eroded more slowly over the past *c.* 5–9 ka than it has over the past 330 ka. Third, it is possible that the river incision rate is faster than the hillslope denudation rate. Fourth, it is possible that the ages Merritts and Bull (1989) assigned to the terraces are too young. Aside from the 24 m terrace, which was dated using amino-acid racemization (Kennedy *et al.*, 1982; Lajoie *et al.*, 1991), all terrace ages near Caspar Creek were assigned by correlating terraces to sea-level highstands of known age (Merritts and Bull, 1989). Elsewhere in California, cosmogenic dating of marine terraces (Perg *et al.*, 2001) has yielded ages that differ from those determined by sea-level correlation. This suggests that the older marine terraces near Caspar Creek might have significantly different ages than those reported in Merritts and Bull (1989), and implies that the uplift rate estimates should be treated with caution. If the 130 m terrace were *c.* 1·4 million years old instead of 330 ka, the calculated rock uplift rate would match our cosmogenic denudation rate of 0·09 ± 0·02 mm a^{-1}. Assuming the terrace ages assigned by Merritts and Bull (1989) are correct, the denudation rates in upper Caspar Creek over the past 5–9 ka are slower than both the average river incision rate in lower Caspar Creek and the average rock uplift rate over the past 330 ka.

Conclusions

Our measurements of ^{10}Be in stream sediment imply that, at most of the basins examined in this study, millennial-scale denudation rates are in rough agreement with, or somewhat higher than, sediment yields measured over the past few decades. At Caspar Creek millennial-scale denudation rates tend to be faster, relative to decadal-scale rates, than at Redwood Creek; millennial-scale measurements are 1·5–16 times as fast as decadal-scale measurements at Caspar Creek, and 0·4–3·6 times as fast at Redwood Creek.

In addition, millennial-scale and decadal-scale erosion rates tend to show large discrepancies over small catchments and small discrepancies over larger catchments (i.e. at North Fork Caspar Creek, South Fork Caspar Creek, Redwood Creek at Orick). In contrast to order-of-magnitude differences found elsewhere (e.g. Kirchner *et al*., 2001; Hewawasam *et al*., 2003), the sediment yields measured over the past few decades at the mouths of Caspar Creek and Redwood Creek differ from millennial-scale rates of sediment production by less than a factor of three.

These measurements also imply that, within these two catchments, there is greater spatial variability in erosion rates over decadal timescales than over millennial timescales. At Caspar Creek, sediment yields measured over the past few decades vary by nearly an order of magnitude from site to site, but ^{10}Be measurements imply nearly spatially uniform denudation rates over the past *c*. 5–9 ka. At Redwood Creek, decadal-scale sediment yields differ in space by a factor of 12, while millennial-scale denudation rates inferred from cosmogenic ^{10}Be measurements differ by a factor of three. This greater spatial variability over short timescales might be a reflection of episodic erosion.

Lastly, previous estimates of marine terrace ages and elevations near Caspar Creek (Merritts and Bull, 1989) indicate that rock uplift rates are substantially faster than denudation rates, implying that the mean elevation of Caspar Creek is rising at an average rate of 0·2–0·3 mm a^{-1}. This suggests that spatially uniform denudation rates, such as those observed at Caspar Creek, are not necessarily indicative of topographic steady state.

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SOUTH FORK WAGES CREEK STREAMFLOW AND SEDIMENT TRANSPORT MONITORING WY2004-2005

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SOUTH FORK WAGES CREEK

STREAFLOW AND SEDIMENT TRANSPORT MONITORING PROJECT – WATER YEAR 2004-2005

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STREAMFLOW AND SEDIMENT TRANSPORT IN THE SOUTH FORK WAGES CREEK WATERSHED – WY2004 - 2005

1.0 INTRODUCTION

The purpose of this report is to describe the methods and results for streamflow and sediment transport monitoring conducted in the SF Wages Creek Watershed during the 2004 and 2005 water years. The SF Wages Creek watershed is located north of Fort Bragg, in Mendocino County, California (Figure 1, contained in the back of this report). SF Wages is a tributary to Wages Creek, which drains to the Pacific Ocean. SF Wages is located in the headwaters of Wages Creek and encompasses the watershed area above Tank Gulch.

This study was undertaken for the California Board of Forestry and Campbell Timberland Management and is intended to be the baseline data collection in a long-term streamflow and sediment transport monitoring study. This study is one of two components of the SF Wages Creek THP Effectiveness Monitoring Plan.

In Water Year 2004 Streamflow and sediment transport data were collected and analyzed by Graham Matthews and Associates at seven sites throughout the SF Wages Creek watershed (Figure 2, contained in the back of this report). In Water Year 2005 Campbell Timberland Management took over operation and data collection at the sites while Graham Matthews and Associates retained responsibility for computing and analyzing the data.

2.0 SCOPE AND OBJECTIVES

The scope of this project is to provide detailed streamflow and sediment transport data for the major sub-watershed areas in the SF Wages Creek watershed. The work consisted of collecting field data and developing and then completing the following tasks for each sampling site:

1. Install and operate 5 continuous streamflow/sediment transport gages within the SF Wages Creek project area along with 2 manual streamflow stations.
2. Collect streamflow measurements and turbidity/suspended sediment samples,
3. Develop stage/discharge relationships,
4. Develop turbidity/suspended sediment concentration (SSC) relationships,
5. Develop SSC/discharge relationships (Where appropriate),
6. Compute streamflow records, and
7. Compute sediment records

3.0 METHODS

3.1 GAGING STATION ESTABLISHMENT

In Water Year 2004 the gaging network consisted of 5 continuous recording and 2 periodic stations (Table 1). In Water Year 2005 the gaging network consisted of 4 continuous recording stations and 3 periodic stations (Table 2). The continuous recording stations consist of a datalogger, pressure transducer, turbidity probe, as well as a staff plate or fence post, pump sampler, turbidity boom, and a small equipment house. Photos of all the sites can be found in the back of this report.

TABLE 1
SOUTH FORK TENMILE WATERSHED
General Site Description WY2004

SITE NAME	ACRONYM	WSA (mi^2)	Continuous Station
Center Gulch above SF Wages	CASFW	0.29	yes
SF Wages above Center Gulch	SFWAC	1.10	yes
Grey Gulch above SF Wages	GASFW	0.17	no
Wood Creek above SF Wages	WASFW	0.10	yes
SF Wages above Wood Creek	SFWAW	0.73	no
Rock Creek above SF Wages	RASFW	0.24	yes
SF Wages above Rock Creek*	SFWAR	0.39	yes

*Continuous Site does not contain ISCO pump sampler

Dataloggers (Campbell Scientific CR510) and pump samplers (Isco 6712) were installed in steel enclosures to prevent vandalism and to provide a secure area to hold deep cycle batteries (Photo 1, Contained in the back of this report). Cable mounted booms were fabricated and installed to allow the turbidity sensors and pump sampler intakes to sample at the same relative position in the water column during a wide range of stages. In general fabrication and deployment followed the guidelines established by USFS, Pacific Southwest Research Station, Redwood Sciences Lab (Johnston et. al. 2001). A number of the sites required channel improvement at the gage location in order to collect reliable streamflow and turbidity data. At these sites, small weirs were constructed using on-site rock, concrete and/or wood.

3.2 STAGE AND STREAMFLOW MESUREMENT

3.2.1 Stage Measurement

Staff plates were attached to channel iron that was driven into the streambed at 2 of the 7 study sites as stage measuring devices. River stage was measured directly off the staff plate at each of these locations. At the other 5 locations, river stage was measured from the water surface to the top of a fence post using a pocket surveyor's tape. Crest gages were installed at periodic stations, to measure river stage in order to record the peak or maximum river stage during storm events.

TABLE 2
SOUTH FORK TENMILE WATERSHED
General Site Description WY2005

SITE NAME	ACRONYM	WSA (mi^2)	Continuous Station
Center Gulch above SF Wages	CASFW	0.29	yes
SF Wages above Center Gulch	SFWAC	1.10	yes
Grey Gulch above SF Wages	GASFW	0.17	no
Wood Creek above SF Wages	WASFW	0.10	yes
SF Wages above Wood Creek	SFWAW	0.73	no
Rock Creek above SF Wages*	RASFW	0.24	no
SF Wages above Rock Creek**	SFWAR	0.39	yes

*Site was continuous in WY 2004 then switched to a manual site in WY 2005

**Added pump sampler in WY 2005

Stage data collected using the fence posts were recorded as negative stages. In order to put the data in standard form, all fence post tops were assigned a positive reference elevation. The stage reading was added to this value to determine a positive river stage from the streambed to the water surface.

3.2.2 Continuous Stage Measurement

Continuous stage was read using pressure transducers. The pressure transducers (Design Analysis H-310), with an accuracy of less than or equal to 0.025% of the full scale output (FSO) were installed in flexible armored conduit down the streambank and anchored to the bottom of the streambed. Continuous stage readings were recorded in the datalogger at 15 minute intervals. Stage offsets were applied to the pressure transducer readings so that continuous stage readings matched observed stage heights taken from the fence posts or the staff plates.

3.2.3 Streamflow Measurements

Streamflow measurements were taken at all sites, with the exception of SFWAW, using standard or modified USGS methods. All measurements were performed by wading at the gage location. Streamflow equipment for wading measurements included a 4ft top-set wading rod, JBS Instruments AquaCalc 5000 -Advanced Stream Flow Computer, and either a Price AA or Pygmy current meter. All measurements were made with the magnetic head version of the Price AA or Pygmy meter. Due to the small size of the channels and the low flows it was necessary to perform measurements below the depth and velocity limits of the current meters. During periods of rapidly changing river stage, fewer verticals were used in order to improve the accuracy of the measurement. Fewer verticals were also used in some of measurements due to the limited width of the channel. However, most discharge measurements still contained 15-30 verticals.

3.3 STAGE AND STREAMFLOW COMPUTATION

All continuous stage and streamflow data was processed and computed using the WISKI Suite (Water Information Management System Kisters) developed by KISTERS AG. WISKI is a Windows based professional time series hydrological management package based on a relational database client-server platform such as Microsoft Sequel Server. The WISKI Suite is comprised of three components WISKI, BIBER, and SKED. The main WISKI shell is the hydrologic workbench where all data is organized and where computations on time series data are carried out. BIBER is used to evaluate and management discharge measurements as well as track current meters, counters and users of said equipment. SKED is a rating curve editor that uses graphical user interface to assist the hydrologist in developing, maintaining, and using rating curves. The U.S. version of WISKI uses standard hydrologic computations and techniques as set forth by the United States Geological Survey (USGS).

3.3.1 Stage Hydrographs

Stage hydrographs were developed for all sites with continuous stage records. Recorded gage height (GH) was plotted and compared to observed stage height (SH) observations. Gage height records were corrected to observed SH readings when necessary. In general only reliable (low to mid-staff height) readings were used to evaluate whether the GH record needed to be adjusted.

3.3.2 Rating Curves

Stage-discharge rating curves were developed in SKED for the following six sites: SFWAC, CASFW, GASFW, WASFC, RASFW, and SFWAR. Rating curve development involved plotting discharge verses stage and fitting a curve to the data. Regression equations were evaluated and used to guide curve development but ultimately all stage-discharge ratings were developed by eye fit. Once the curve had been developed skeletal rating points were pulled from the curve in order to develop the stage-discharge relationship. Log by Log interpolation was used between all skeletal rating points.

For sites that did not have stable stage-discharge relationships or where debris became lodged on the control rating shifts were developed.

3.3.3 Discharge Hydrographs

Discharge hydrographs were developed in WISKI using standard hydrologic practices. Corrected gage height records and discharge rating tables were used in the process. For sites without continuous gage height recorders, synthetic stage/discharge relationships were developed through a combination of direct and indirect methods. In general, sites with continuous records were scaled by watershed area to produce synthetic records at locations that did not have continuous records. Once a synthetic discharge hydrograph had been developed the record was adjusted based on discharge measurements made at the site.

Once discharge hydrographs were developed they were reviewed and checked against discharge measurements and to adjacent stations to insure that the records were as accurate as possible.

3.4 SEDIMENT SAMPLE COLLECTION

Sediment sampling included both measurements of turbidity and suspended sediment. In general the continuous stations were operated following the TTS protocols developed by USFS, Pacific Southwest Research Station, Redwood Sciences Lab (Johnston et. al. 2001). Suspended sediment was sampled with depth-integrating samplers (DH-48), and as much as practical and possible using procedures standardized by the USGS (Guy and Norman 1970, Edwards and Glysson 1988).

3.4.1 Turbidity and Suspended Sediment Sampling

At all study sites, sediment samples were needed to relate turbidity to suspended sediment concentration, to calibrate the turbidity probes, and to calibrate point pump samples to cross sectional depth-integrated samples. Depth-integrated turbidity and suspended sediment concentration (SSC) sampling was performed at all locations. Sediment samples were collected using a US DH-48 Depth-Integrating Suspended Sediment Sampler. Sampling sites were located at or near stage measurement sections. Standard methods, as developed by the USGS and described in Glysson and Edwards (1988) were generally used for sampling. In all cases depth integrated samples were collected using the Equal Width Increment Method (EWI). Due to the number of sites being sampled and the limited budget the following departures from the protocols were used: In Water Year 2004 transit rates for depth integrated samples were estimated and the distance between verticals was also estimated. For each sample the location, time, stage, number of verticals, estimated distance between verticals, bottle #, and whether a field replicate was taken were recorded. At locations where it was not possible to get a true depth-integrated sample, grab samples or modified depth-integrated samples were taken, and this information was recorded.

Samples were kept chilled after collection and stored in ice chests. Turbidity values were obtained within 48 hours using a Lamotte 2020 turbidimeter. Suspended sediment concentrations were determined in the GMA sediment lab following USGS and ASTM D-3977 protocols. A laboratory QAPP is available to interested parties.

3.4.2 Continuous Turbidity Sampling

A continuous turbidity probe was installed at each of the continuous sampling locations. The continuous stations were generally operated following the TTS protocols developed by USFS, Pacific Southwest Research Station, Redwood Sciences Lab (Johnston et. al. 2001). The turbidity probes used are the Forest Technologies Systems DTS-12 with wipers. The DTS-12 has a range between 0 and 1,600 FNU's. Accuracy of the unit is as follows: 0-499.99 FNU ± 2% of reading +0.2FNU and 500.00 to 1600 FNU ± 4% of reading. Each turbidity sensors was mounted in a PVC housing that was fixed to the end of a boom arm. Data was read by turbidity meter and recorded by the data logger. Recording interval was set to 15 minutes.

3.4.3 Pump Samples

In Water Year 2004 An ISCO 6700 or 3700 series pump sampler was installed at all continuous sites except one (SFWAR). In Water Year 2005 SFWAR was upgraded with the pump sampler that was removed from RASFW when the station was downgraded from a continuous site to a periodic station. The pump samplers were programmed following the TTS protocols developed by USFS, Pacific Southwest Research Station, Redwood Sciences Lab (Johnston et. al. 2001). Intakes for the pump samplers were located on the turbidity probe housings. Pumped samples were removed from sampler and processed for turbidity with in 48 hours or as soon as possible.

3.5 TURBIDITY AND SUSPENDED SEDIMENT TRANSPORT COMPUTATION

Turbidity and suspended sediment data can be analyzed in many ways. Some of the more common relationships that are investigated are turbidity versus suspended sediment concentration (SSC), turbidity versus discharge, SSC versus discharge, suspended sediment load versus discharge and suspended sediment yield. In Years past it was quite common to produce continuous concentration sedigraphs based on the relationship between discharge and SSC. In recent years however, affordable, accurate and dependable continuous turbidity probes have become readily available and have proved very reliable for producing sediment discharge records. For the SF Wages Creek THP effectives monitoring project it was determined that continuous turbidity would be an appropriate surrogate for SSC. Sediment analysis will focus on the relationship between turbidity and SSC at each of the study sites. If a good turbidity-SSC relationship did not exist at the site discharge-SSC relationships were investigated.

In general standard methods, as described by the USGS and described in Computation of Fluvial-Sediment Discharge (Porterfield 1977) were used for sediment computations.

3.5.1 Suspended Sediment Concentration

WISKI was used to develop sediment-tranport curves and continuous sediment concentration curves (sedigraphs). Sedigraphs were developed using the turbidity-SSC relationship (sediment tranport curve) that existed at each site. Many times several relationships existed at the site. For instance a relationship may have been developed for a specific storm, a set of storms or for the entire storm season. Based on these sediment-transport curves a sedigraph or set of sedigraphs was developed for each site. Once a base sedigraph had been developed, depth integrated and automatic samples were used to adjust the base sedigraph in order to produce a final sedigraph. Where sufficient sample data existed the sedigraph was adjusted to pass through all sample points. During periods when no sample data existed the transport curve was used to estimate continuous concentration.

Development and use of sediment-transport curves followed the basic principles outlined by the USGS and described in Sediment-Transport Curves (Glysson, 1987).

For periodic sites where continuous turbidity data was not available sediment concentration came from the depth integrated lab results. No attempt was made to develop continuous sedigraphs for these sites.

3.5.2 Suspended Sediment Discharge Computation

WISKI was used to compute continuous sediment discharge. Once sedigraphs were developed and finalized for all of the continuous sites the concentrations were transformed into continuous sediment discharge curves using the equation: Sediment Discharge = Q*SSC*.002697). Pump and depth integrated samples were also transformed.

3.5.3 Sediment Load Computation and Yield Computations

WISKI was used to compute all sediment loads for the continuous sites. Loads were totaled for each water year. At this time sediment loads have not been computed for individual storm events. Sediment loads were not calculated for periodic sites.

Sediment yields were computed in Excel on a per square mile basis. Sediment yields were computed for depth integrated and and pump samples for all sites.

4.0 RESULTS

4.1 GAGING STATION OPERATION

TTS sampling is dependent on the proper functioning of the electronic equipment at the site. In WY2004 and WY 2005 there were periodic electronic equipment failures. Most problems were pin-pointed and fixed, while others are still under investigation. Some problems have been; loose or faulty cable connections, ISCO sampler malfunctions, pressure transducer malfunctions, and over consumption of battery power.

Being the first year of a challenging study, many problems were encountered with the project in WY2004. Most of the problems were solved and fixed. However, some of the problems will require continued effort and are a result of the logistical challenges of the study and the specific site locations.

The location of the study area presented a significant challenge. A total time of about 2.5 hours is required to reach the study site from Fort Bragg. This includes truck travel time, ATV travel time, and the time it takes to load up all sampling gear, personal gear, and tools (Photo 2). The travel time is increased if fallen trees block the road. It was extremely important that the sampling crew was prepared for any problems that needed to be remedied.

The size and shape of the channel at the sampling sites made automated sampling problematic. On of the common problems with the channels in SF Wages Creek watershed is the width to depth ration of the channels. At several sites, depth during storms did not increase enough for the instrumentation to work properly. Shallow depths often caused the turbidity probes to see the channel bottom, which would initiate false pump samples. This caused the 24 bottle supplies in the Isco pump samplers to be exhausted. In an effort to remedy this problem, large boulders were placed along the banks and within the channel at some of the sampling locations to decrease the width to depth ratio. Another factor that makes sampling problematic is the large amount of bedload transport in the system. The wood and rock weirs installed at many of the sampling locations, intended to provide stable channel controls, act as bedload traps. As bed material builds up behind the controls the bed elevation is raised making it necessary to increase the minimum stage in the TTS program. Due to the build up of material turbidity probes became buried. This is not a problem at sites where the width to depth ration was decreased. The final problem and the hardest to remedy is the turbulent flow nature of the channels. At many of the sites during high flows entrained air causes poor turbidity records. In some cases, the turbidity boom can be moved laterally along the cable, placing the probe in a less turbulent location. At other locations it was necessary to move the turbidity booms upstream or downstream.

During the second year of sampling gage operation was taken over by Campbell Timerland Management. Many of the challenges that existed in Water Year 2004 were encountered in Water Year 2005 (K. Faucher, Personal Communication). In general Campbell Timberland Management did a good job in keeping the sites in operating condition. When problems occurred they were remedied in a timely fashion.

In Water Year 2005 Rock Creek above SF Wages Creek was downgraded to periodic station and the Isco pump sampler was installed at SF Wages Creek above Rock Creek

4.2 STEAM FLOW MEASUREMENTS

All streamflow measurements were entered and cataloged using the standard USGS-type 9-207 discharge measurement summary form. A 9-207, for each site, summarizing all streamflow measurements made over the course of WY2004 and Water Year 2005 is contained in the appendix.

A total of 27 discharge measurements were made at the six of the seven sites in WY2004. Streamflow measurements were collected from December 2003 through February 2004. The number of streamflow measurements collected at each site is shown in Table 3. Between 4 and 5 discharge measurements were taken at six of the sampling sites. Six to eight discharge measured is preferred to adequately define a stage-discharge relationship, but due to the relative small range of discharge encountered in the SF Wages Creek watershed the number of discharge measurements was considered adequate for the first year of the program. Due to the small size of the stream channels, and low discharges that were encountered, it was necessary to modify standard discharge measurement protocol. When flows were very low the pygmy meter was used below the recommended depth and velocity limits. During periods of low flow it was not always possible to have less than 10%, the recommended maximum percent of flow for any one vertical, flow in each discharge verticals. When discharge measurements were made that fell outside of standard protocols the measurement quality was downgraded. No check measurements were made in WY 2004 and no gage height of zero flow (GZF) measurements were made.

A total of 35 discharge measurements were made at six of the seven sites in WY 2005. Streamflow measurements were collected between December 2004 and May of 2005. The

TABLE 3
SOUTH FORK WAGES CREEK WATERSHED
Streamflow Measurement Summary WY 2004

SITE NAME	ACRONYM	# of Streamflow Measurements collected in WY 2004
Center Gulch above SF Wages	CASFW	4
SF Wages above Center Gulch	SFWAC	5
Grey Gulch above SF Wages	GASFW	4
Wood Creek above SF Wages	WASFW	5
SF Wages above Wood Creek	SFWAW	0
Rock Creek above SF Wages	RASFW	5
SF Wages above Rock Creek	SFWAR	4

number of streamflow measurements collected at each site as well as the total number of measurements that have been collected at each site is summarized in Table 4. Collection of discharge measurements during Water Year 2005 focused on filling gaps in the stage-discharge relationships and adequately defining any stage-discharge shifts that may have occurred. During Water Year 2005 a few check measurements were made when a measured discharge indicated a departure from the current rating. In Water Year 2005 GZF’s were also measured on a regular basis. This helped to improve the low end of the stage-discharge relations and greatly improved confidence in the low end of the rating curve. GZF’s were also used as a check to verify that shifts had occurred when check measurements were not made.

In general the discharge measurements made in Water Year 2005 improved the quality of the stage-discharge relations at each of the sites. Further, the measurements adequately filled in gaps in the stage-discharge relationships and did a good job in defining the magnitude and timing of shifts in the stage-discharge relationships.

4.3 STREAMFLOW COMPUTATIONS

Surface water station analysis containing complete details of computations made at each continuous site can be found in the appendix.

TABLE 4
SOUTH FORK WAGES CREEK WATERSHED
Streamflow Measurement Summary WY 2005

SITE NAME	ACRONYM	# of Streamflow Measurements collected in WY 2005	Total Number of Streamflow Measurements
Center Gulch above SF Wages	CASFW	7	11
SF Wages above Center Gulch	SFWAC	7	12
Grey Gulch above SF Wages	GASFW	3	7
Wood Creek above SF Wages	WASFW	2	7
SF Wages above Wood Creek	SFWAW	0	0
Rock Creek above SF Wages	RASFW	9	14
SF Wages above Rock Creek	SFWAR	7	11

4.3.1 Rating Curve Development

Stage-discharge rating curves were developed in SKED for all sites except for SFWAW. Base curves were developed and percent differences from the rating were computed for each of the streamflow measurements. For sites that had unstable hydraulic controls shifts were developed Rating curves and rating tables can be found in the appendix for the six sites where stage-discharge relationships were developed.

<u>Center Gulch above SF Wages Creek</u>

Rating 2.1 was used for computation if Water Year 2004. In Water Year 2004 four discharge measurements (1-4) were made. Measured discharge ranged from 0.78 cfs to 13.8 cfs. Measurements 2-4 were used to develop the middle and upper portion of Rating 2.1. Measurement 1 was not used in rating develop. No shifts were used in Water Year 2004.

Rating 2.1 was continued in use in Water Year 2005. Seven discharge measurements (5-11) were made in Water Year 2005. Measured discharge ranged from 0.09 cfs to 6.13 cfs. Measurements 5-9 were used to develop the lower and middle portions of Rating 2.1. Measurement six was not used in rating development. Time variable shift (TV) TV05-1 and TV05-2 were developed to deal with debris that became lodged on the control between October 8, 2004 and October 13, 2004. Once the material had been cleared from the control Rating 2.1 was brought back into effect and continued in use for the remainder of the record.

Based on the measurement ratings, accuracy of Rating 2.1 is considered poor.

<u>SF Wages Creek above Center Gulch</u>

Rating 1.2 was used for computation in Water Year 2004. Five discharge measurements (1-5) were made in Water Year 2004. Measured discharge ranged from 5.45 cfs to 53.3 cfs. Measurements 1-5 were used to develop the middle and upper portions of Rating 1.2. TV04-1 was developed to deal with a debris jam that occurred between January 1, 2004 and January 7, 2004. After the debris jam had been cleared Rating 1.2 was put back into effect. No other shifts were used in Water Year 2004.

Rating 1.2 was continued in use for Water Year 2005. In Water Year 2005 seven discharge measurements (6-12) were made. Measured discharge ranged from 0.20 cfs to 34.2 cfs. Measurement 6 was used to develop the low-flow portion of Rating 1.2. Measurement 7 was used to check the mid-flow portion of Rating 1.2. Measurements 8 and 9 indicated a fill of the control had occurred. TV05-1 was developed based on the shifts indicated by measurements 8 and 9. TV05-1 was prorated into effect beginning on December 8, 2004 and reached full weight by December 9, 2004. Measurement 10 indicated a return to Rating 1.2. The return to Rating 1.2 was prorated into effect beginning on January 28, 2004 and was complete by January 29, 2005. Measurement 11, made on March 28, 2005, again indicated fill of the control had occurred. Measurement 11 was used to develop TV05-2, which was prorated into effect beginning on March 22, 2005. Measurement 12, made on May 18, 2005, indicated that scour of the control had occurred. Measurement 12 was used to develop TV05-3, which was prorated into effect beginning on April 8, 2005. TV05-3 was held in effect until the end of the record on July 7, 2005.

Based on the measurement ratings, the accuracy of Rating 1.2 is considered fair.

<u>Grey Creek above SF Wages Creek</u>

In Water Year 2004 four discharge measurements (1-4) were made. Measurements 1-4 were used to develop the middle and upper portions of Rating 1.2. Measured discharge ranged from 3.09 cfs to 7.90 cfs. Measurements 1-4 all plotted within 5% of Rating 1.2.

In Water Year 2005 three discharge measurements (5-7) were made. Measurement 5 was used to develop the low-flow portion of Rating 1.2 while measurement 6 and 7 were used to check the middle and upper portions of the rating. Measurements 5 and 7 plotted within 5%of Rating 1.2 and were rated poor and fair respectively. Measurement 6 plotted 8% from Rating 1.2 and was rated poor. No shift was computed for measurement 6 because it plotted within acceptable limits considering the measurement rating.

No continuous record is available for Grey Creek. Rating 1.2 was used to produce instantaneous flows and in calibration of the synthetic hydrograph discussed in section 4.2.3. Based on the measurement ratings, the accuracy of Rating 1.2 is considered fair.

<u>Wood Creek above SF Wages Creek</u>

In Water Year 2004 five discharge measurements (1-5) were made. Measurements 1-5 were used to develop the middle and upper portions of Rating 1.2. Measured discharge ranged from 0.17 cfs to 4.71 cfs. All measurements plotted within acceptable limits considering the measurement ratings.

In Water Year 2005 two discharge measurements (6 and 7) were made. Measured discharge ranged from 0.09 cfs to 2.52 cfs. Measurement 6 was used to develop the low-flow portion of Rating 1.2. Measurement 7 plotted -15% from Rating 1.2. No check measurement was made. No shift was computed for this measurement because no check measurement was made and no other information was available that would support a shift at this site.

Based on the measurement ratings, 4 poor and 3 fair, the accuracy of Rating 1.2 should be considered poor for the entire period.

<u>SF Wages above Wood Creek</u>

No rating was developed at this site.

<u>Rock Creek above SF Wages Creek</u>

In Water Year 2004 five discharge measurements (1-5) were made. Measured discharge ranged from 0.30 cfs to 11.3 cfs. Measurements 1-5 were used to develop the entire range of Rating 1.2. All measurements plotted within 5% of Rating 1.2.

In Water Year 2005 four discharge measurements (6-9) were made. Measured discharge ranged from 0.63 cfs to 5.97 cfs. Measurements 6-9 indicated that a change in rating had occurred to the low-flow and mid-flow portions of Rating 1.2. Measurements 6-9 were used to develop Rating 1.3. Rating 1.3 has a different shape than Rating 1.2 up to 3.29 ft. Above 3.29 ft Rating 1.3 is very similar is shape to Rating 1.2. Measurement 9 was used to verify this. All measurements plotted within acceptable limits given the measurement ratings.

No continuous record is available for Rock Creek. Rating 1.2 was used to produce instantaneous flows and in calibration of the synthetic hydrograph discussed in section 4.2.3. Based on the measurement ratings, the accuracy of Rating 1.2 and 1.3 is considered poor.

<u>SF Wages above Rock Creek</u>

In Water Year 2004 four discharge measurements (1-4) were made. Measured discharge ranged from 1.52 to 17.4 cfs. Measurements 1-4 were used to develop the middle and upper portions of Rating 1.2. Measurements 1-4 all plotted within acceptable limits given the measurement ratings.

In Water Year 2005 seven discharge measurements (5-11) were made. Measured discharge ranged from 0.08 cfs to 7.59 cfs. Measurement 5, made on October 13, 2004 was used to develop the low-flow portion of Rating 1.2. Measurements 7-10 all indicated that aggradation of the control (shift indicated: -0.02 ft to -0.03 ft) had occurred. Measurement 6 was not used in rating development because no left edge water was available for the measurement. Rating 2.1 was developed in for use in Water Year 2005 by shifting Rating 1.2 by -0.03 ft. Rating 2.1 has the same shape as Rating 1.2. Rating 2.1 was prorated into effect beginning at the peak of the December 8, 2004 storm. Measurements 7-10 all plotted within acceptable limits given the measurement ratings. Measurement 11, made on May 18, 2005, indicated that the control had further aggraded. Measurement 11 was used to develop TV05-1. TV05-1 is prorated into effect beginning at the peak of the storm on March 29, 2005. TV05-1 is held in effect until the record ends on Jul 7, 2005.

Based on the measurement rating, the accuracy of Rating 1.2 is considered fair and the accuracy of Rating 2.1 is considered poor.

4.3.2 Discharge Hydrographs

For sites that had acceptable continuous gage height data discharge hydrographs were produced according to the station analysis. Discharge hydrographs for each of the sites can be found in the appendix.

In Water Year 2004 12 significant storms occurred between of December 2003 and April 2004. A significant storm event is defined as an event that causes SF Wages Creek above Center Gulch (SFWAC) to flow at 5 cfs or greater. 6 storms occurred in December (December 4th -6th, 9th-11th, 12th-14th, 23rd-25th, 28th-29th and 31st-January 1st), Two in January (January 8th-10th and 27th -28th), three storms in February (February 2nd -3rd, 15th -18th, and 24th – 27th), and one in April (April 18th -21st). The largest storm of the year occurred from December 31, 2003 through January 1, 2004. . The shape of the discharge hydrographs for each of the sites is very similar, differing only in discharge amount and only slightly in the timing of the event. Differences in the timing of events are due to the amount and timing of rainfall in each sub-basin as well as the size and shape of each sub-basin.

In Water Year 2005 14 significant storms occurred between December 2004 and June 2005. A significant storm event is defined as an event that causes SF Wages Creek above center gulch to flow at 5 cfs or greater. Two storms occurred in December (December 6th-8th and December 29th –January 2nd), two storms occurred in January (January 7th-11thand 27th-29th), two storms occurred in February (February 12th-14thand 19th-21st), three storms occurred in March (March 18th-21st, 22nd-23rd, and 26th-29th), one storm occurred in April (April 8th-9th), two storms occurred in May (May 7th-10thand 17th-18$^{th)}$, and two storms occurred in June (June 7th-9th and 17th-19th).

In Water Year 2004 and Water Year 2005 synthetic hydrographs were developed for Grey Creek above SF Wages (GASFW), SF Wages above Wood Creek (SFWAW), and Rock Creek above SF Wages (RASFW). Synthetic hydrographs were developed by using basin area relationships.

<u>Grey Creek above SF Wages Creek</u>
The Grey Creek above SF Wages Creek synthetic hydrograph was developed by scaling the SF Wages Creek above Center Gulch hydrograph by drainage basin area. Once a base synthetic hydrograph was developed streamflow measurements were used to further calibrate the hydrograph. This synthetic hydrograph could be improved if all staff height observations taken at the site were used to calibrate the hydrograph.

<u>SF Wages Creek above Wood Creek</u>

The SF Wages Creek above Wood Creek synthetic hydrograph was developed by scaling the SF Wages Creek above Center Gulch hydrograph by drainage basin area. No discharge measurements were taken at this site so it was not possible to calibrate the hydrograph. This hydrograph should be considered a rough estimate.

Rock Creek above SF Wages Creek

Rock Creek above SF wages Creek (RASFW) was initially set up as a continuous station in Water Year 2004. Rating 1.2 was developed by the continuous gage height file was not useable at the site. The pressure transducer continuously malfunctioned over the course of Water Year 2004. In Water Year 2005 RASFW was downgraded to a periodic sampling location. Discharge measurements were continued in WY 2005. A synthetic hydrograph was developed for RASFW by scaling the SF Wages above Rock Creek hydrograph by drainage basin area. The base synthetic hydrograph was then calibrated using the discharge measurements made in WY 2004 and WY 2005. This synthetic hydrograph could be improved if all staff height observations taken at the site were used to calibrate the hydrograph.

4.3.3 Peak Discharges

A summary of peak discharges, by water year, for each of the sub-watersheds is provided in Table 5 and Table6 below. The peak discharges for SFWAC, CASFW, WASFT, RASFW, and SFWAR were obtained directly from the appropriate rating tables. The remaining 2 peak discharges for SFWAW and GASFW were obtained from the developed synthetic hydrographs, and thus only represent estimates of the actual peak flows. Since complete streamflow records were not available for the entire water year, typical WY statistics were not computed.

TABLE 5
SOUTH FORK WAGES CREEK WATERSHED
Summary of Peak Discharge WY 2004

Site	Date	Discharge (cfs)	Note
CASFW	2/17/2004	15.6	
SFWAC	1/1/2004	102	
GASFW	1/1/2004	15.8	Obtained From Synthetic Hydrograph
WASFW	2/17/2004	5.28	
SFWAW	1/1/2004	67.8	Obtained From Synthetic Hydrograph
RASFW	12/13/2003	13.8	
SFWAR	12/13/2003	22.4	

TABLE 6
SOUTH FORK WAGES CREEK WATERSHED
Summary of Peak Discharge WY 2005

Site	Date	Discharge (cfs)	Note
CASFW	12/8/2004	12.1	
SFWAC	12/8/2004	56.2	
GASFW	12/8/2004	8.65	Obtained From Synthetic Hydrograph
WASFW	12/8/2004	17.0	
SFWAW	12/8/2004	37.3	Obtained From Synthetic Hydrograph
RASFW	12/8/2004	15.7	Obtained From Synthetic Hydrograph
SFWAR	12/8/2004	25.7	

Table 7 and 8 show the highest measured discharge, the computed peak discharge, the ratio between the computed and highest measured peak discharge, and the unit peak discharge for WY2004 and WY 2005. In Table 7 all of the ratios of computed peak to highest measured discharge are 2.0 and below, indicating that it was not necessary to extrapolate rating curves beyond 100% of the maximum measured discharge. Unit peak discharges range from 50 cfs/mi^2 to 95 cfs/mi^2. In WY 2005 the ratios of computed peak to highest measured

TABLE 7
SOUTH FORK WAGES WATERSHED
Comparison of Peak Discharges and Unit Peak Discharges WY 2004

SITE NAME	WSA	WY 2004 HIGHEST MEASURED DISCHARGE (cfs)	WY 2004 PEAK COMPUTED DISCHARGE (cfs)	RATIO COMPUTED PEAK TO HIGHEST MEASURED DISCHARGE (cfs)	WY 2004 UNIT PEAK DISCHARGE (cfs/mi^2)
CASFW	0.29	13.8	15.6	1.1	54.1
SFWAC	1.10	53.3	102	1.9	92.5
GASFW	0.17	7.90	15.8	2.0	94.9
WASFW	0.10	4.71	5.28	1.1	50.6
SFWAW	0.73	NA	67.8	NA	93.5
RASFW	0.24	11.3	13.8	1.2	58.6
SFWAR	0.39	17.4	22.4	1.3	57.5

Discharge was more varied than in WY 2004. Values ranged from 1.6 to 6.7 indicating that field crews did not do as good of a job getting high flow discharge measurements. Center Gulch above SF Wages, SF Wages above Center Gulch, and Grey Creek above SF Wages all had ratios under 2.0 indicating that a good job was done in obtaining high flow measurements. The Ratio of 6.7 for Wood Creek above SF Wages is high but Rating 1.2 is used in WY 2004 and WY 2005 with no shifts and high flow measurements were obtained in WY 2004. The ratios for Rock Creek above SF Wages and SF Wages above Rock Creek are not that significant because both sites are periodic stations. Unit peak discharges ranged from 42.0 cfs/mi^2 to 163 cfs/mi^2. Thing range was also greater than in WY2004.

TABLE 8
SOUTH FORK WAGES WATERSHED
Comparison of Peak Discharges and Unit Peak Discharges WY 2005

SITE NAME	WSA	WY 2005 HIGHEST MEASURED DISCHARGE (cfs)	WY 2005 PEAK COMPUTED DISCHARGE (cfs)	RATIO COMPUTED PEAK TO HIGHEST MEASURED DISCHARGE (cfs)	WY 2005 UNIT PEAK DISCHARGE (cfs/mi^2)
CASFW	0.29	6.13	12.1	2.0	42.0
SFWAC	1.10	34.2	56.2	1.6	51.0
GASFW	0.17	5.11	8.65	1.7	51.9
WASFW	0.10	2.52	17.0	6.7	163
SFWAW	0.73	NA	37.3	NA	51.4
RASFW	0.24	5.97	15.7	2.6	66.6
SFWAR	0.39	7.59	25.7	3.4	65.9

4.4 SEDIMENT TRANSPORT

A complete summary of all sediment samples listing the date and time of sample collection, sample measurement #, turbidity (NTU), SSC (mg/l), stage (ft), discharge (cfs), discharge per watershed area (cfs/mi^2), SSL (tons/day), SSLPA (tons/day/mi^2), type of sample, and notes for each site is contained in the appendix of this report.

4.4.1 Turbidity and Suspended Sediment Sampling

In Water Year 2004 a total of 131 turbidity and suspended sediment concentration (SSC) measurements were. This includes 88 depth-integrated samples and 43 pump samples. The number of samples for each site is listed below in Table 9. Between 11 and 33 samples were collected at each site.

TABLE 9
SOUTH FORK WAGES CREEK WATERSHED
Suspended Sediment Sample Summary WY 2004

SITE NAME	ACRONYM	# of Depth Integrated Suspended Sediment Samples Collected in WY 2004	# of ISCO Pump Suspended Sediment Samples Collected in WY 2004
Center Gulch above SF Wages	CASFW	14	8
SF Wages above Center Gulch	SFWAC	15	18
Grey Gulch above SF Wages	GASFW	12	NA
Wood Creek above SF Wages	WASFW	11	8
SF Wages above Wood Creek	SFWAW	12	NA
Rock Creek above SF Wages	RASFW	13	9
SF Wages above Rock Creek	SFWAR	11	NA

In Water Year 2005 a total of 137 turbidity and suspended sediment concentration measurements were made. This includes 72 depth-integrated samples and 65 pump samples. The number of sample for each site is listed below in Table 10. Between 8 and 38 samples were collected at each site.

TABLE 10
SOUTH FORK WAGES CREEK WATERSHED
Suspended Sediment Sample Summary WY 2005

SITE NAME	ACRONYM	# of Depth Integrated Suspended Sediment Samples Collected in WY 2005	# of ISCO Pump Suspended Sediment Samples Collected in WY 2005
Center Gulch above SF Wages	CASFW	13	15
SF Wages above Center Gulch	SFWAC	14	24
Grey Gulch above SF Wages	GASFW	11	NA
Wood Creek above SF Wages	WASFW	6	8
SF Wages above Wood Creek	SFWAW	8	NA
Rock Creek above SF Wages	RASFW	8	NA
SF Wages above Rock Creek	SFWAR	12	18

Not all samples collected were used in analysis. It was necessary to censor samples that contained erroneous data. Erroneous data was caused by pump sampler intakes being buried or being to close to the bottom and sampler nozzles striking the streambed during sampling. Censored sample are noted in the sediment sample summary contained in the appendix for each sit.

4.4.2 Pump Samples

In WY 2004 Isco pump samples were collected at four sampling locations (CASFW, SFWAC, WASFW, and RASFW). In WY 2005 the pump sampler from Rock Creek above SF Wages was moved to SF Wages above Rock Creek. The number of samples taken at each site during WY 2004 and WY2005 are listed in Table 9 and Table 10. These numbers only include samples that were taken to the lab and run for SSC. Pump samples that were triggered by erroneous turbidities during storm events were run for turbidity and not processed for SSC and used as a check for the turbidity probe. Once channel modifications were made and minimum stages for sampling were re-established at each site, erroneous turbidities and consequently pump samples were reduced.

Relatively few usable pump samples were taken in WY 2004. This was primarily due to turbidity thresholds being set too high for the SF Wages Creek watershed. The turbidity thresholds used ranged from 0 to 1850 ntu. The first rising threshold began at 20 ntu. Since most sampling locations only had peak turbidities of 15-25 ntu, only the first threshold was reached. The majorities of the pump samples taken during storm events were due to continuous erroneous turbidity readings or were triggered manually by field crews.

In Water Year 2005 turbidity thresholds were reduced and the coverage of pump samples during storm hydrographs increased. In Water Year 2005 the number of erroneous pumps was greatly reduced as well. Continued work on refining the turbidity thresholds should provide even better coverage during storms

Pump sample turbidity and SSC results were calibrated to cross-stream depth-integrated samples. In Water Year 2004 between one and three correlating pump samples to DIS samples were taken. This was mostly due to a lack of cover from rain at equipment houses (to cover lap top) and limited time available for sampling crews to be onsite. In some cases one of three calibration samples had a high variance from the other two samples. A Box coefficient was developed for each set of correlating set of pump and DIS samples. Box coefficients were evaluated on an individual basis as well as on a season or water year basis. Table 11 summarizes the box coefficients used at each site for both water years. With the exception of the SSC box coefficient at SFWAC in WY 2004 the box coefficients were reasonable. The SSC box coefficient of 1.7 at SFWAC in WY 2004 indicates that the pump intake location is not representative of the mean channel conditions. In WY 2005 the intake location was altered and the coefficient was much more reasonable.

4.4.3 Continuous Turbidity Records

Continuous turbidity was measured at 4 of the sampling locations (SFWAC, CASFW, WASFW, and SFWAR). Turbidity values measured by the DTS-12 turbidity meter were generally close to values obtained by depth integrated samples measured using the Lamotte 2020 Turbidimeter. When DTS-12 turbidities and depth-integrated turbidities did not agree it was usually due to turbulent flow or the DTS-12 being to close to the streambed. DTS-12 turbidities were not correlated to Lamotte 2020 turbidity values.
The 15 minute continuous turbidity records were plotted with their corresponding discharge hydrograph for Water Year 2004 and Water Year 2005. Plots of continuous discharge and

turbidity can be found in the appendix for each site. Also included on these graphs are the depth-integrated turbidity values and well as the corrected pump sample values.

TABLE 11
SOUTH FORK WAGES CREEK WATERSHED
Box Coefficients Used to Correct Pump Samples

	Water Year 2004		Water Year 2005		
Site Name	**Turbidity Coefficient**	**SSC Coeficient**	**Turbidity Coefficient**	**SSC Coeficient**	**Notes**
CASFW	1.0	1.0	1.0	1.0	First correlating set considered and outlier (WY04)
SFWAC	1.0	1.7	1.0	0.8	
GASFW	NA	NA	NA	NA	No pump sampler
WASFW	1.0	1.5	1.3	1.3	First correlating set considered and outlier (WY04)
SFWAW	NA	NA	NA	NA	No pump sampler
RASFW	0.9	0.8	NA	NA	based on one correlating set. No Pump Sampler in WY 2005
SFWAR	NA	NA	1.0	1.0	Pump sampler added in WY04

.
Except for SFWAC the turbidity records do not become useable until January of WY 2004. This is due to either the sites being dry or the fact that it took several storms to get the probes in the right position to collect valid turbidities over a wide range of flows. The turbidity record at SFWAC is good from November on.

In WY 2005 the continuous turbidity records for each of the sites was greatly improved. Far less time was spent in cleaning the turbidity record and in general the stations were much more reliable. SFWAC was operational by October 13, 2004 and the rest of the stations came online in late November or early December when flows became high enough for the turbidity meters to function properly.

4.4.4 Sediment Transport Rates

Turbidity verses SSC relationships were developed for both the continuous sites and the periodic sites. Initially, turbidity values were pulled from the DTS-12 continuous record, whereas the SSC values were a combination of the corrected pump samples and the depth-integrated samples. If no continuous turbidity record was available at the site then the depth-integrated turbidity values were used. If no relationship existed between turbidity and SSC then a discharge verses SSC relationship was developed. The results, by water year, are shown below in Table 12 and Table 13. Plots of each of these relationships can be found the appendix.

TABLE 12
WY 2004 REGRESSION EQUATIONS USED FOR SUSPENDED SEDIMENT

Site Name	X vs SSC	Equation	(r^2)
CASFW	Discharge	y = 1.55317x^1.11729	0.71
SFWAC	DTS-12 Turbidity	y = 1.45428x^0.826475	0.81
GASFW	DIS Turbidity	y = 1.94118x - 5.78901	0.96
WASFW	Discharge	y = 2.65992x - 1.60672	0.94
SFWAW	DIS Turbidity	y = 1.89499x - 4.89592	0.86
RASFW	DIS Turbidity	y = 1.7782x - 8.85853	0.85
SFWAR	DTS-12 Turbidity	y = 0.898812x - 1.64343	0.92

In Water Year 2004 only two of the continuous turbidity stations (SFWAC and SFWAR) had adequate enough relationships to produce continuous SSC concentration from turbidity. The other two continuous turbidity sites (CASFW and WASFW) had poor turbidity verses SSC relationship so discharge verses SSC relationships were developed. WASFW had a surprising good relationship (based on WY04-WY05 data) between discharge and SSC. CASFW had a fair to poor relationship between discharge and SSC. Because it was not possible to develop any good relationships at CASFW continuous SSC was only developed for two storms when sufficient depth-integrated and pump samples were available. Continuous SSC was developed for the following sites and periods:

CASFW: January 7, 2004, September 30, 2004
SFWAC: December 17, 2003-September 30, 2004
WASFW: January 1, 2004- September 30, 2004
SFWAR: February 2, 2040- September 30, 2004

No SSC was developed for sites where synthetic hydrographs (GASFW, SFWAW, and RASFW) where developed because the error associated with these estimates would be too great.

In Water Year 2005 three of the four (CASFW, SFWAC, and SFWAR) continuous turbidity stations had adequate relationships to develop continuous SSC from turbidity. The fourth continuous site, WASFW, did not show a strong relationship between turbidity and SSC but did have a good relationship (based on WY04-WY05 data) between discharge and SSC. Continuous SSC was developed for the following sites and periods:

CASFW: October1, 2004-July 7, 2005
SFWAC: October 19, 2004- July 7, 2005
WASFW: December 8, 2004- July 7, 2005
SFWAR: December 6, 2004- July 7, 2005

TABLE 13
WY 2005 REGRESSION EQUATIONS USED FOR SUSPENDED SEDIMENT

Site Name	SSC vs x	Equation	(r^2)
CASFW	DTS-12 Turbidity	y = 1.03243x + 0.0661806	0.83
SFWAC	DTS-12 Turbidity	y = 0.832588x + 1.81593	0.92
GASFW	DIS Turbidity	y = 2.1725x - 4.40485	0.97
WASFW	Discharge	y = 2.65992x - 1.60672	0.94
SFWAW	DIS Turbidity	y = 1.34937x^0.813326	0.79
RASFW	DIS Turbidity	y = 0.984669x^0.734836	0.55
SFWAR	DTS-12 Turbidity	y = 1.23261x - 1.85884	0.88

No SSC was developed for sites where synthetic hydrographs (GASFW, SFWAW, and RASFW) where developed because the error associated with these estimates would be too great.

4.4.5 Sediment Loads

Partial sediment loads and partial yields were calculated for each of the continuous Water Year. Results are summarized in Table 14. Discharge and sediment discharge plots can be found in the appendix.

TABLE 14
SOUTH FORK WAGES CREEK WATERSHED
Partial Suspended Sediment Load Water Year 2004

SITE NAME	WSA	SSL (tons)	SSLPA (tons/mi^2)
CASFW	0.29	0.32	1.12
SFWAC	1.10	0.44	0.40
GASFW	0.17	NA	NA
WASFW	0.10	0.06	0.53
SFWAW	0.73	NA	NA
RASFW	0.24	NA	NA
SFWAR	0.39	0.14	0.36

The loads presented for Water Year 2004 must be viewed with caution. Due to the amount of time that it took to get stations operating and the challenges that were encountered during the water year the loads presented are partial load. Yields were also calculated for each of the continuous stations but again one must be careful in interpreting this data. In addition to the partial loads computed for Water Year 2004 instantaneous loads and yield were computed for each sediment sample collected. These values are summarized in the sediment summary contained in the appendix of each station.

Total loads and total yields were calculated for each of the continuous sites in Water Year 2005. Results are summarized in Table 15. Plots of sediment discharge can be found in the appendix. Unlike Water Year 2004, the total loads calculated can be considered representative of the period. Total loads in Water Year 2005 ranged from 0.05 tons (WASFW) to 7.62 tons (SFWAC). Yields were also computed for Water Year 2005 and the results range from 0.36 tons/mi^2 (SFWAR) to 1.12 tons/mi^2(CASFW). CASFW had the highest yield even though it is the fourth largest sub-basin. WASFW, the smallest sub-basin, had the second highest yield, SFWAR the fifth largest sub-basin had the lowest yield, and SFWAC the largest sub-basin had the second lowest yield.

It is important to realize that the loads between the two water years are not comparable because the periods of record are different. The total loads computed in Water Year 2004 are not representative of the actual load during that year for the reasons discussed above.

Appendix H-1 and H-2 summarize the sediment yields on a watershed level for Water Year 2004. Appendix H-1 is a plot of sediment yield verses discharge. Appendix H-1 indicates that that sediment yield increased at roughly the same rate for SFWAC, SFWAW, and SFWAR. This is not to say the yields for a given discharge are the same but that as discharge increased the yields for each of these sub-basins increases at the same rate relative

TABLE 15
SOUTH FORK WAGES CREEK WATERSHED
Total Suspended Sediment Load Water Year 2005

SITE NAME	WSA	SSL (tons)	SSLPA (tons/mi^2)
CASFW	0.29	1.36	4.72
SFWAC	1.10	7.62	6.91
GASFW	0.17	NA	NA
WASFW	0.10	0.05	0.48
SFWAW	0.73	NA	NA
RASFW	0.24	0.53	2.24
SFWAR	0.39	1.69	4.33

to one another. Two sites, CASW and GASFW, increase at a much faster rate relative to the other sites. RASFW and WASFW have yields that increase at a slower rate than the other sub-basins. A more useful tool in watershed levels relationships is presented in Appendix H-2. Appendix H-2 is a plot of sediment yield verses discharge yield for the data collected in Water Year 2004. Plotting the data in this form makes each of the sub-basins directly compared to one another. WASFW immediately stands outs as having the lowest yield per unit discharge in Water Year 2004. Several of the sites SFWAW, SFWAC, GASFW, and CASFW all have very similar yields per unit discharge especially at the mid to high ranges of unit discharge. The yields for these sites diverge as unit discharges decrease.

Appendix H-3 and H-4 summarize the sediment yield data on a watershed level for Water Year 2005. In Water Year 2005 Appendix H-3 indicates that sediment yields increased at relatively the same rate for all of the sites. Again this is not to say that each of the sub-basins yields the same amount for a given discharge but rather that the rate of yield increases at relatively the same rate between the sub-basins. Appendix H-4 indicates that in Water Year 2005 WASFW, RASFW, and SFWAW all have very similar sediment yields for a given discharge. GASFW, CASFW, SFWAR, SFWAC all have higher yields per unit discharge.

5.0 CONCLUSIONS

A stream gage network was established throughout the South Fork Wages Creek Watershed in WY2004. Streamflow and sediment transport measurements were collected at 7 sites ranging in drainage area from 0.1 mi^2 to 1.10 mi^2. Over 131 measurements of turbidity and suspended sediment concentration were made over the winter of WY2004. Computed partial suspended sediment loads at the 7 sites ranged from0.06 tons to 0.44tons. Overall, most sites produced sediment at consistent rates.

Operation of the gage network continued in Water Year 2005. In Water Year 2005 RASFW creek was changed to a periodic station and SFWAR was upgraded with a pump sampler. Over 137 measurements of turbidity and suspended sediment were made in Water Year 2005. Computed total sediment loads ranged from 0.53 tons to 7.62 tons. Overall, most sites produces sediment at consistent rates. Station operation and data quality was much better in Water Year 2005 than in Water Year 2004. The data collected in Water Year 2005 is representative to the actual loads being transported in the watershed and can be used in future years for comparison

6.0 RECOMMENDATIONS

The following recommendations have been reached as a result of WY2004 and WY2005 data collection and analysis:

1. Where possible grade control structures should be installed to prevent shifts in rating. These grade controls structures should be installed at grade so as not to act as bedload traps

2. Every effort should be made to collect turbidity and SSC samples near the turbidity probe and pump intake. If the turbidity probe and pump intake are not in a representative reach they should be moved

3. Check measurements need to be made for every discharge measurement that does not plot within acceptable limits of the rating.

4. Staff plates and reference level gages need to be surveyed and checked on an annual basis

5. Further adjust of the turbidity thresholds is necessary to insure adequate coverage during a wide range of turbidity events.

6. Site visit forms should be developed so all pertinent and necessary information is written down each and every time the station is inspected and downloaded.

7. Transit rates for depth-integrated turbidity and SSC samples should be documented. It is not necessary to calculate a transit rate through a discharge each time. One easy way to do this would be for field crews to go to the thalweg and apply different transit rates until a bottle is filled between 60% and 90%. Knowing the depth at the thalweg and the transit time a transit rate can be calculated.

7.0 REFERENCES

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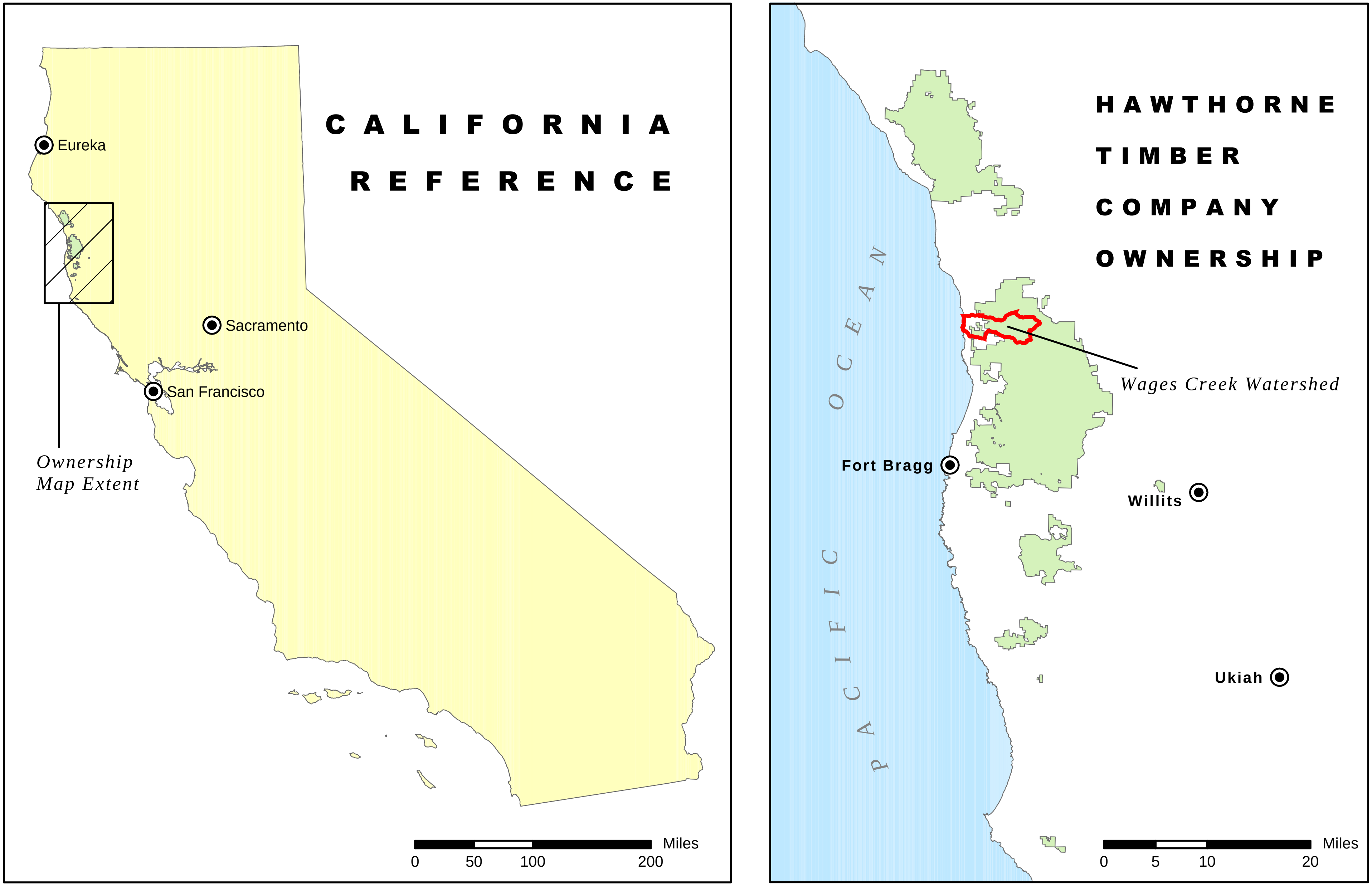


Figure 1. Regional Vicinity Map for The Hawthorne Timber Company

Hawthorne Timberlands
(Total Acres = 184,168)

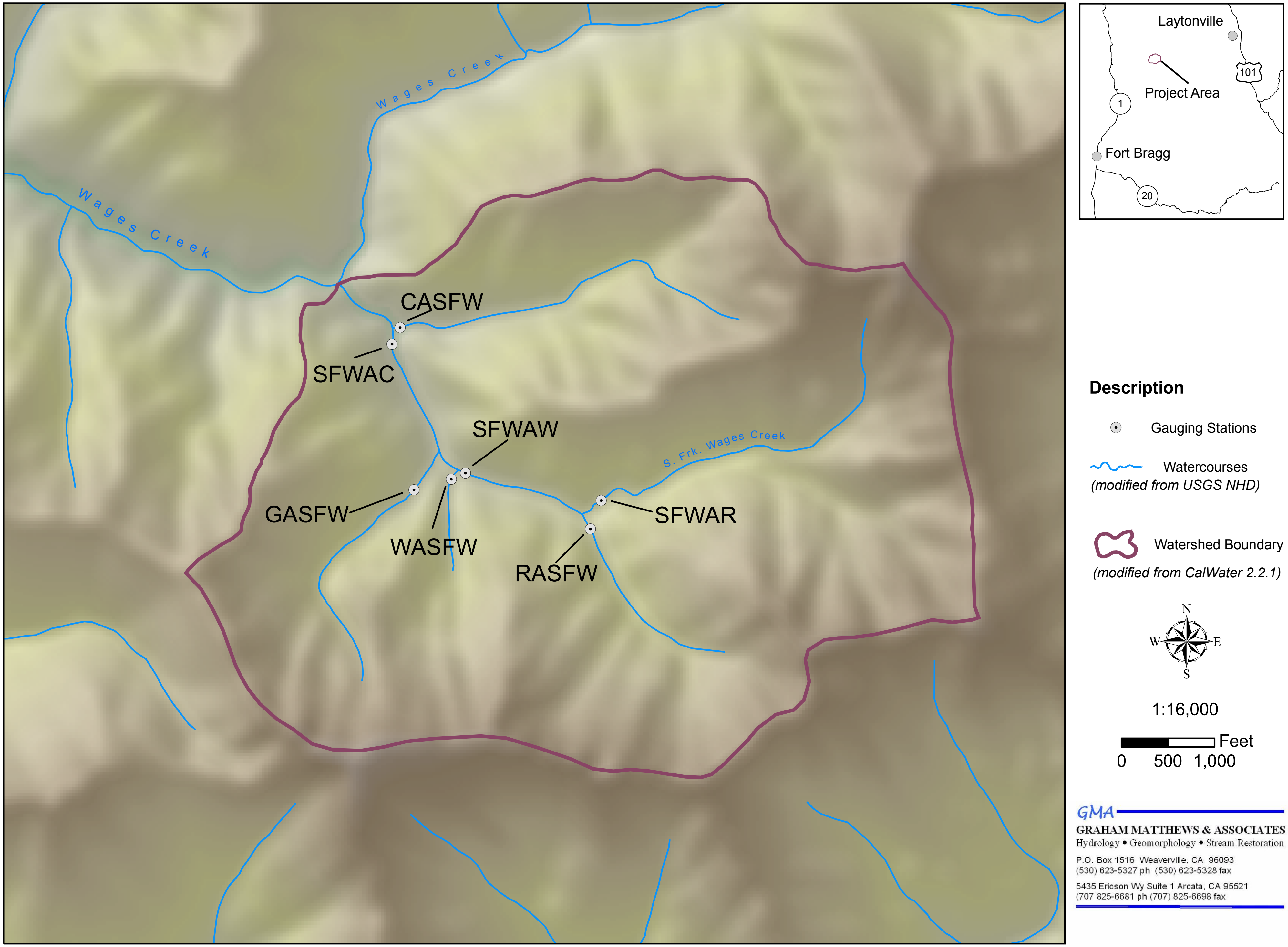
Wages Creek Watershed
(Total Acres = 8,583)

N W E S

Campbell TIMBERLAND MANAGEMENT LLC

7/17/2003 SH

Figure 2. South Fork Wages Creek Gauging Locations



SOUTH FORK WAGES CREEK STATION PHOTOS
WATER YEAR 2004

Photo 1. Steel Enclosure installed at Rock Creek.

Photo 2. Loading of ATV's at landing where the trucks are parked.

Photo 3. SF Wages above Center Gulch on 10/29/03 with a discharge of <1 cfs.

Photo 4. SF Wages above Center Gulch on 2/17/04 with a discharge of ~55 cfs. In this photo turbidity probe readings are being affected by turbulence. Boom has since been moved towards the right bank and out of the turbulence.

Photo 5. Center Gulch on 01/06/04 with a discharge of <1 cfs. Photo taken before boulders were added to channel in order to backwater turbidity probe.

Photo 6. Center Gulch on 02/17/04 with a discharge of ~13 cfs. Photo taken after boulders were added to channel in order to backwater turbidity probe.

Photo 7. Wood Creek above SF Wages on 10/29/03 with a discharge of 0 cfs.

Photo 8. Wood above SF Wages on 2/17/04 with a discharge of ~5 cfs. In this photo turbidity probe readings are being affected by turbulence. Boom has since been moved towards the right bank and out of the turbulence.

Photo 9. Rock Creek on 01/06/04 with a discharge of <1 cfs. Photo taken after channel shape had been modified by placement of large boulders.

Photo 10. Rock Creek on 2/17/04 with a discharge of ~14 cfs. Hydrologist is performing DIS sediment sample with a DH-48.

Photo 11. SF Wages above Rock Creek on 1/07/04 with a discharge of ~2.5 cfs. Photo taken before large boulders were added to channel.

Photo 12. SF Wages above Rock Creek on 2/18/04 with a discharge of ~17 cfs. Note that large boulders placed in channel are working well at backwatering the turbidity probe.

Photo 13. SF Wages above Wood Creek on 2/17/04 with a discharge of ~ 35 cfs. Note Crest Gage on right bank.

Photo 14. Grey Creek on 2/17/04 with a discharge of ~8 cfs. Note Crest Gage on left Bank. A rock weir was built to allow stage measurements.

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
(STATION # CTM 0283005)
STATION ANALYSIS
WATER YEAR 2004-2005

RECORDS – Surface Water & Water Quality

EQUIPMENT – A Turbidity Threshold Sampling (TTS) station is installed at the site. The TTS station includes an Isco 6712 full size portable sampler, a Campbell Scientific CR510 data collection platform (DCP), a waterlog H-310 pressure transducer and a forest technology systems DTS-12 turbidity sensor. The station battery power is supplemented by a solar panel. The DCP is housed in a locked steel box that is installed on the left bank. The DTS-12 is housed in an aluminum boom assembly, which is attached to a cable way strung over the creek. The pressure transducer is located on the left bank five feet downstream of the turbidity boom. One staff plate is located on the right bank 5 feet downstream of the cable way.
Inside recording gage: Less than or equal to 0.02% of full scale output (FSO) over temperature range referenced (0 to 40^{o} C) to a straight line stretched from zero psi to maximum pressure (15 psi).
Outside staff gage: One USGS style C staff gage mounted on redwood and attached to channel iron that has been pounded into the streambed. Limits 0.00 ft. to 3.33 ft.

GAGE HEIGHT RECORDS – Record is incomplete for the period.
Water Year 2004 station operation began on October 29, 2003 at 12:00 hours. The station was down for maintenance on October 31, 2003 from 14:15 hours to 14:45 hours. A gap in the records exists on February 17, 2004 from 11:30 hours to 13:30 hours and from 16:30 hours to 19:15 hours. The field notes do not contain any record or station maintenance or troubleshooting during this time period. No other problems were encountered in Water Year 2004.
The Maximum gage height in Water Year 2004 of 1.03 ft occurred on February 17, 2004 at 14:00 hours. The minimum gage in Water Year 2004 of 0.31 ft occurred on September 6, 2004 at 14:15 hours.
Gage operation continued in Water Year 2005. A debris jam occurred on October 8, 2004 17:45 and was cleared on October 13, 2004 11:43 changing the stage from 0.32 to 0.29. On November 1, 2004 a gap in the record exists from 16:30 hours to 17:00 hours while the station was down for maintenance. On November 12, 2004 a gap in the record exists from 12:00 hours to 12:30 hours. No entries could be found in the field notes on why the station was down. On December 14, 2004 a gap in the record exists from 12:00 hours to 12:30 hours. Field notes indicate that batteries were being replaced at the station and that maintenance was being performed. The record contains a gap from February 22, 2005 and 15:15 hours to February 23 at 15:15 hours. Field notes indicate that on February 22, 2005 that the Isco pump sampler was not operating due to a bad fuse. The fuse was replaced. Notes indicate that the Isco sampler problem was fixed and that the station was running. There are no field notes indicating a visit to the site on February 23, 2005 when the record begins again.
Staff height observations made on May 18, 2005 and May 19, 2005 indicated that the gage height file needed to be corrected by .08 ft and .07 ft respectively. A staff height observation made on April 22, 2005 at 11:27 hours indicated that the recorded gage height needed no correction and previously recorded staff heights had always been within .01ft to .02 ft of the recorded gage height. The gage height file was inspected for any obvious offsets but none where found. The field notes were re-checked to verify the staff height readings. On the July 7, 2005 station data download no staff observation was recorded. The gage height was corrected according to the staff height observations made on May 18 and May 19. The correction was started on May 18, 2005 05:15 hours. For the time period between April 22, 2005 at 11:30

hours and July 7, 2004 at 14:00 hours the record is considered suspect.
The maximum gage height in Water Year 2005 of 0.94 ft occurred on December 8, 2004 at 06:15 hours.
The minimum gage height in Water Year 2005 of 0.28 ft occurred on October 16, 2004 at 03:45 hours

DATUM CORRECTIONS – Staff plate has not been surveyed, no datum correction known.

CONTROL – The control is a four foot diameter downed redwood tree that creates a three foot waterfall on the downstream side. The channel at the gage has a steep vegetated right bank while the left bank has a large terrace. The left bank at the site will overtop during extreme events.

RATING – In Water Year 2004 four discharge measurements (1-4) were made. Measured discharge for the period ranged from 0.78 cfs to 13.8 cfs. Computed instantaneous discharge ranged from 0.15 cfs to 15.6 cfs. Measurements 2-4 were used to develop the upper portion of Rating 2.1. Measurement 1 was not used because the measurement was made by and inexperienced hydrographer and subsequent measurements indicated that it was not valid. Measurements 2-4 all plotted within 5% of Rating 2.1
In Water Year 2005 seven discharge measurements (5-11) were made. Measured discharge for the period ranged from 0.09 cfs to 6.13 cfs. Computed instantaneous discharge ranged from .05 cfs to 12.21 cfs. Rating 2.1 in use at the end of WY 2004 was continued in use.
Measurements 5-9 were used to develop the lower and middle portion of Rating 2.1. Measurement six was not used in rating development.
On October 13, 2004, when measurement 5 was made, the control was cleared of debris causing the gage height to drop 0.03 ft. Inspection of the gage height file indicated that the debris had become lodged on the control on October 8, 2004 starting at 18:30 hours. Using the gage height file and the staff height observations made on October 13, 2004 TV05-1 and TV05-2 were developed. TV05-1 is prorated into effect on October 8, 2004 at 19:45 hours. TV05-2 is prorated into effect beginning on October 8, 2004 at 19:45 hours and reaches full weight by October 13, 2004 at 11:30. TV05-2 is prorated into effect with the idea that after the initial obstruction of the control, as indicated by the gage height file, material began to build up slowly over time. Rating 2.1 is brought back into effect on October 13, 2004 at 11:45 hours after the control had been cleared and the gage height had stabilized.
Measurement 6 plotted -15% from Rating 2.1 and was rated poor. No check measurement was made. No shift was computed for measurement 6 because of the poor measurement rating, the relative inexperience of the hydrographer, and the lack of a check measurement.
Measurement 7 plotted withing 5% Rating 2.1 and was rated poor.
Measurement 8 plotted 6% from Rating 2.1 and was rated poor. No shift was computed for measurement six because of the poor measurement rating. A GZF measurement also verified that the elevation of the control had not changed.
Measurement 9 plotted 5% from Rating 2.1 and was rated poor.
Measurement 10 plotted 7% from Rating 2.1 and was rated poor. A GZF measurement indicated that the elevation of the control was 0.03ft higher but this is likely an artifact of a different hydrographer measuring the GZF. No shift was computed because the measured plotted within acceptable limits given the measurement rating.
Measurement 11 plotted -12% from Rating 2.1 and was rated poor. No check measurement was made. A GZF measurement indicated that the control was now 0.08 ft higher than earlier in the year and .05 ft higher than the previous GZF measurement made on March 28, 2005. No shift was computed because the measurement plotted with acceptable limits given the measurement rating.

DISCHARGE – Rating #2.1 was used during the WY 2004 – 2005 as follows:

Water Year 2004

Oct. 29 to Sept. 30 (24:00)	Rating 2.1

Water Year 2005

Oct. 1 to Oct. 8 (18:00)	Rating 2.1
Oct. 8 to Oct. 8 (19:45)	Prorate to TV05-1
Oct. 8 to Oct. 13 (11:30)	Prorate to TV05-2
Oct. 13 to Oct. 13 (11:45)	Direct to Rating 2.1
Oct. 13 to Jul. 7 (14:00)	Rating 2.1

SPECIAL COMPUTATIONS – None Made

REMARKS – Based on the error associated with the measurements and the hydraulic conditions at the site the record is considered poor for the entire period.

Gage height records worked by T. Gray 10-05
Gage height records checked by C. Pryor 10-05
Discharge computation worked by C. Pryor 11-05
Discharge computation checked by C. Pryor 12-05

DISCHARGE SUMMARY SHEET

LOCATION: Center Gulch Above South Fork Wages Creeek **WATER YEAR: 2004-2005**

Measurement Number	WY Msmt #	Date	Made By	Width (feet)	Mean Depth (feet)	Area (ft^2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating 2.1 Shift Adj.	Rating 2.1 Percent Diff.	Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	GZF	Notes
1	2004-01	12/7/2003	T. Grey	2.9	0.20	0.59	1.32	0.51	0.78		-53	wading	13	14:23	14:41	fair		Inexperienced Hydrographer, No shift Computed
2	2004-02	2/4/2004	T. Grey	4.2	0.52	2.17	2.00	0.68	4.35		-4	wading	22	12:02	12:35	fair		
3	2004-03	2/17/2004	K. Faucher	5.9	0.72	4.23	3.26	0.99	13.8		-1	wading	26	17:50	18:18	fair		
4	2004-04	2/18/2004	T. Grey	5.0	0.75	3.73	2.53	0.85	9.42		5	wading	26	12:10	12:39	fair		
5	2005-01	10/13/2004	K. Fuacher	2.4	0.14	0.34	0.27	0.29	0.09		0	wading	13	11:07	11:42	Poor	0.20	
6	2005-02	12/28/2004	T. Bolton	4.4	0.34	1.51	0.57	0.45	0.86		-15	wading	14	13:33	13:52	Poor	X	Began on REW & no PZF; No shift computed
7	2005-03	1/3/2005	T. Bolton	3.4	0.27	0.93	1.59	0.49	1.47		4	wading	12	14:20	14:32	Poor	0.27	
8	2005-04	1/3/2005	T. Bolton	3.4	0.26	0.89	1.68	0.49	1.50		6	wading	12	14:36	14:44	Poor	0.27	
9	2005-05	2/22/2005	R. Leisse	3.0	0.27	0.81	1.57	0.47	1.27		5	wading	12	15:37	15:49	Poor	0.27	
10	2005-06	3/28/2005	K. Faucher	4.2	0.33	1.40	2.15	0.59	3.01		7	wading	14	10:33	10:49	Poor	0.30	
11	2005-07	5/18/2005	K. Faucher	4.1	0.51	2.09	2.93	0.78	6.13		-12	wading	14	20:57	21:09	Poor	0.35	

PROJECT:

SOUTH FORK WAGES CREEK
STREAMFLOW AND SEDIMENT TRANSPORT MONITORING

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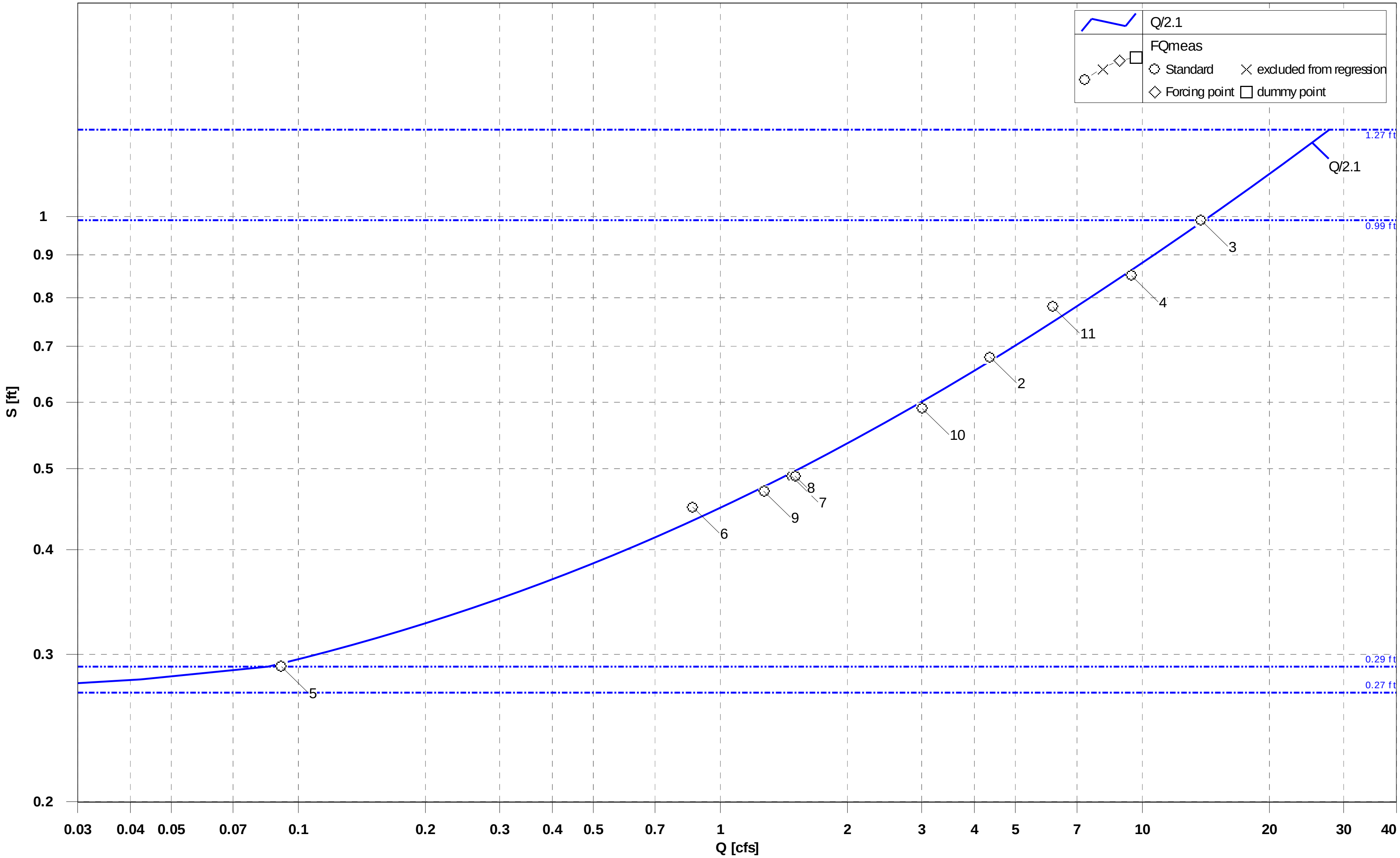
WY 04-05 APPENDIX

A-2

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge Rating Curve 2.1



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WY 04-05
APPENDIX

A-3

Graham Matthews & Associates

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK

RATING TABLE NO.2.1 ------ Begin Date 02/04/04

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
0.0	---	---	---	---	---	---	---	---	---	---	---	---
0.1	---	---	---	---	---	---	---	---	---	---	---	---
0.2	---	---	---	---	---	---	---	*0.00*	*0.04*	*0.08*	---	---
0.3	0.11	0.14	0.18	0.21	0.26	0.30	0.35	0.41	0.47	0.53	0.45	
0.4	0.60	0.67	0.75	0.83	0.92	1.01	1.11	1.21	1.31	1.42	0.89	0.44
0.5	1.54	1.66	1.79	1.92	2.05	2.19	2.34	2.50	2.65	2.82	1.40	0.51
0.6	2.98	3.16	3.34	3.52	3.71	3.91	4.11	4.32	4.53	4.75	1.93	0.53
0.7	4.97	5.19	5.43	5.67	5.92	6.17	6.43	6.69	6.96	7.23	2.48	0.55
0.8	7.52	7.81	8.10	8.40	8.70	9.01	9.33	9.65	9.98	10.3	3.07	0.59
0.9	10.7	11.0	11.4	11.7	12.1	12.5	12.8	13.2	13.6	14.0	3.70	0.63
1.0	*14.4*	*14.8*	*15.2*	*15.7*	*16.1*	*16.5*	*17.0*	*17.5*	*17.9*	*18.4*	4.40	0.70
1.1	*18.8*	*19.3*	*19.8*	*20.3*	*20.8*	*21.3*	*21.8*	*22.3*	*22.8*	*23.3*	4.90	0.50
1.2	*23.8*	*24.4*	*24.9*	*25.5*	*26.0*	*26.6*	*27.2*	*27.7*	---	---	---	---
1.3	---	---	---	---	---	---	---	---	---	---	---	---
1.4	---	---	---	---	---	---	---	---	---	---	---	---
1.5	---	---	---	---	---	---	---	---	---	---	---	---
1.6	---	---	---	---	---	---	---	---	---	---	---	---
1.7	---	---	---	---	---	---	---	---	---	---	---	---
1.8	---	---	---	---	---	---	---	---	---	---	---	---
1.9	---	---	---	---	---	---	---	---	---	---	---	---
2.0	---	---	---	---	---	---	---	---	---	---	---	---
2.1	---	---	---	---	---	---	---	---	---	---	---	---
2.2	---	---	---	---	---	---	---	---	---	---	---	---
2.3	---	---	---	---	---	---	---	---	---	---	---	---
2.4	---	---	---	---	---	---	---	---	---	---	---	---
2.5	---	---	---	---	---	---	---	---	---	---	---	---

Values in italics are beyond the validated range of the rating

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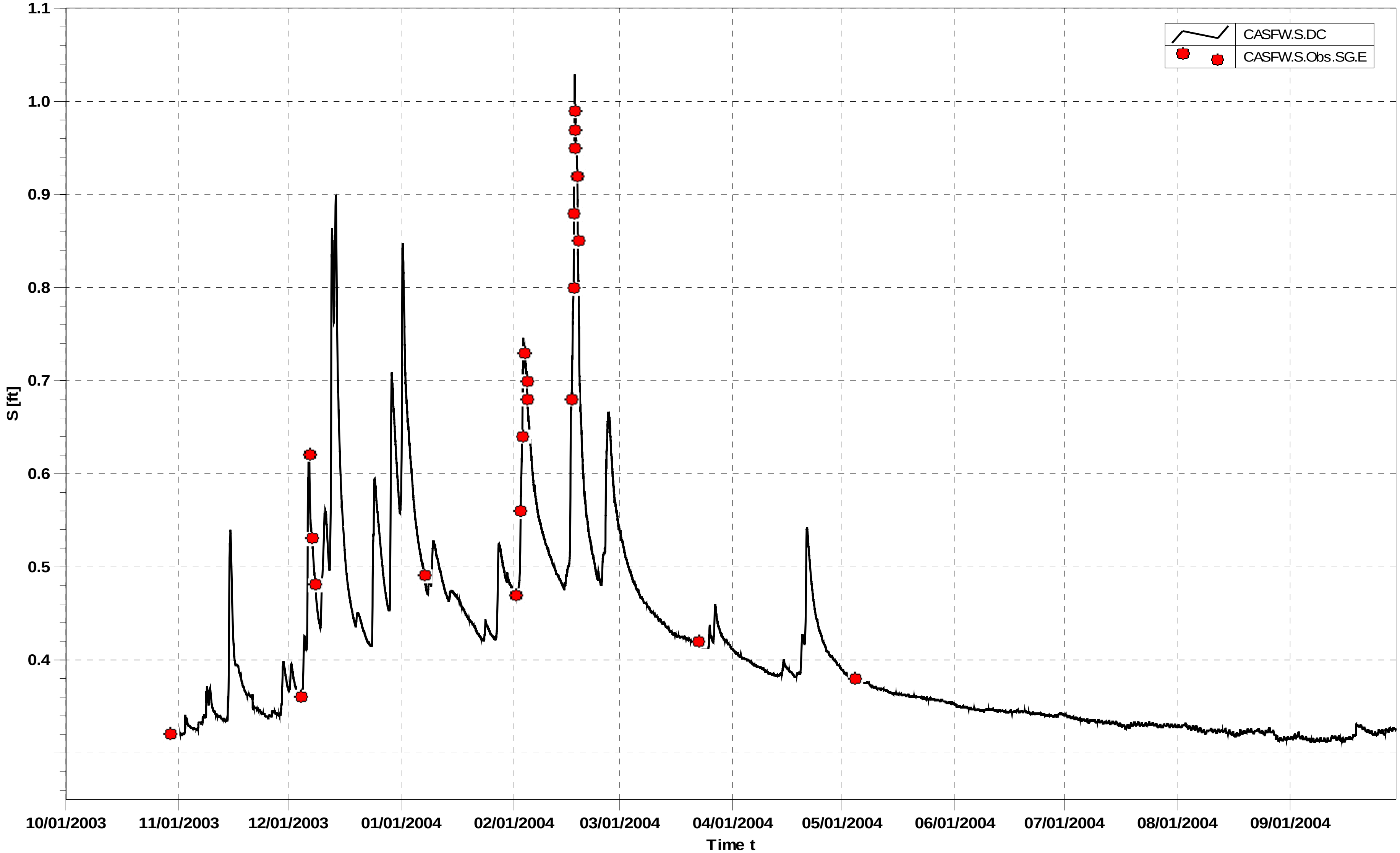
WY 04-05
APPENDIX

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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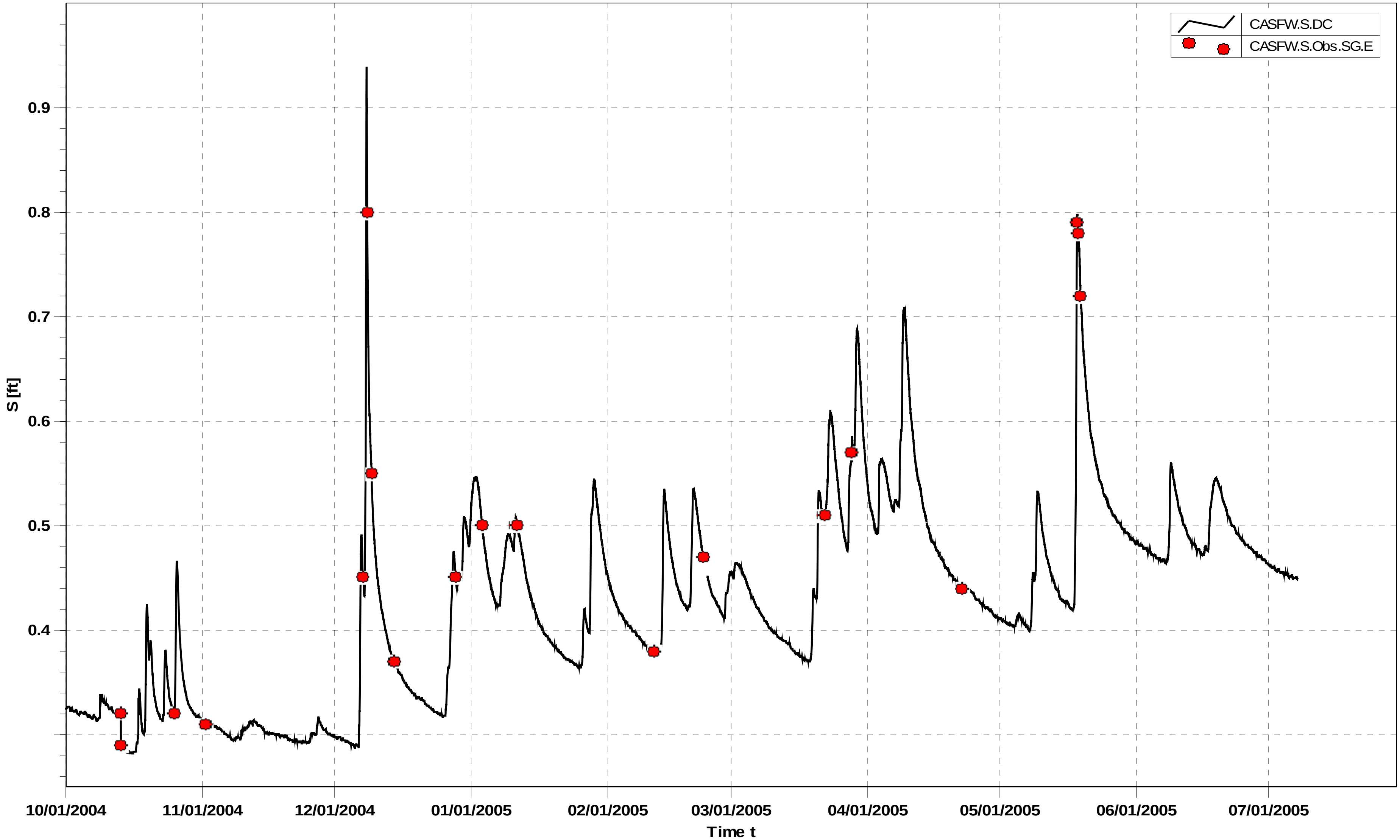
WY 2004
APPENDIX

A-5a

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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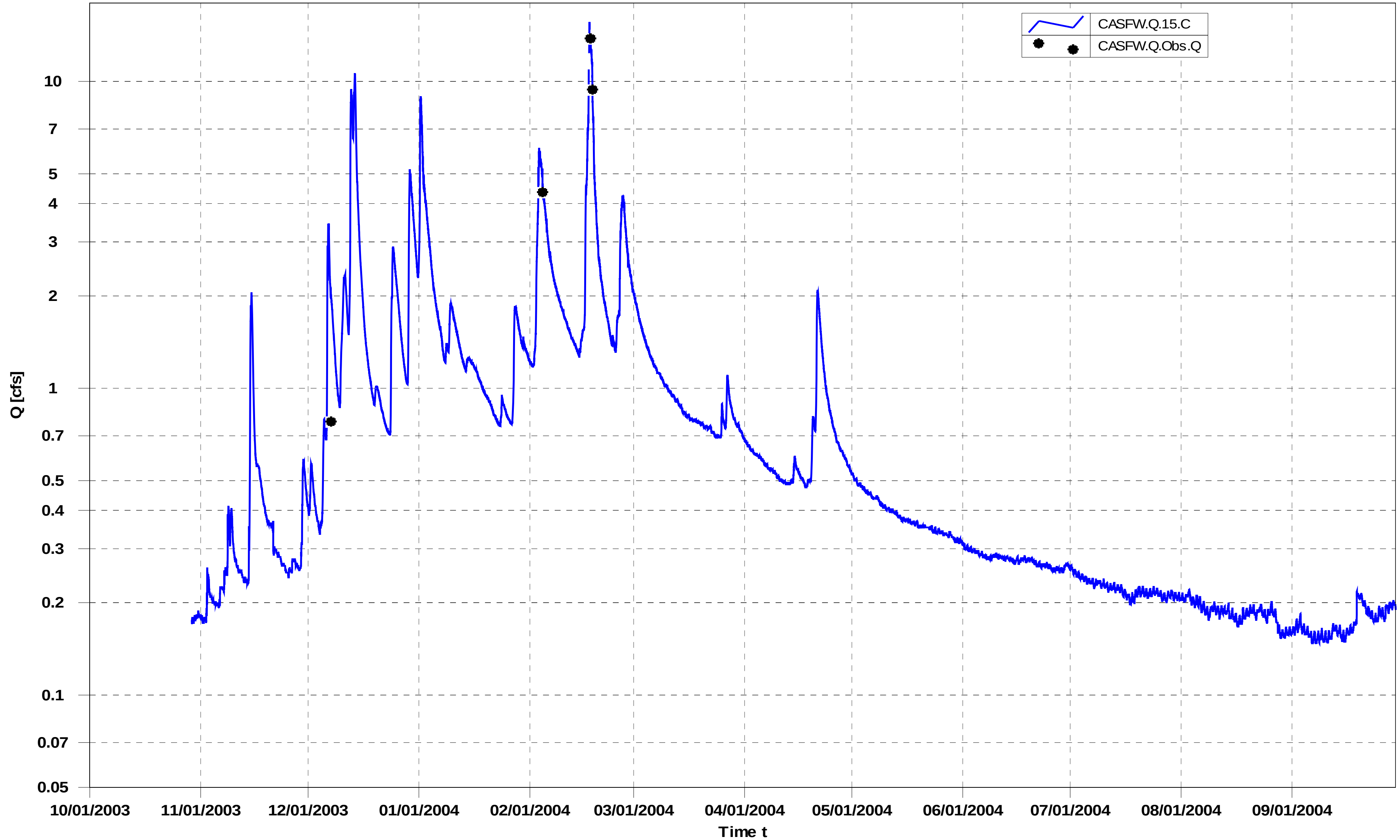
WY 2005
APPENDIX

A-5b

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge Hydrograph and Discharge Measurements



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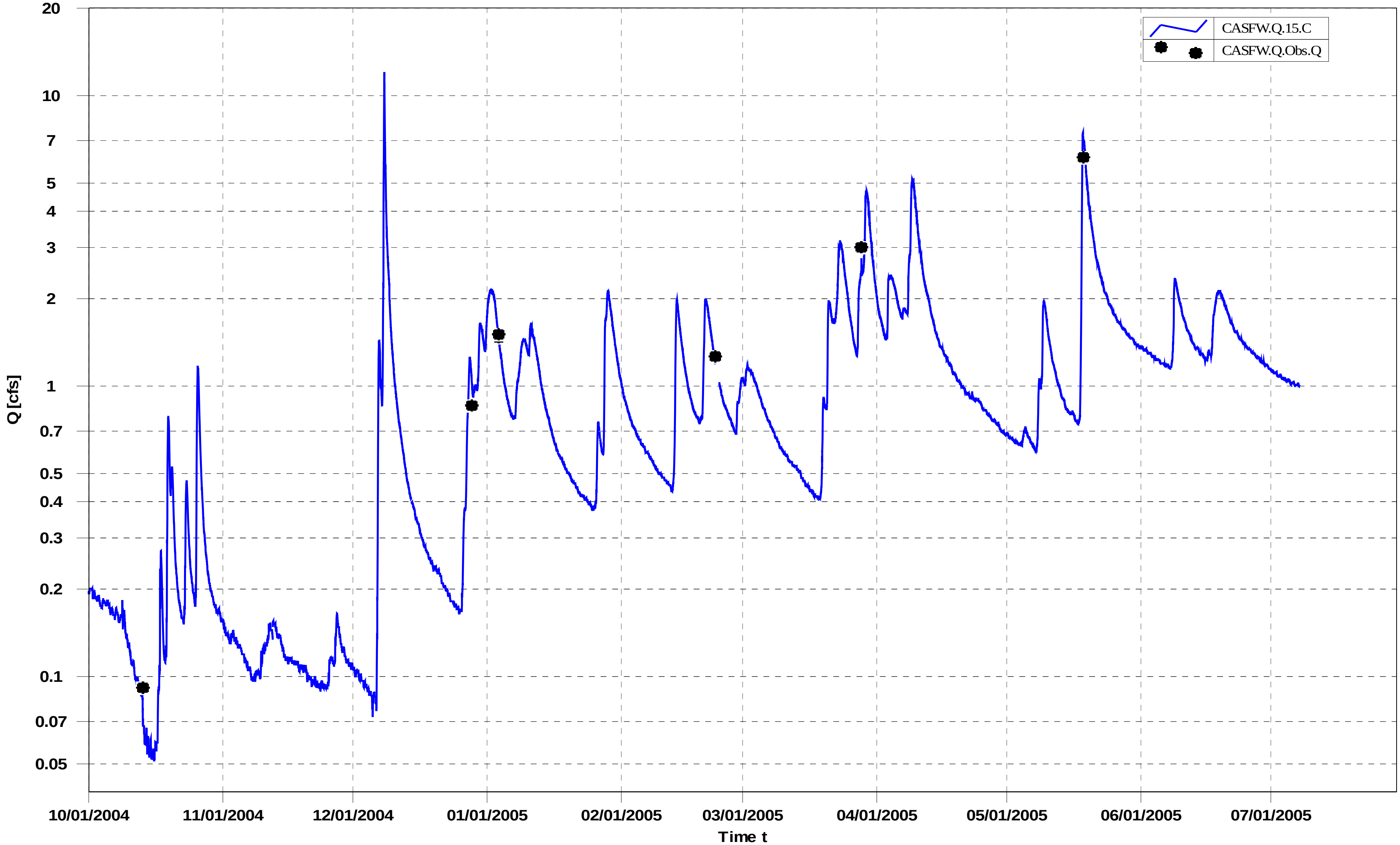
WY 2004
APPENDIX

A-6a

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge Hydrograph and Discharge Measurements



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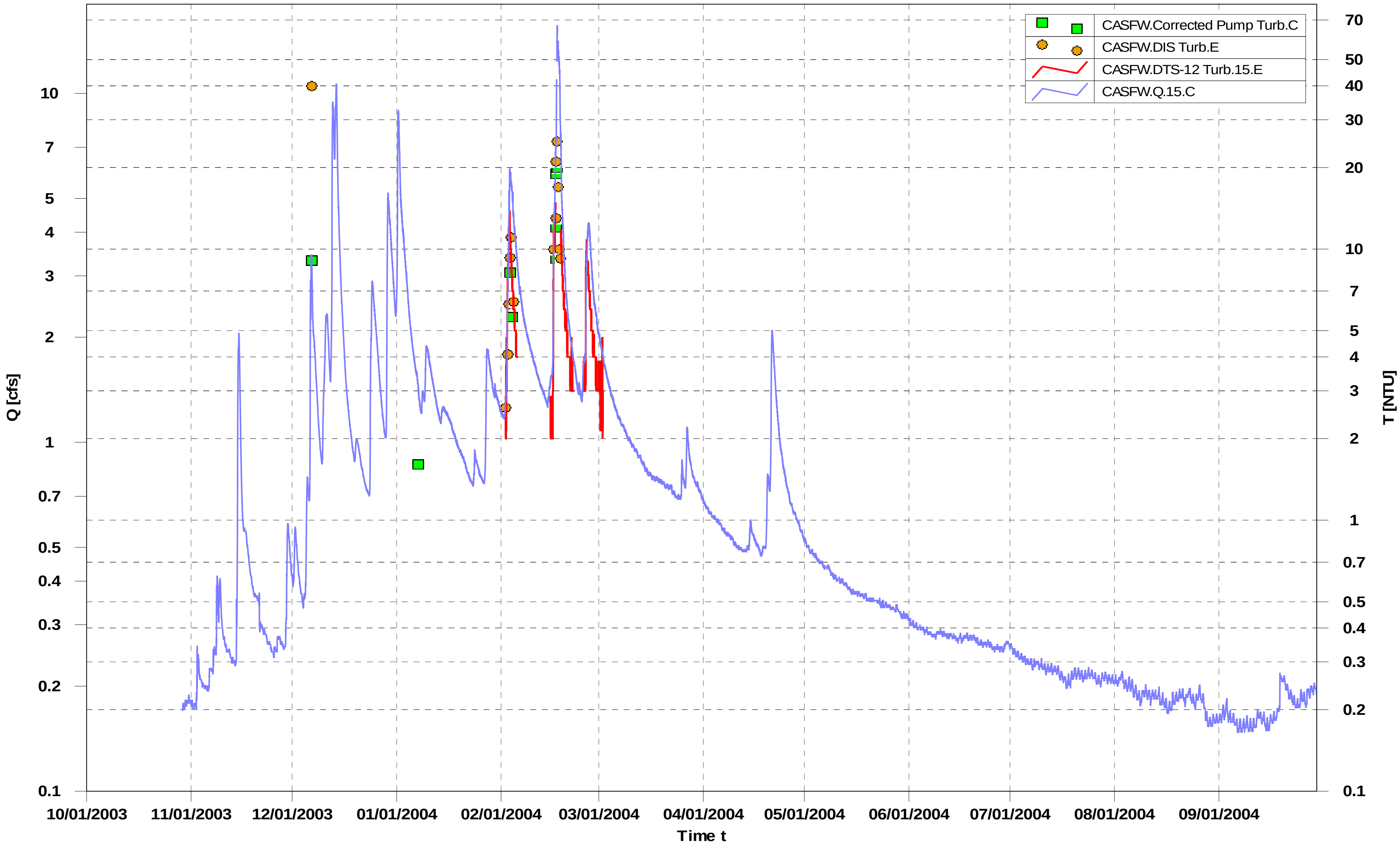
CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge Hydrograph, Continuous Turbidity with Pump and Depth-Integrated Turbidity Samples



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WY 2004
APPENDIX

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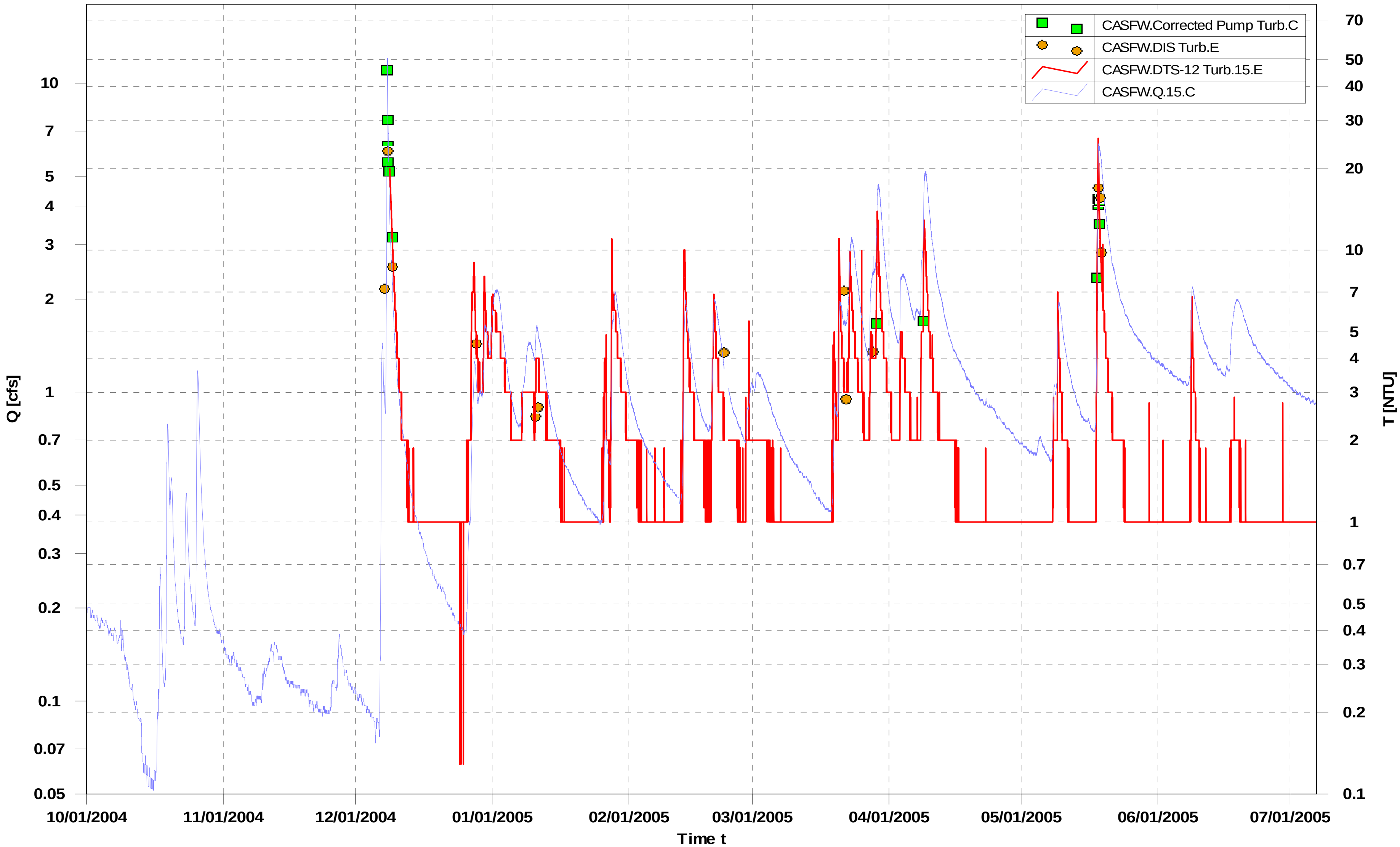
CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge Hydrograph, Continuous Turbidity with Pump and Depth-Integrated Turbidity Samples



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WY 2005
APPENDIX

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SUSPENDED SEDIMENT MEASUREMENT SUMMARY SHEET

LOCATION: CENTER GULCH ABOVE SOUTH FORK WAGES CREEK **WATER YEAR**: 2004

Date/ Time	Msmt No.	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (tons/day)	SSLPA ($tons/day/mi^2$)	Type (DIS, Pump)	Notes
12/6/2003 18:16	CASFW-SSCT2004-01	40	201	0.63	3.52	12	1.9	6.6	DIS	Censored
12/6/2003 18:17	CASFW-SSCT2004-02	9.1	11	0.63	3.52	12	0.1	0.4	PUMP	
1/7/2004 13:01	CASFW-SSCT2004-03	2.6	0.5	0.50	1.54	5.3	0.0	0.0	PUMP	
2/2/2004 4:40	CASFW-SSCT2004-04	2.6	4.2	0.52	1.79	6.2	0.0	0.1	DIS	
2/2/2004 20:20	CASFW-SSCT2004-05	4.1	8.4	0.56	2.34	8.1	0.1	0.2	DIS	
2/3/2004 5:46	CASFW-SSCT2004-06	6.3	8.7	0.64	3.71	13	0.1	0.3	DIS	
2/3/2004 13:02	CASFW-SSCT2004-07	9.3	7.8	0.73	5.67	20	0.1	0.4	DIS	Bottle # 918
2/3/2004 13:02	CASFW-SSCT2004-08	9.2	9.0	0.73	5.67	20	0.1	0.4	PUMP	Calibrate w/ bottle # 918
2/3/2004 20:20	CASFW-SSCT2004-09	11	13	0.73	5.67	20	0.2	0.7	DIS	
2/4/2004 11:01	CASFW-SSCT2004-10	6.6	3.0	0.70	4.97	17	0.0	0.1	PUMP	T-PROBE = 7 NTU
2/4/2004 12:52	CASFW-SSCT2004-11	6.4	2.1	0.68	4.53	16	0.0	0.1	DIS	
2/16/2004 18:35	CASFW-SSCT2004-12	10	22	0.68	4.53	16	0.3	0.9	DIS	
2/17/2004 6:31	CASFW-SSCT2004-13	10	13	0.78	6.96	24	0.2	0.7	PUMP	T-PROBE = 17 NTU
2/17/2004 8:10	CASFW-SSCT2004-14	13	19	0.80	7.52	26	0.4	1.3	DIS	
2/17/2004 8:16	CASFW-SSCT2004-15	13	17	0.80	7.52	26	0.3	0.9	PUMP	T-PROBE = 26 NTU
2/17/2004 10:46	CASFW-SSCT2004-16	21	39	0.88	9.98	34	1.0	3.6	DIS	
2/17/2004 11:01	CASFW-SSCT2004-17	20	39	0.93	11.7	40	0.9	3.2	PUMP	T-PROBE = 105 NTU
2/17/2004 11:46	CASFW-SSCT2004-18	21	40	0.95	12.5	43	1.0	3.5	PUMP	T-PROBE = 316 NTU
2/17/2004 13:46	CASFW-SSCT2004-19	25	67	0.95	12.5	43	2.3	7.8	DIS	
2/17/2004 19:28	CASFW-SSCT2004-20	17	24	0.97	13.2	46	0.9	2.9	DIS	
2/18/2004 10:42	CASFW-SSCT2004-21	10	9.8	0.91	11.0	38	0.3	1.0	DIS	
2/18/2004 16:46	CASFW-SSCT2004-22	9.2	10.0	0.82	8.10	28	0.2	0.8	DIS	

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WY 2004
APPENDIX

A-8a

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: CENTER GULCH ABOVE SOUTH FORK WAGES **WATER YEAR: 2005**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSL (ton/day)	SSLPA (ton/day/mi2)	Type (DIS, PUMP)	Note
12/7/2004 13:18	CASFW-SSCT2005-01	7.2	4.5	0.45	1.01	3.5	0.0	0.0	DIS	
12/8/2004 01:46	CASFW-SSCT2005-02	82	174	0.61	3.13	11	1.5	5.1	PUMP	
12/8/2004 02:16	CASFW-SSCT2005-03	46	102	0.68	4.64	16	1.3	4.4	PUMP	
12/8/2004 05:46	CASFW-SSCT2005-04	30	61	0.91	11.2	39	1.8	6.4	PUMP	
12/8/2004 08:46	CASFW-SSCT2005-05	24	19	0.83	8.45	29	0.4	1.5	PUMP	
12/8/2004 09:31	CASFW-SSCT2005-06	24	14	0.80	7.80	27	0.3	1.0	PUMP	
12/8/2004 09:38	CASFW-SSCT2005-07	23	16	0.80	7.52	26	0.3	1.1	DIS	
12/8/2004 11:01	CASFW-SSCT2005-08	21	8.2	0.76	6.54	23	0.1	0.5	PUMP	
12/8/2004 14:01	CASFW-SSCT2005-09	19	7.4	0.71	5.34	18	0.1	0.4	PUMP	
12/9/2004 10:15	CASFW-SSCT2005-10	11	4.8	0.54	2.26	7.8	0.0	0.1	PUMP	
12/9/2004 10:20	CASFW-SSCT2005-11	8.7	1.2	0.55	2.19	7.6	0.0	0.0	DIS	
12/28/2004 12:42	CASFW-SSCT2005-12	4.5	2.8	0.45	1.01	3.5	0.0	0.0	DIS	
1/10/2005 22:07	CASFW-SSCT2005-13	2.5	4.7	0.50	1.54	5.3	0.0	0.1	DIS	
1/11/2005 11:20	CASFW-SSCT2005-14	2.6	3.6	0.50	1.55	5.3	0.0	0.1	DIS	
2/22/2005 15:40	CASFW-SSCT2005-15	4.2	77	0.47	1.21	4.2	0.3	0.9	DIS	sand, discharge taken from rating table not from 15 mintute discharge record, Censored
3/21/2005 18:39	CASFW-SSCT2005-16	7.1	30	0.51	1.66	5.7	0.1	0.5	DIS	Censored
3/22/2005 07:44	CASFW-SSCT2005-17	2.8	3.3	0.51	1.66	5.7	0.0	0.1	DIS	
3/28/2005 10:40	CASFW-SSCT2005-18	4.2	3.4	0.57	2.52	8.7	0.0	0.1	DIS	
3/29/2005 06:16	CASFW-SSCT2005-19	5.4	19	0.65	3.48	12	0.2	0.6	Pump	
4/8/2005 21:01	CASFW-SSCT2005-20	5.5	18	0.66	3.88	13	0.2	0.6	Pump	
5/18/2005 06:31	CASFW-SSCT2005-21	7.9	16	0.57	2.48	8.6	0.1	0.4	Pump	
5/18/2005 10:31	CASFW-SSCT2005-22	15	20	0.71	5.00	17	0.3	0.9	Pump	
5/18/2005 12:46	CASFW-SSCT2005-23	17	27	0.79	6.78	23	0.5	1.7	DIS	
5/18/2005 13:01	CASFW-SSCT2005-24	15	21	0.79	6.80	23	0.4	1.3	Pump	
5/18/2005 14:26	CASFW-SSCT2005-25	15	19	0.80	6.88	24	0.4	1.2	Pump	manual pump for calibration however DIS bottle broke and lost sample.
5/18/2005 17:01	CASFW-SSCT2005-26	13	12	0.78	6.34	22	0.2	0.7	Pump	
5/18/2005 20:14	CASFW-SSCT2005-27	16	7.8	0.78	6.16	21	0.1	0.4	DIS	
5/19/2005 07:38	CASFW-SSCT2005-28	9.8	11	0.72	4.75	16	0.1	0.5	DIS	

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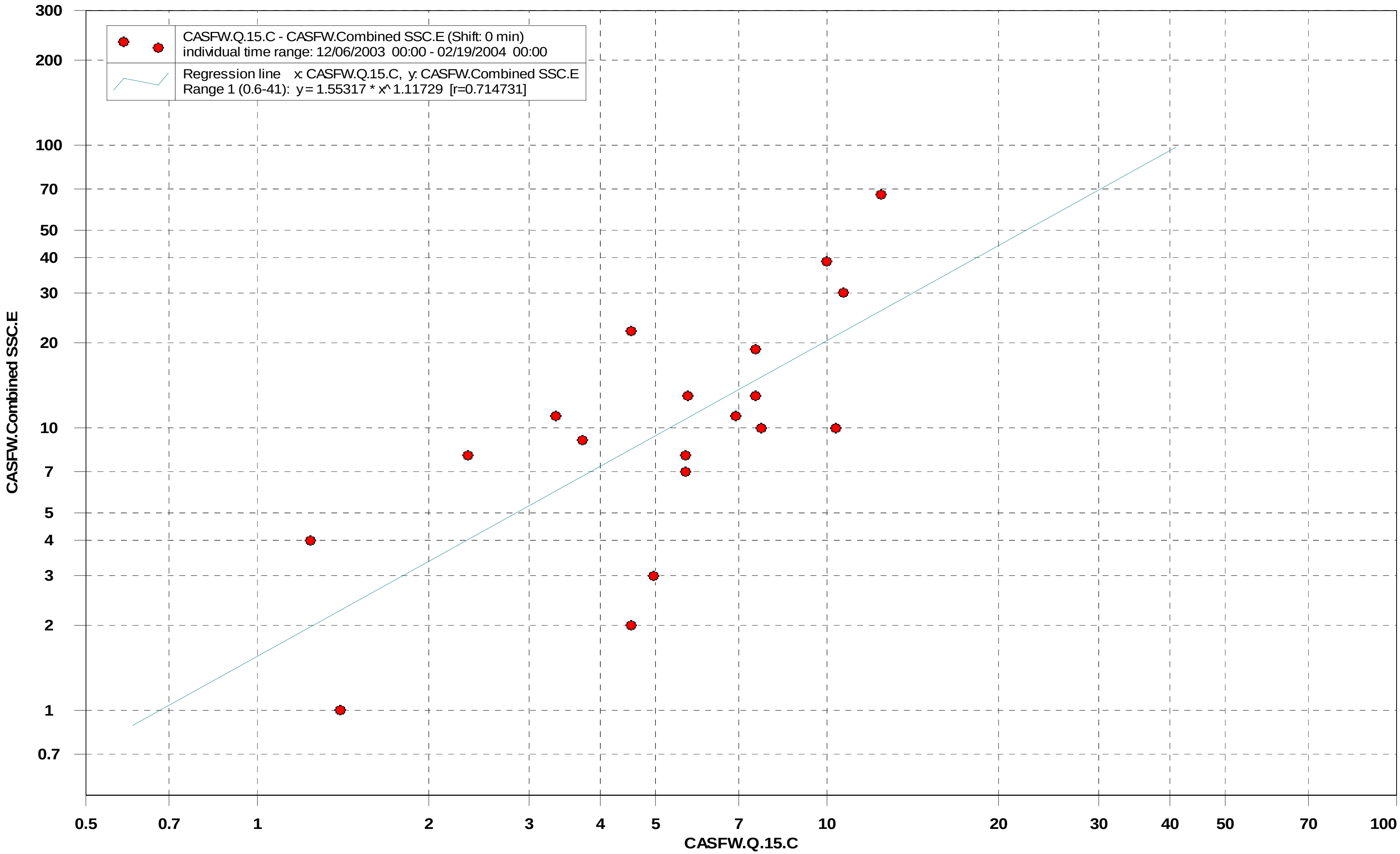
WY 2005 APPENDIX

A-8b

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge vs Depth-Integrated and Pump SSC



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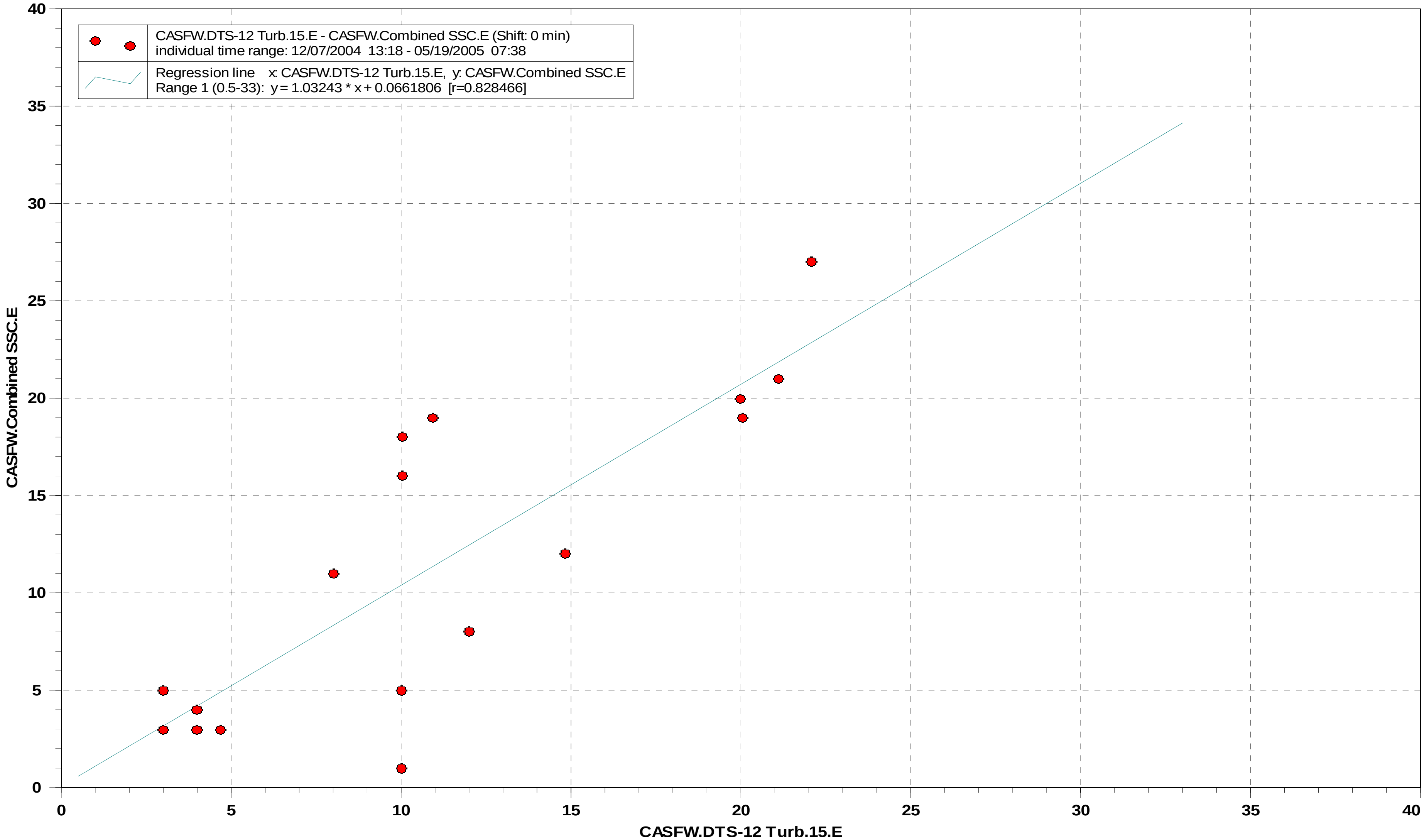
WY 2004
APPENDIX

A-9a

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
DTS-12 Turbidity vs Depth-Integrated and Pump SSC



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WY 2005
APPENDIX

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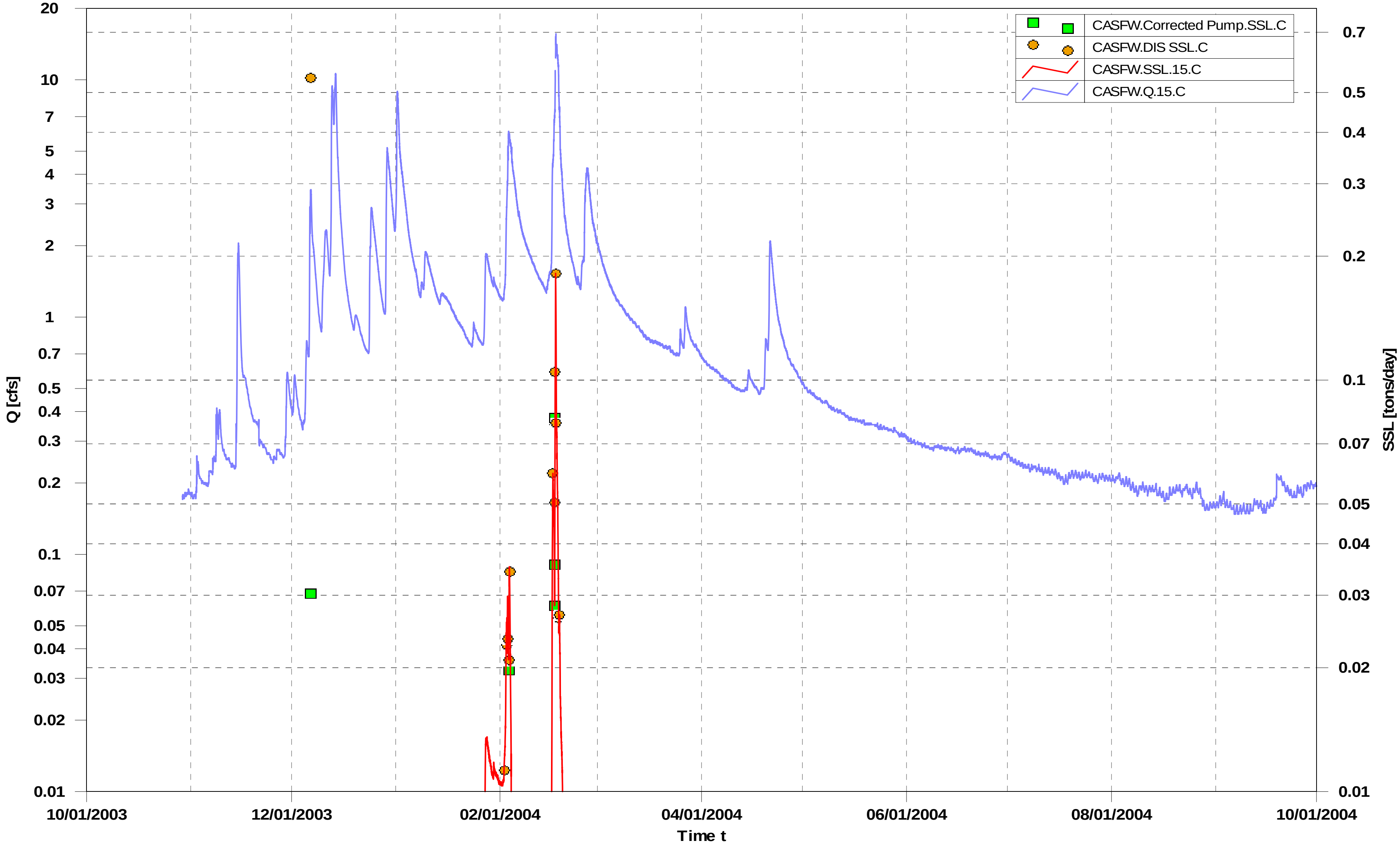
CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge and Suspended Sediment Load



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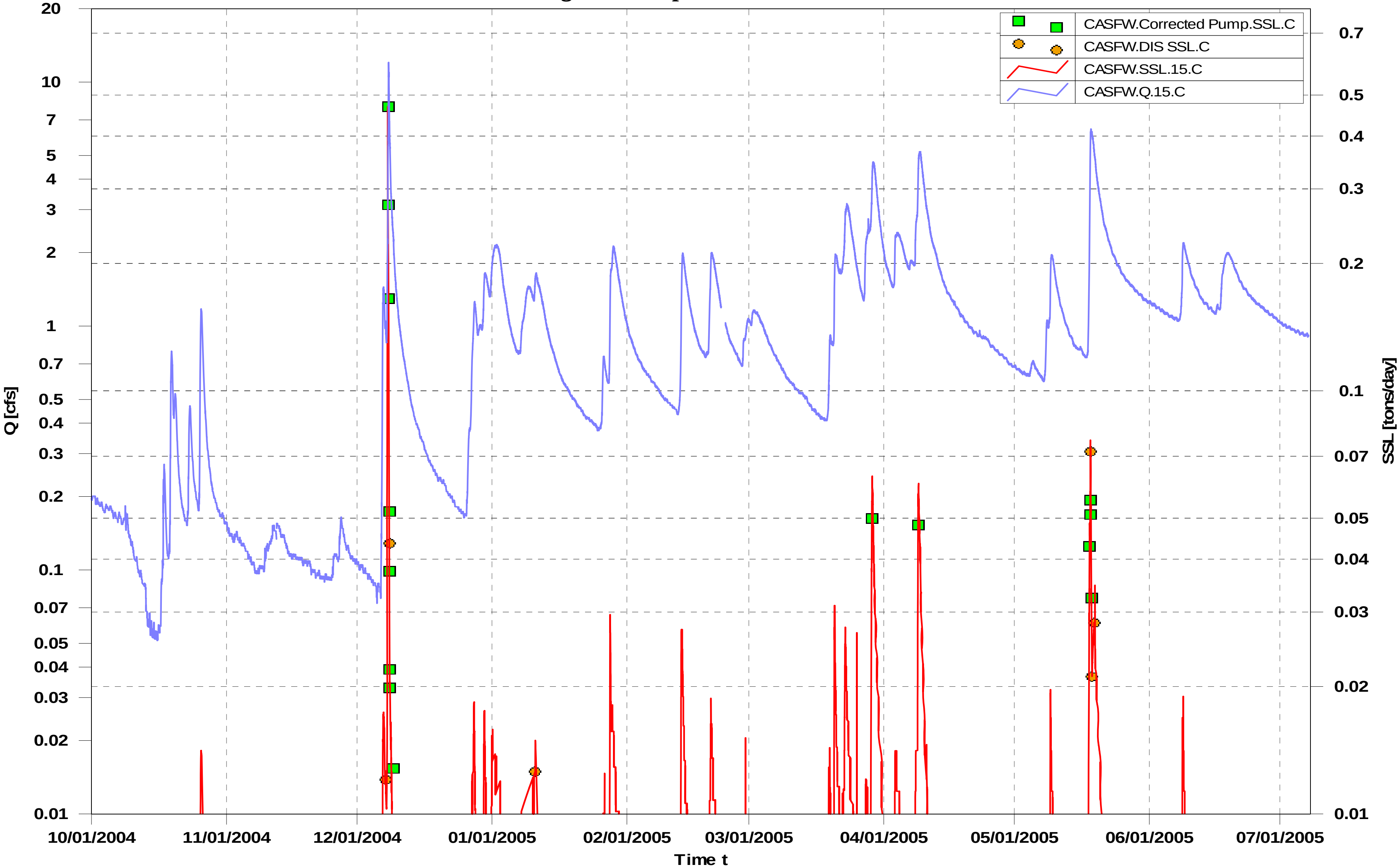
WY 2004
APPENDIX

A-10a

CENTER GULCH ABOVE SOUTH FORK WAGES CREEK
Discharge and Suspended Sediment Load



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WY 2005
APPENDIX

A-10b

SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
(STATION # CTM 0283010)
STATION ANALYSIS
WATER YEAR 2004-2005

RECORDS – Surface Water

EQUIPMENT – A Turbidity Threshold Sampling (TTS) station is installed at this site. The TTS station includes an Isco 6712 full size portable sampler, a Campbell Scientific CR510 data collection platform (DCP), a waterlog H-310 pressure transducer and a forest technology systems DTS-12 turbidity sensor. The station battery power is supplemented by a solar panel. The DCP is housed in a locked steel box that is installed on the right bank. The DTS-12 is housed in an aluminum boom assembly, which is attached to a cable way strung over the creek. The pressure transducer is located on the right bank close to the cable way. One staff plate is located on the left bank 5 feet downstream of the cable way.
Inside recording gage: Less than or equal to 0.02% of full scale output (FSO) over temperature range referenced (0 to 40^{o} C) to a straight line stretched from zero psi to maximum pressure (15 psi).
Outside staff gage: One USGS style A staff gage mounted on redwood and attached to channel iron that has been pounded into the streambed. Limits 0.00 ft. to 3.32 ft.

GAGE HEIGHT RECORDS – Record is incomplete for the period.
Water Year 2004 station operation of the station began on October 29, 2003 at 15:30 hours. Campbell datalogger malfunctioned on December 5, 2003 at 10:15 hours and was replaced on December 7, 2003 at 16:45 hours. Station operation became intermittent on August 4, 2004. Station operation ceased for the water year on August 5, 2005 at 15:45 hours.
The maximum gage height inWater Year 2004 of 2.16 ft occurred on January 1, 2004 at 14:00 hours. The minimum gage height in Water Year 2004 of 0.31 ft occurred on October 29, 2003 at 19:30 hours.
Water Year 2005 station operation began on October 13 at 10:45 hours. Gage height record runs through July 7, 2005 at 13:45 hours.
The maximum gage height in Water Year 2005 of 1.72 feet occurred on December 8, 2004 at 07:00 hours. The minimum gage height in Water Year 2004 of 0.30 feet occurred on December 6, 2004 10:00 hours.

DATUM CORRECTIONS – Staff plate has not been surveyed, no datum correction known.

CONTROL – The low to mid range control is a semi-stable cobble and boulder riffle. During periods of very high flow (>100 cfs) the control becomes drown out and channel control dominates. The channel at the gage has a steep vegetated right bank while the left bank has a small terrace with a steep upper bank. The Left bank at the site will overtop during extreme events.

RATING – In Water Year 2004 five discharge measurements (1-5) were made. Measured discharge for the period ranged from 5.45 cfs to 53.3 cfs. Computed instantaneous discharge ranged 0.15 cfs to 102 cfs. Measurements 1-5 were used to develop the base rating 1.2.
On January 7, 2004 a debris jam downstream of the control was backwatering the site. The debris jam was cleared causing the gage height to drop from 1.17 ft to 0.82 ft. No information was available on when the debris jam had occurred. Based the observations made when the debris jam was cleared and inspection of the gage height file TV04-1 was developed. TV04-1 was prorated into effect beginning on January 1, 2004 and gained full weight by January 7, 2004 at 11:45 hours with the idea that the debris jam had initially

formed near the peak on January and that material had continued to collect on it until it was cleared. Rating 1.2 was prorated back into effect immediately after the debris had been cleared and the gage height stabilized.
In Water Year 2005 seven discharge measurements (6-12) were made. Measured discharge for the period ranged from 0.20 cfs to 34.2 cfs. Computed instantaneous discharge ranged from 0.14 cfs to 56.2 cfs
Rating
Rating 1.2 in used at the end of station operation in Water Year 2004 was continued in use. Measurement 6, made on October 13, 2004 (WY 2005), was used to refine the low end of the Rating 1.2. Measurement 7, made on December 28, 2004 plotted within 1% of Rating 1.2 and was rated poor.
Measurements 8 and 9, both made on January 3, 2005, plotted -10% and -16% from Rating 1.2. Measurement 9 was a check measurement for measurement 8. The shifts indicated by measurements 8 and 9 where -0.03 ft and -.04 ft respectively. Measurements 8 and 9 were used to develop time variable shift (TV) TV05-1. TV05-1 is prorated into effect beginning on December 8, 2004 at 07:00 hrs and reaches full weight on December 9 at 17:15 hours. TV05-1 is prorated into effect beginning at the peak of the December 8th storm with the idea that material was transported into the section and raised the elevation of the control. TV05-1 is defined by measurement 8 to within 1% and measurement 9 to within -6% of Rating 2.1.
Measurement 10, made on February 22, 2005 indicates a return to Rating 1.2. No check measurement was made for measurement 10. The return to Rating 1.2 is prorated into effect beginning on January 28, 2005 at 14:00 hours and is fully accomplished by January 29, 2005 at 07:30 with the idea that the material that had been transported into the section was removed by the high flows of January 28 and 29, 2005.
Measurement 11, made on March 28, 2005, plotted -14% from Rating 1.2. No check measurement was made. Measurement 11 indicates that material had been transported into the section raising the elevation of the control. The GZF measurement made concurrent with the discharge measurements confirms this. Measurement 11 was used to develop TV05-2, which is defined by measurement 11 to within 0% of Rating 1.2. TV05-2 is prorated into effect beginning on March 22, 2005 at 09:30 hours and reaches full weight by March 25 at 10:00 hours. TV05-2 is prorated into effect with the idea that material was transported into the section during the high flow of March 22, 2005 and that the control did not stabilize until March 25.
Measurement 12, made on May 18, 2005 indicates that scour of the control had occurred. No check measurement was made. The GZF recorded during the measurement verifies the elevation of the control had been lowered. Measurement 12 was used to develop TV05-3, which is defined by measurement 12 to within 0% of Rating 1.2. TV05-3 is prorated into effect beginning on April 8, 2005 at 09:45 hours and reaches full weight by April 09, 2005 at 10:15 hours with the idea that the material was removed from the control on the rising limb. TV05-3 is held in effect through July 7, 2005 when the record ends.

DISCHARGE – Rating #1.2 was used during WY 2004-2005 as follows:

Water Year 2004

Oct. 29 to Jan. 1. (14:00)	Rating 1.2
Jan. 1 to Jan. 7 (11:45)	Prorate to TV04-1 (0.32,-.35; 2.00,-.35; 2.36,-.35)
Jan. 7 to Jan. 7 (12:00)	Prorate to Rating 1.2
Jan. 7 to Aug. 5 (15:45)	Rating 1.2

Water year 2005

Oct. 13, to Dec. 8 (07:00)	Rating 1.2
Dec. 8 to Dec. 9 (17:15)	Prorate to TV05-1 (0.32,-0.03; 2.00;-.03; 2.36,0.00)
Dec. 9 to Jan. 28 (14:00)	TV05-1 (0.32,-0.03; 2.00;-.03; 2.36,0.00)
Jan. 28 to Jan 29 (07:30)	Prorate to Rating 1.2

Jan. 29 to Mar. 22 (09:30)	Rating 1.2
Mar. 22 to Mar 25 (10:00)	Prorate to TV05-2 (0.32,-.05; 2.00; -.05; 2.36,0.00)
Mar 25 to Apr. 8 (09:45)	TV05-2 (0.32,-.05; 2.00; -.05; 2.36,0.00)
Apr. 8 to Apr. 9 (10:15)	Prorate to TV05-3 (0.32,.04; 2.00,.04; 2.36,0.00)
Apr. 9 to Jul. 7(13:45)	TV 05-3 (0.32,.04; 2.00,.04; 2.36,0.00)

SPECIAL COMPUTATION: None

REMARKS – Records considered fair for Water Year 2004 and Water Year 2005. No regulation or diversion upstream from the station.

Gage height records worked by T. Grey 10-05
Gage height records checked by C. Pryor 10-05
Discharge computation worked by C. Pryor 11-05
Discharge computation checked by C. Pryor 12-05

DISCHARGE SUMMARY SHEET

LOCATION: South Fork Wages Creek Above Center Gulch **WATER YEAR: 2004-2005**

Measurement Number	WY Msmt #	Date	Made By:	Width (feet)	Mean Depth (feet)	Area (ft^2)	Mean Velocity (ft/sec)	Gage Height (feet)	Discharge (cfs)	Rating 1.2		Method	No. of Msmt sections	Begin Time (hours)	End Time (hours)	Msmt Rating	PZF level	Notes
										Shift Adj.	Percent Diff.							
1	2004-01	12/7/2003	T. Grey	7.1	0.54	3.85	1.42	0.82	5.45		-1	wading	27	12:47	13:34	fair		
2	2004-02	2/3/2004	K. Faucher	8.9	0.92	8.22	3.14	1.30	25.8		1	wading	21	13:54	14:28	fair		
3	2004-03	2/4/2004	T. Grey	8.0	0.90	7.18	2.73	1.19	19.6		1	wading	18	10:21	10:55	fair	0.26	
4	2004-04	2/17/2004	K. Faucher	8.8	1.45	12.78	4.17	1.68	53.3		1	wading	30	18:31	19:08	fair	0.27	
5	2004-05	2/18/2004	T. Grey	9.2	1.18	10.87	3.47	1.50	37.8		-2	wading	21	13:10	13:39	fair	0.27	
6	2005-01	10/13/04	K. Faucher	3.4	0.24	0.80	0.25	0.32	0.20		0	wading	18	11:54	11:15	poor		
7	2005-02	12/28/04	T. Bolton	8.6	0.54	4.66	1.08	0.80	5.04		1	wading	27	12:30	13:08	poor		no pzf measurement
8	2005-03	01/03/05	T. Bolton	8.7	0.51	4.46	1.75	0.93	7.82	-0.03		wading	30	12:37	13:15	fair	0.26	
9	2005-04	01/03/05	T. Bolton	8.9	0.48	4.26	1.78	0.94	7.55	-0.03	-6	wading	19	13:46	14:08	poor	0.27	2nd measure, quick and dirty
10	2005-05	02/22/05	T. Bolton	9.3	0.46	4.31	1.61	0.87	6.90		1	wading	32	14:19	15:05	fair	0.27	
11	2005-06	03/28/05	K. Faucher	10.0	0.56	5.64	2.24	1.09	12.7	-0.05		wading	20	11:10	11:51	fair	0.30	
12	2005-07	05/18/05	T. Bolton	10.0	0.85	8.47	3.70	1.40	34.2	0.04		wading	20	20:10	20:41	fair	0.28	

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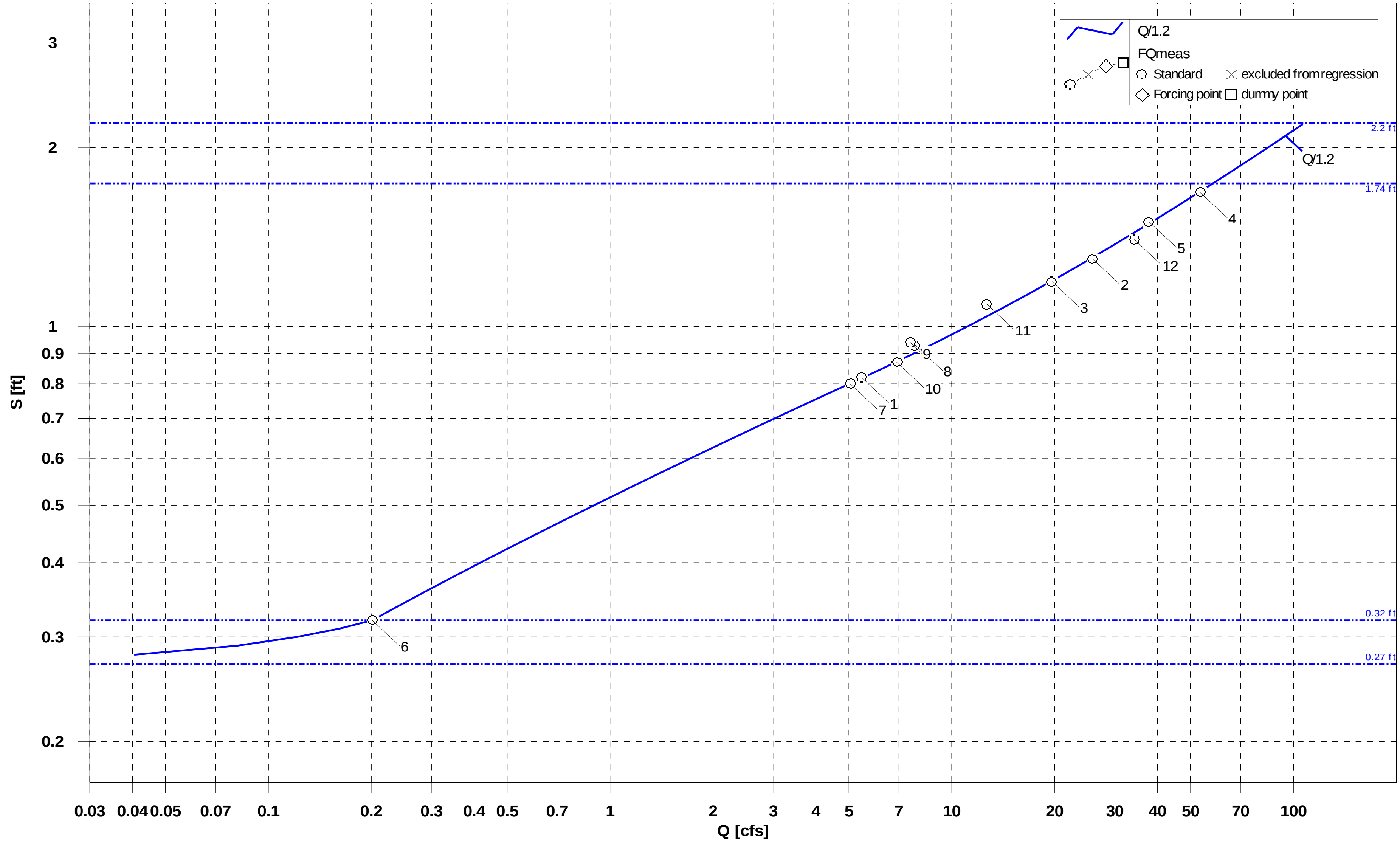
WY 04-05 APPENDIX

B-2

SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
Discharge Rating Curve 1.2



PROJECT:	GMA GRAHAM MATTHEWS & ASSOCIATES	WY 04-05 APPENDIX
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Graham Matthews & Associates

SOUTH FORK WAGES CREEK ABOVE CENTER GULCH

RATING TABLE NO.1.2 -- Begin Date 12/7/03

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1st Diff	2nd Diff
0.0	---	---	---	---	---	---	---	---	---	---		
0.1	---	---	---	---	---	---	---	---	---	---	---	
0.2	---	---	---	---	---	---	---	---	---	---	---	---
0.3	*0.12*	*0.16*	*0.20*	0.22	0.24	0.27	0.29	0.32	0.35	0.38	---	---
0.4	0.42	0.45	0.49	0.53	0.58	0.62	0.67	0.73	0.78	0.84	0.46	---
0.5	0.90	0.96	1.03	1.11	1.18	1.26	1.35	1.43	1.52	1.62	0.78	0.32
0.6	1.72	1.83	1.94	2.06	2.18	2.31	2.44	2.58	2.73	2.88	1.26	0.48
0.7	3.03	3.20	3.37	3.54	3.73	3.93	4.13	4.34	4.55	4.78	1.90	0.64
0.8	5.01	5.25	5.50	5.74	6.01	6.28	6.56	6.84	7.14	7.44	2.66	0.76
0.9	7.74	8.05	8.37	8.69	9.02	9.36	9.71	10.1	10.4	10.8	3.36	0.70
1.0	11.2	11.5	11.9	12.3	12.7	13.1	13.5	13.9	14.4	14.8	4.00	0.64
1.1	15.2	15.7	16.1	16.6	17.1	17.5	18.0	18.5	19.0	19.5	4.70	0.70
1.2	20.0	20.5	21.0	21.6	22.1	22.7	23.2	23.8	24.3	24.9	5.40	0.70
1.3	25.5	26.1	26.6	27.3	27.9	28.5	29.1	29.7	30.4	31.0	6.10	0.70
1.4	31.7	32.3	33.0	33.6	34.3	35.0	35.7	36.4	37.1	37.8	6.80	0.70
1.5	38.6	39.3	40.0	40.8	41.5	42.3	43.1	43.8	44.6	45.4	7.60	0.80
1.6	46.2	47.0	47.8	48.6	49.4	50.3	51.1	52.0	52.8	53.7	8.30	0.70
1.7	54.6	55.5	56.4	57.2	58.1	*59.0*	*60.0*	*60.9*	*61.8*	*62.8*	9.10	0.80
1.8	*63.7*	*64.7*	*65.6*	*66.6*	*67.6*	*68.5*	*69.5*	*70.5*	*71.5*	*72.6*	9.80	0.70
1.9	*73.6*	*74.6*	*75.6*	*76.7*	*77.7*	*78.8*	*79.9*	*81.0*	*82.0*	*83.1*	10.5	0.70
2.0	*84.2*	*85.3*	*86.4*	*87.6*	*88.7*	*89.8*	*91.0*	*92.1*	*93.3*	*94.5*	11.4	0.90
2.1	*95.6*	*96.8*	*98.0*	*99.2*	*100*	*102*	*103*	*104*	*105*	*107*	12.5	1.10
2.2	---	---	---	---	---	---	---	---	---	---	---	---
2.3	---	---	---	---	---	---	---	---	---	---	---	---
2.4	---	---	---	---	---	---	---	---	---	---	---	---
2.5	---	---	---	---	---	---	---	---	---	---	---	---

Values in italics are beyond the validated range of the rating

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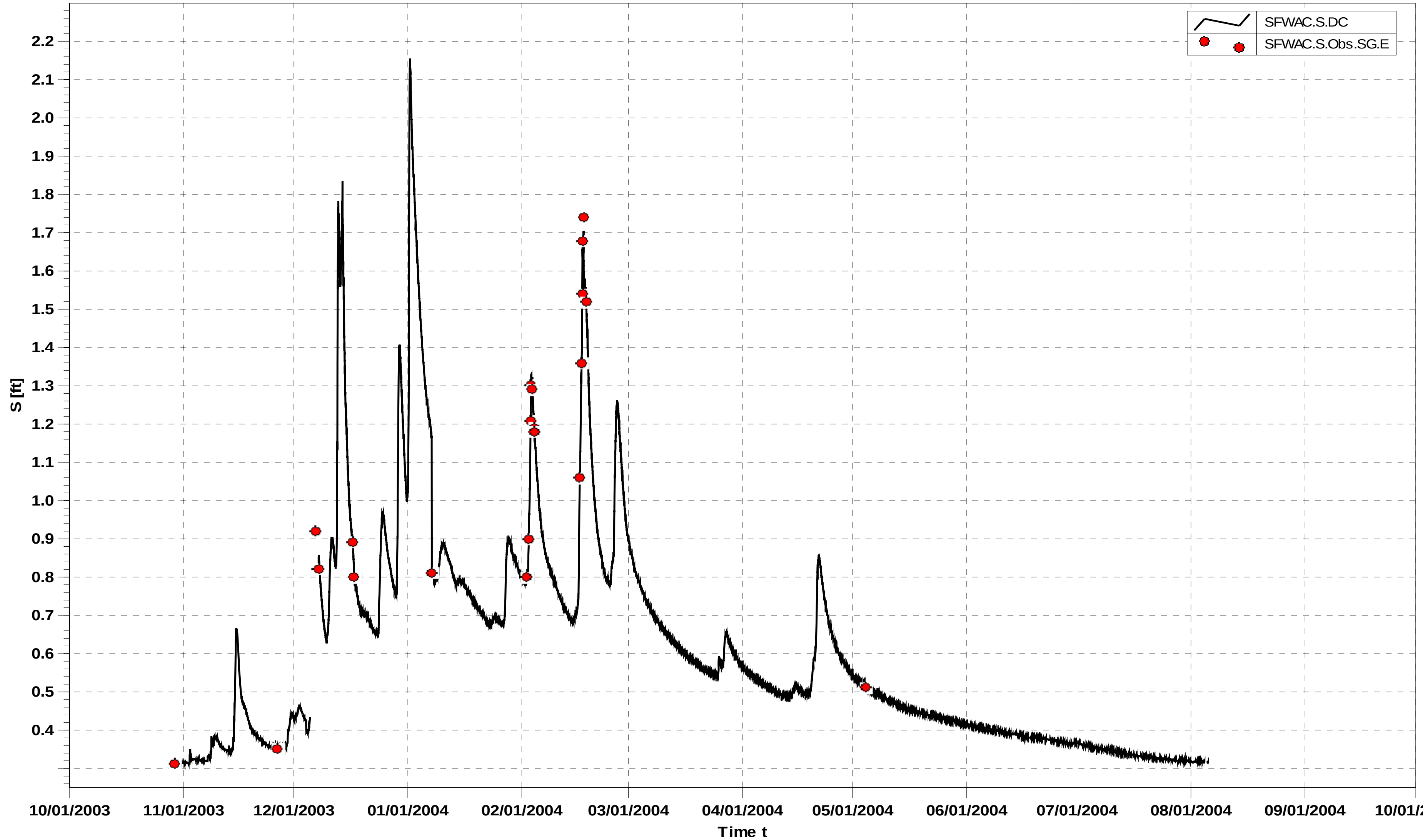
SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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APPENDIX

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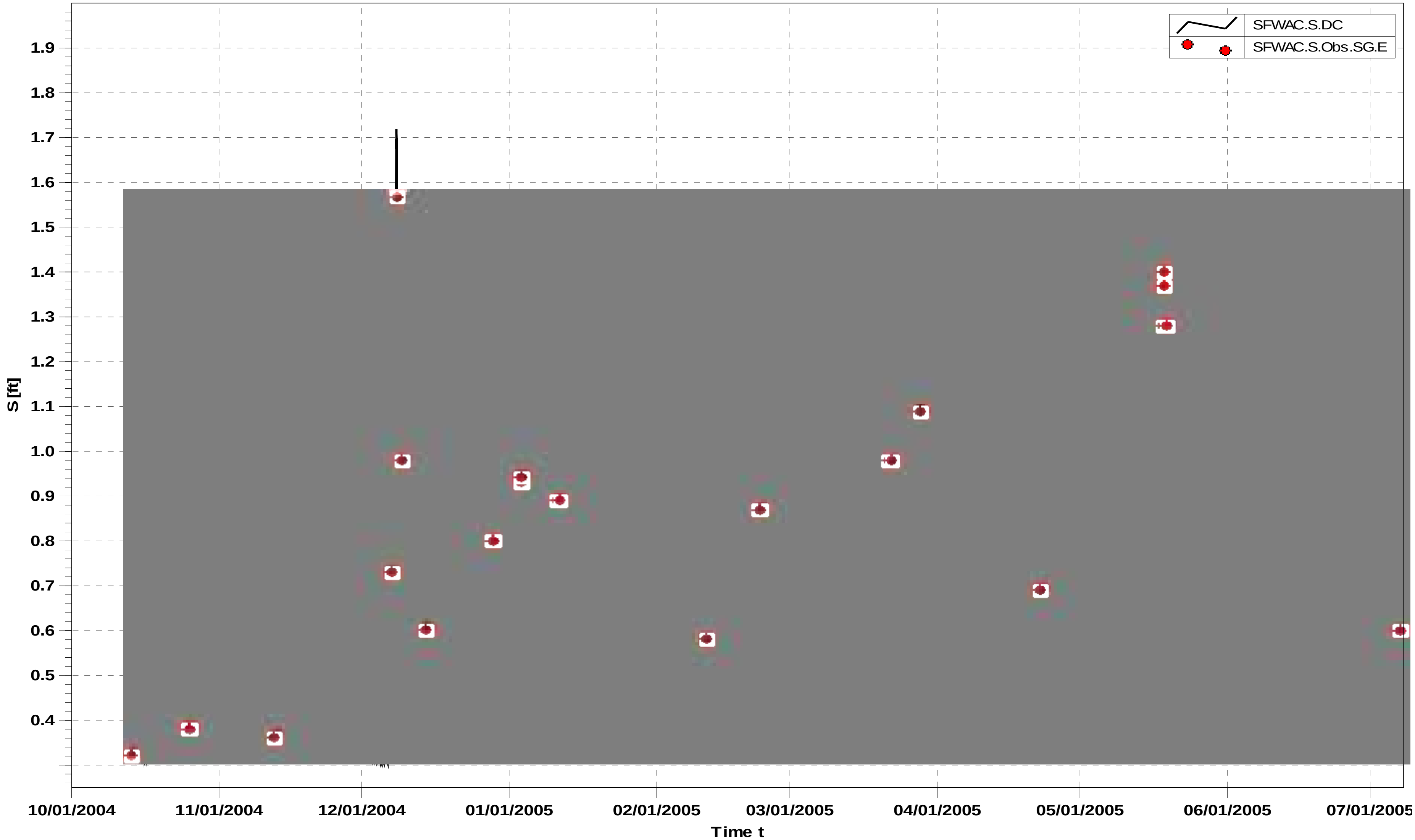
SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
15-Minute Adjusted Gage Height Record and Observed Staff Gage Readings



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APPENDIX

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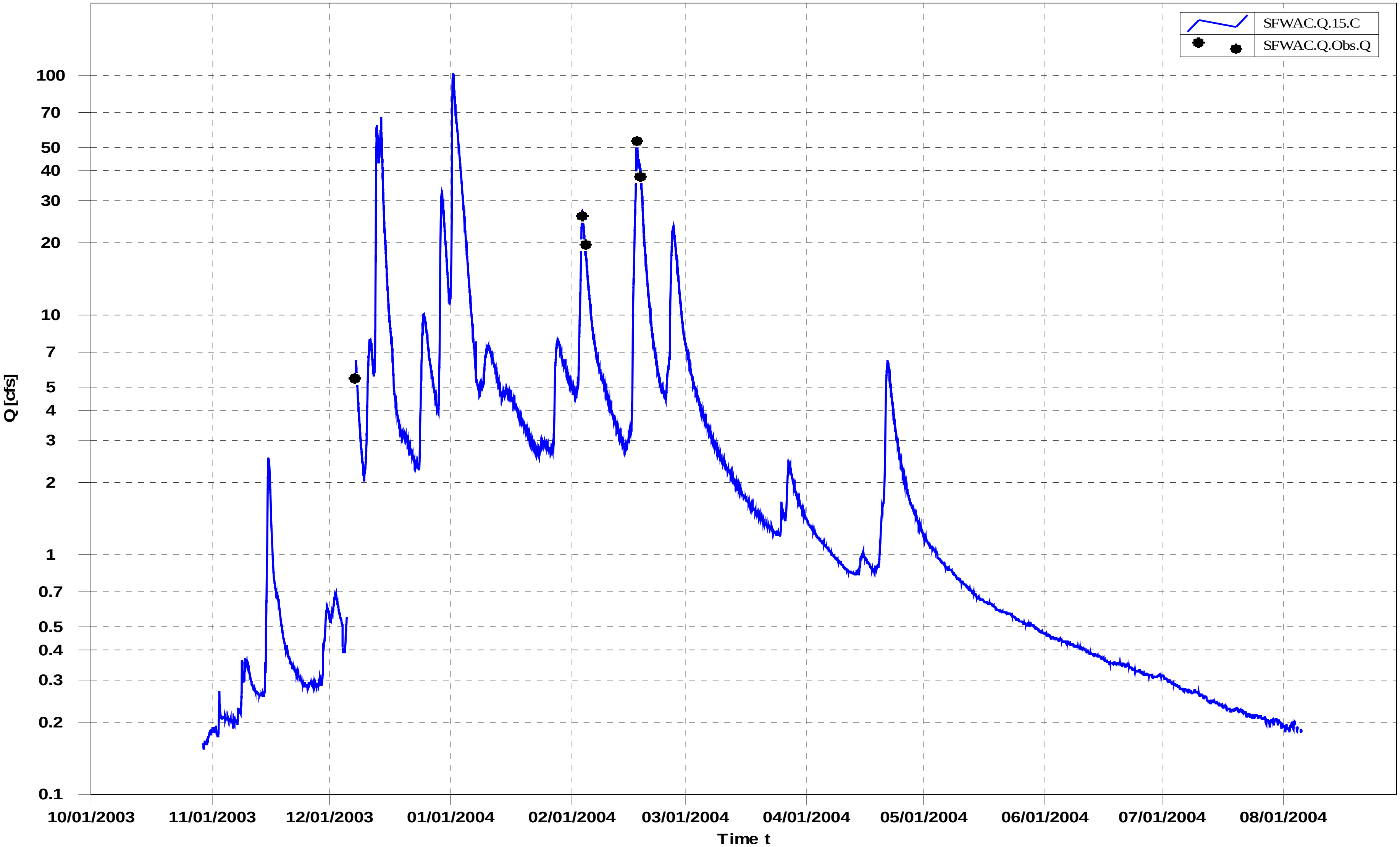
SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
Discharge Hydrograph and Discharge Measurements



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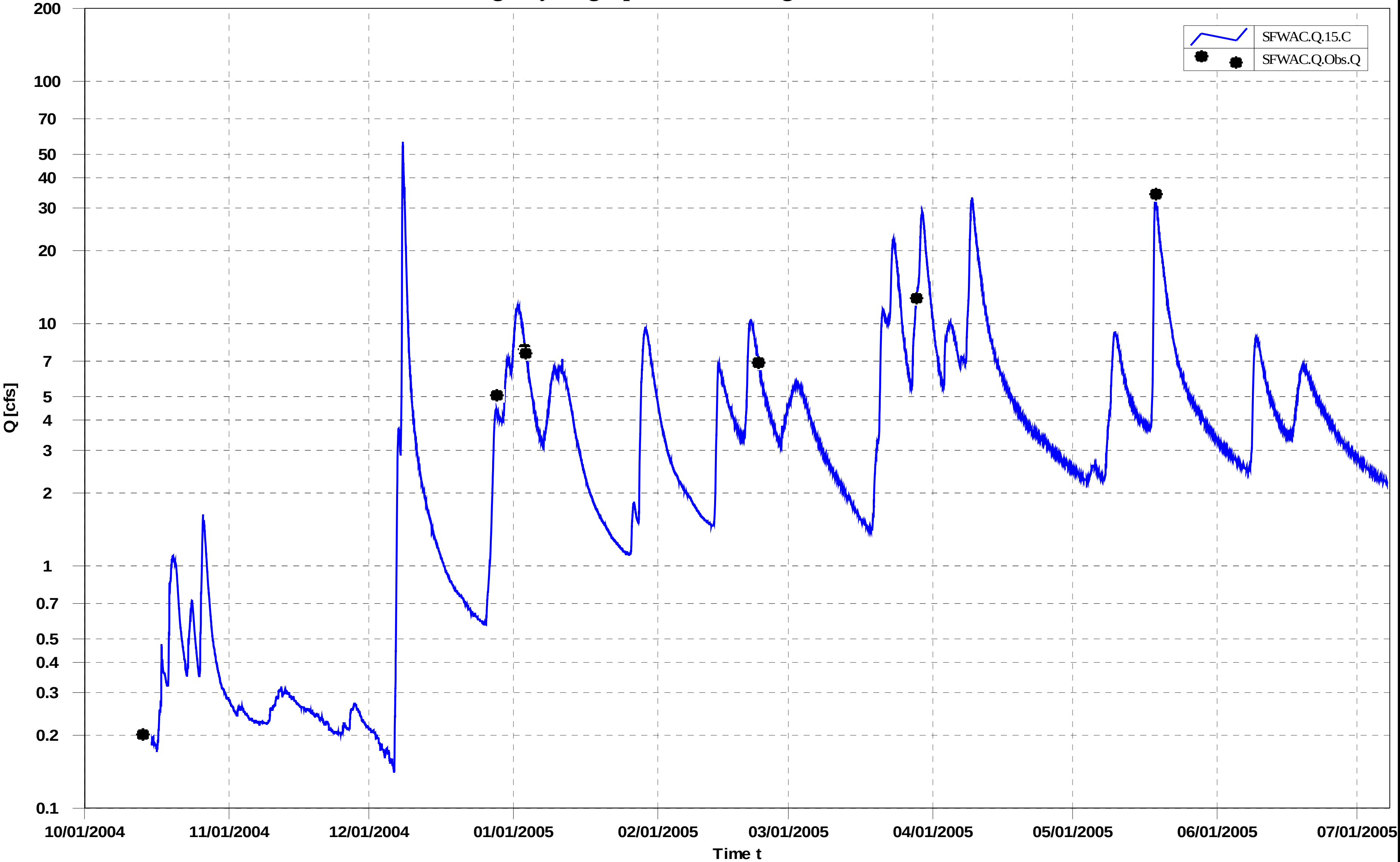
SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
Discharge Hydrograph and Discharge Measurements



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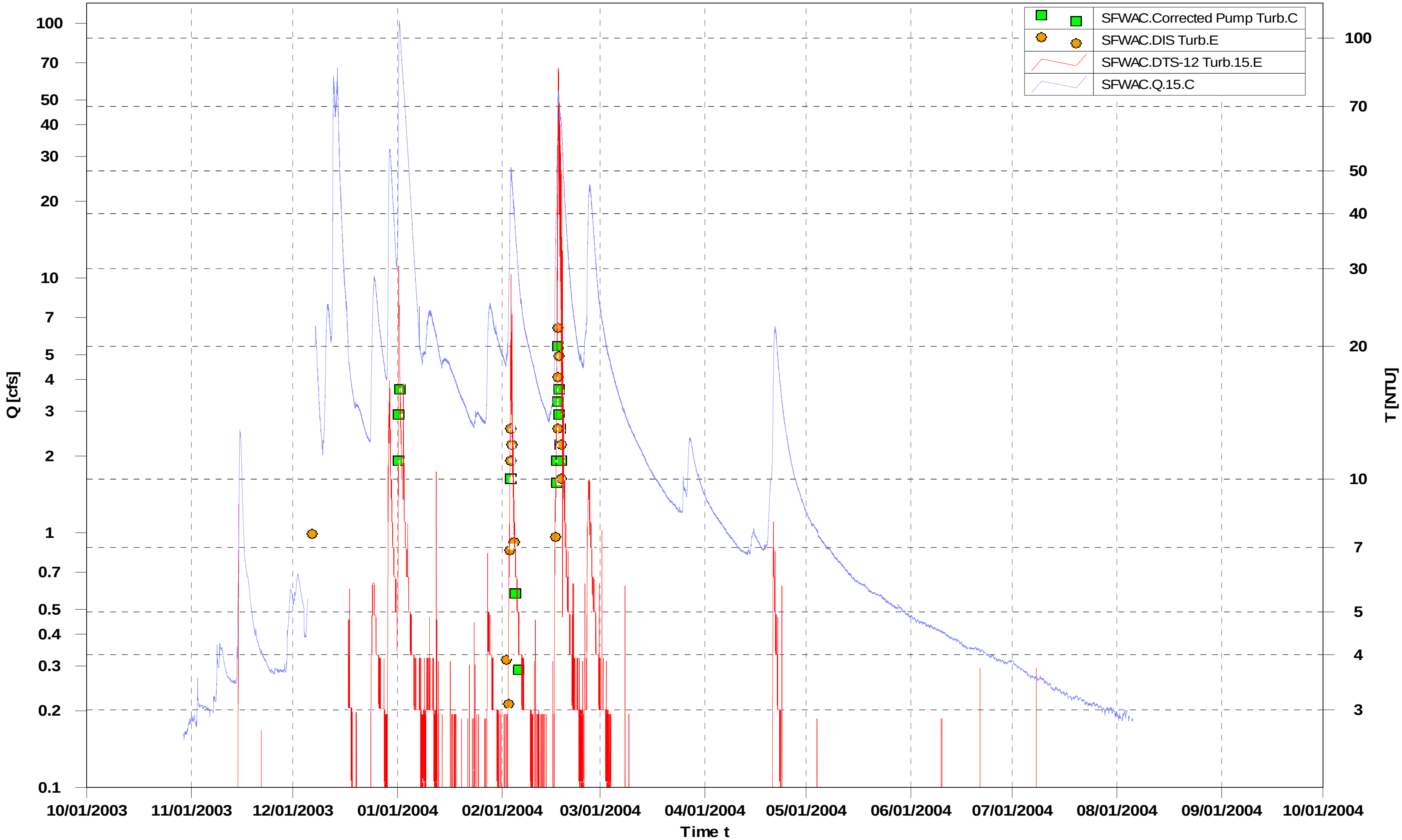
APPENDIX

B-6b

SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
Discharge Hydrograph, Continuous Turbidity with Pump and Depth-Integrated Turbidity Samples



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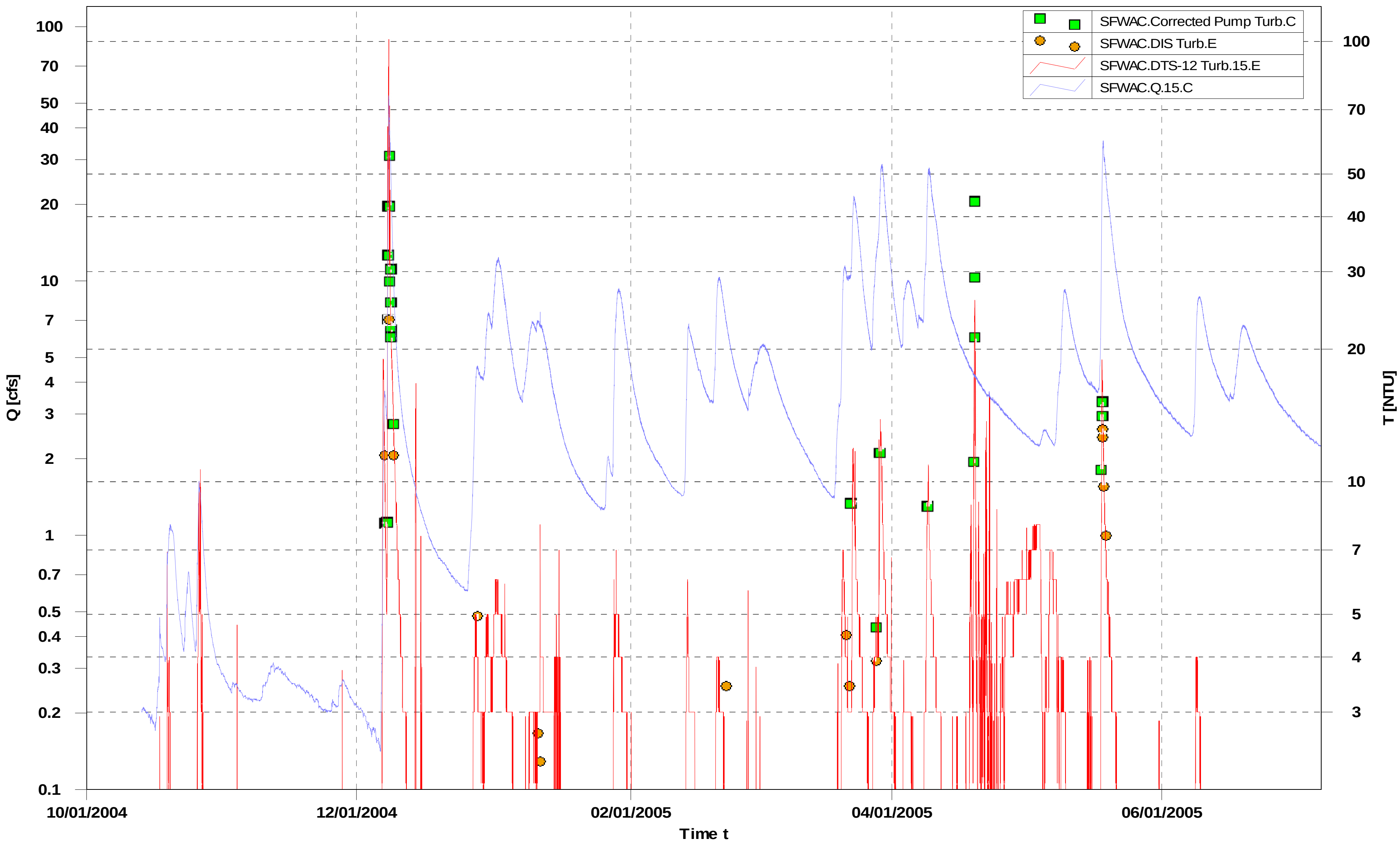
B-7a

SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
Discharge Hydrograph, Continuous Turbidity with Pump and Depth-Integrated Turbidity Samples



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WY 2005
APPENDIX

B-7b

SUSPENDED SEDIMENT MEASUREMENT SUMMARY SHEET

LOCATION: SOUTH FORK WAGES CREEK ABOVE CENTER GULCH **WATER YEAR:** 2004

Date/ Time	Msmt No.	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi2)	SSL (tons/day)	SSLPA (tons/day/mi2)	Type (DIS, PUMP)	Notes
12/6/03 19:24	SFWAC-SSCT2004-01	7.5	7	0.92	8.37	7.61	0.16	0.15	DIS	
1/1/04 8:01	SFWAC-SSCT2004-02	11	35	1.21	20.5	18.6	1.3	1.2	PUMP	
1/1/04 9:31	SFWAC-SSCT2004-03	17	36	1.35	28.5	25.9	2.0	1.8	PUMP	
1/1/04 12:16	SFWAC-SSCT2004-04	21	35	1.66	51.1	46.5	3.4	3.1	PUMP	
2/2/04 4:33	SFWAC-SSCT2004-05	3.9	146	0.80	5.01	4.55	2.0	1.8	DIS	Censored
2/2/04 20:30	SFWAC-SSCT2004-06	3.1	3	0.90	7.74	7.04	0.07	0.06	DIS	
2/3/04 5:30	SFWAC-SSCT2004-07	6.9	10	1.10	15.2	13.8	0.40	0.36	DIS	
2/3/04 9:45	SFWAC-SSCT2004-08	13	35	1.21	20.5	18.6	1.9	1.8	DIS	
2/3/04 13:30	SFWAC-SSCT2004-09	11	16	1.29	24.9	22.6	1.1	0.96	DIS	
2/3/04 13:31	SFWAC-SSCT2004-10	11	18	1.30	25.5	23.2	0.82	0.74	PUMP	Calibrate w/ bottle # 1082
2/3/04 16:31	SFWAC-SSCT2004-11	10	13	1.29	24.9	22.6	0.55	0.50	PUMP	
2/3/04 18:31	SFWAC-SSCT2004-12	11	13	1.28	24.3	22.1	0.51	0.47	PUMP	
2/3/04 20:25	SFWAC-SSCT2004-13	12	13	1.29	24.9	22.6	0.88	0.80	DIS	
2/4/04 12:43	SFWAC-SSCT2004-14	7.2	5	1.18	19.0	17.3	0.27	0.25	DIS	
2/4/04 17:31	SFWAC-SSCT2004-15	5.5	7	1.14	17.1	15.5	0.15	0.14	PUMP	
2/5/04 21:46	SFWAC-SSCT2004-16	3.7	10	0.97	10.1	9.18	0.16	0.15	PUMP	
2/16/04 18:43	SFWAC-SSCT2004-17	7.4	7	1.06	13.5	12.3	0.25	0.23	DIS	
2/17/04 5:46	SFWAC-SSCT2004-18	8.6	18	1.36	29.1	26.5	0.93	0.84	PUMP	
2/17/04 7:16	SFWAC-SSCT2004-19	11	25	1.38	30.4	27.6	1.4	1.2	PUMP	
2/17/04 8:18	SFWAC-SSCT2004-20	13	16	1.36	29.1	26.5	1.2	1.1	DIS	
2/17/04 10:51	SFWAC-SSCT2004-21	17	39	1.50	38.6	35.1	4.1	3.7	DIS	
2/17/04 13:51	SFWAC-SSCT2004-22	22	54	1.68	52.8	48.0	7.6	7.0	DIS	
2/17/04 14:16	SFWAC-SSCT2004-23	19	54	1.67	52.0	47.3	5.4	4.9	PUMP	
2/17/04 14:46	SFWAC-SSCT2004-24	21	61	1.64	49.4	44.9	5.8	5.3	PUMP	
2/17/04 19:01	SFWAC-SSCT2004-25	21	40	1.62	47.8	43.5	3.6	3.3	PUMP	
2/17/04 19:15	SFWAC-SSCT2004-26	19	34	1.74	58.1	52.8	5.3	4.8	DIS	
2/17/04 23:31	SFWAC-SSCT2004-27	17	27	1.55	42.3	38.5	2.1	1.9	PUMP	
2/18/04 4:01	SFWAC-SSCT2004-28	15	22	1.55	42.3	38.5	1.6	1.5	PUMP	
2/18/04 6:31	SFWAC-SSCT2004-29	13	19	1.56	43.1	39.2	1.5	1.3	PUMP	
2/18/04 10:31	SFWAC-SSCT2004-30	11	12	1.54	41.5	37.7	0.81	0.73	PUMP	
2/18/04 11:01	SFWAC-SSCT2004-31	11	13	1.52	40.0	36.4	1.8	1.6	PUMP	
2/18/04 11:01	SFWAC-SSCT2004-32	10	17	1.52	40.0	36.4	0.90	0.81	DIS	Calibrate with 1804
2/18/04 14:32	SFWAC-SSCT2004-33	12	7	1.48	37.1	33.7	0.72	0.65	DIS	

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WY 2004 APPENDIX

B-8a

SEDIMENT SAMPLE SUMMARY SHEET

LOCATION: SOUTH FORK WAGES ABOVE CENTER GULCH **WATER YEAR: 2005**

Date Time	Sample Number	Turbidity (NTU)	SSC (mg/l)	Stage (ft)	Discharge (cfs)	Q/WSA (cfs/mi^2)	SSD (ton/day)	SSY (ton/day/mi2)	Type (DIS, PUMP)	Note
12/7/2004 10:16	SFWAC-SSCT2005-01	12	10	0.73	3.49	3.17	0.09	0.09	DIS	Calibration for SSCT2005-02
12/7/2004 10:16	SFWAC-SSCT2005-02	8.0	12	0.73	3.49	3.17	0.11	0.10	Pump	
12/7/2004 23:01	SFWAC-SSCT2005-03	8.1	14	0.74	3.73	3.39	0.14	0.13	Pump	
12/8/2004 00:16	SFWAC-SSCT2005-04	23	42	0.81	5.11	4.65	0.57	0.52	Pump	
12/8/2004 00:46	SFWAC-SSCT2005-05	33	75	0.89	7.30	6.64	1.5	1.3	Pump	
12/8/2004 02:16	SFWAC-SSCT2005-06	40	54	1.17	17.8	16.2	2.61	2.4	Pump	
12/8/2004 06:16	SFWAC-SSCT2005-07	55	90	1.66	47.8	43.5	12	11	Pump	
12/8/2004 08:01	SFWAC-SSCT2005-08	40	54	1.70	51.9	47.2	7.5	6.8	Pump	
12/8/2004 10:01	SFWAC-SSCT2005-09	29	253	1.57	41.5	37.7	28	26	Pump	Bottle overflowed, Censored
12/8/2004 10:03	SFWAC-SSCT2005-10	23	31	1.57	41.5	37.7	3.4	3.1	DIS	
12/8/2004 12:16	SFWAC-SSCT2005-11	30	2890	1.52	38.0	34.5	296	269	Pump	Bottle overflowed, Censored
12/8/2004 12:46	SFWAC-SSCT2005-12	26	21	1.49	35.8	32.5	2.0	1.9	Pump	
12/8/2004 15:01	SFWAC-SSCT2005-13	22	22	1.42	31.3	28.5	1.8	1.6	Pump	
12/8/2004 16:01	SFWAC-SSCT2005-14	21	11	1.42	31.1	28.3	0.96	0.87	Pump	
12/9/2004 05:16	SFWAC-SSCT2005-15	14	5	1.07	12.6	11.5	0.16	0.15	Pump	
12/9/2004 10:50	SFWAC-SSCT2005-16	12	3	0.98	9.38	8.53	0.07	0.07	DIS	
12/28/2004 11:36	SFWAC-SSCT2005-17	5.0	8	0.80	4.50	4.09	0.10	0.09	DIS	
1/10/2005 22:12	SFWAC-SSCT2005-18	2.7	3	0.89	6.94	6.31	0.06	0.05	DIS	
1/11/2005 11:31	SFWAC-SSCT2005-19	2.3	1	0.89	6.94	6.31	0.02	0.02	DIS	
2/22/2005 14:51	SFWAC-SSCT2005-20	2.7	5	0.87	6.84	6.22	0.08	0.08	DIS	
3/21/2005 18:42	SFWAC-SSCT2005-21	4.5	13	0.98	10.4	9.45	0.37	0.33	DIS	
3/22/2005 07:50	SFWAC-SSCT2005-22	3.4	3	0.98	10.4	9.45	0.08	0.07	DIS	
3/22/2005 16:31	SFWAC-SSCT2005-23	8.9	18	0.98	10.4	9.45	0.51	0.46	Pump	
3/28/2005 11:00	SFWAC-SSCT2005-24	4.7	6	1.08	12.5	11.4	0.19	0.17	Pump	
3/28/2005 11:20	SFWAC-SSCT2005-25	3.9	5	1.09	12.6	11.5	0.16	0.15	DIS	Calibration for SSCT2005-24
3/29/2005 08:01	SFWAC-SSCT2005-26	12	15	1.31	23.0	20.9	0.90	0.82	Pump	
4/9/2005 03:31	SFWAC-SSCT2005-27	8.8	12	1.35	25.6	23.3	0.85	0.77	Pump	
4/19/2005 12:31	SFWAC-SSCT2005-28	11	4560	0.73	4.30	3.91	52.8	48	Pump	sand, Bottle overflowed, Censored
4/19/2005 16:01	SFWAC-SSCT2005-29	29	844	0.73	4.24	3.85	9.7	8.8	Pump	sand, Bottle overflowed, Censored
4/19/2005 19:16	SFWAC-SSCT2005-30	21	20200	0.73	4.23	3.85	231	210	Pump	sand, Bottle overflowed, Censored
4/19/2005 20:16	SFWAC-SSCT2005-31	40	23400	0.72	4.21	3.83	265	241	Pump	sand, Bottle overflowed, Censored
5/18/2005 10:01	SFWAC-SSCT2005-32	10.6	1280	1.10	17.2	15.6	59	54	Pump	sand, Bottle overflowed, Censored
5/18/2005 12:54	SFWAC-SSCT2005-33	13.2	21	1.28	26.6	24.2	1.5	1.4	DIS	
5/18/2005 14:16	SFWAC-SSCT2005-34	14.1	29	1.33	29.6	26.9	2.3	2.1	Pump	
5/18/2005 14:22	SFWAC-SSCT2005-35	12.6	24	1.31	30.1	27.4	1.9	1.8	DIS	Calibration for SSCT2005-34
5/18/2005 17:01	SFWAC-SSCT2005-36	15.2	18	1.40	34.7	31.5	1.7	1.6	Pump	
5/18/2005 20:24	SFWAC-SSCT2005-37	9.8	10	1.37	32.9	29.9	0.87	0.79	DIS	
5/19/2005 08:10	SFWAC-SSCT2005-38	7.6	5	1.28	26.7	24.3	0.38	0.35	DIS	

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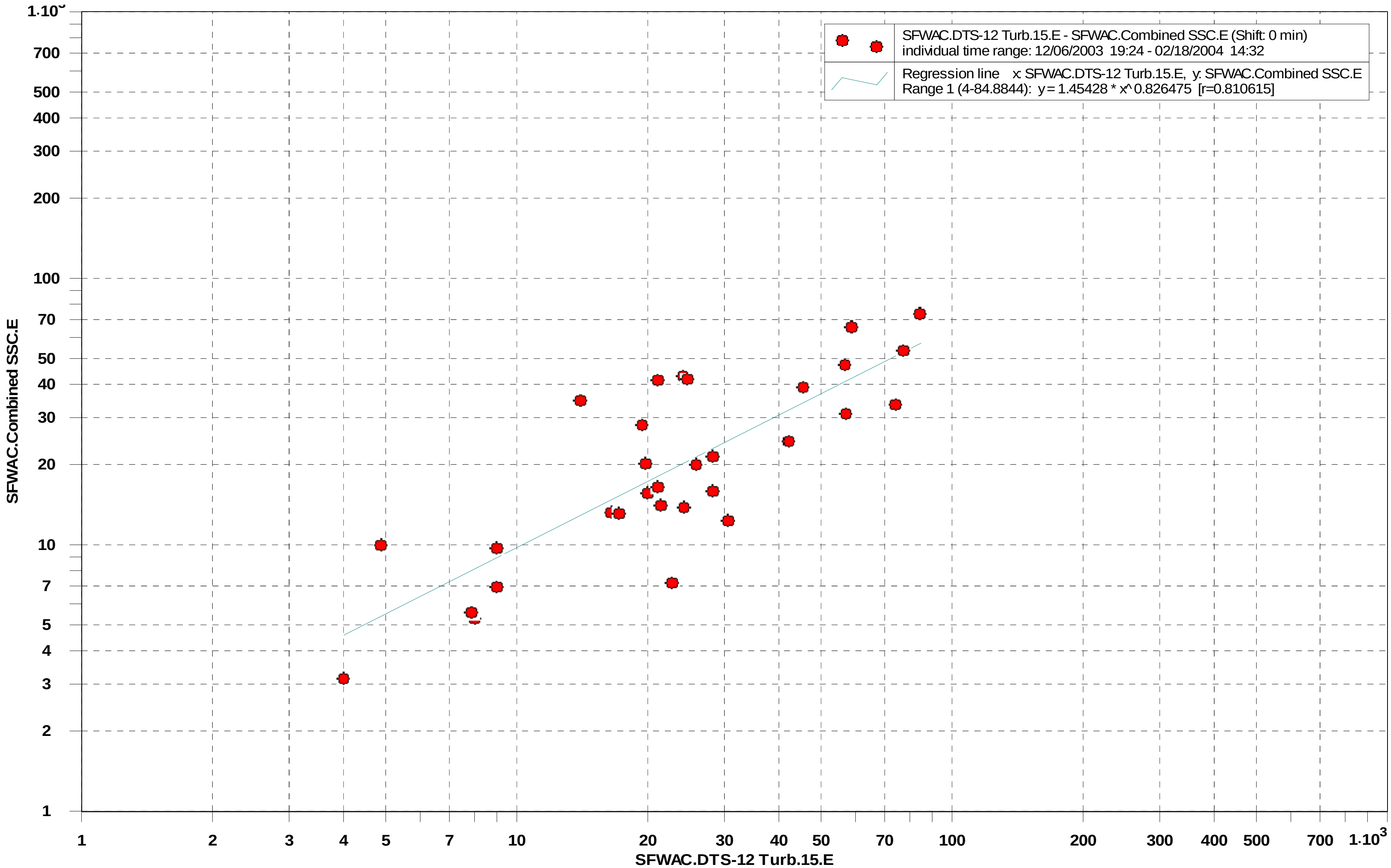
SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
DTS-12 Turbidity vs Depth-Integrated and Pump SSC



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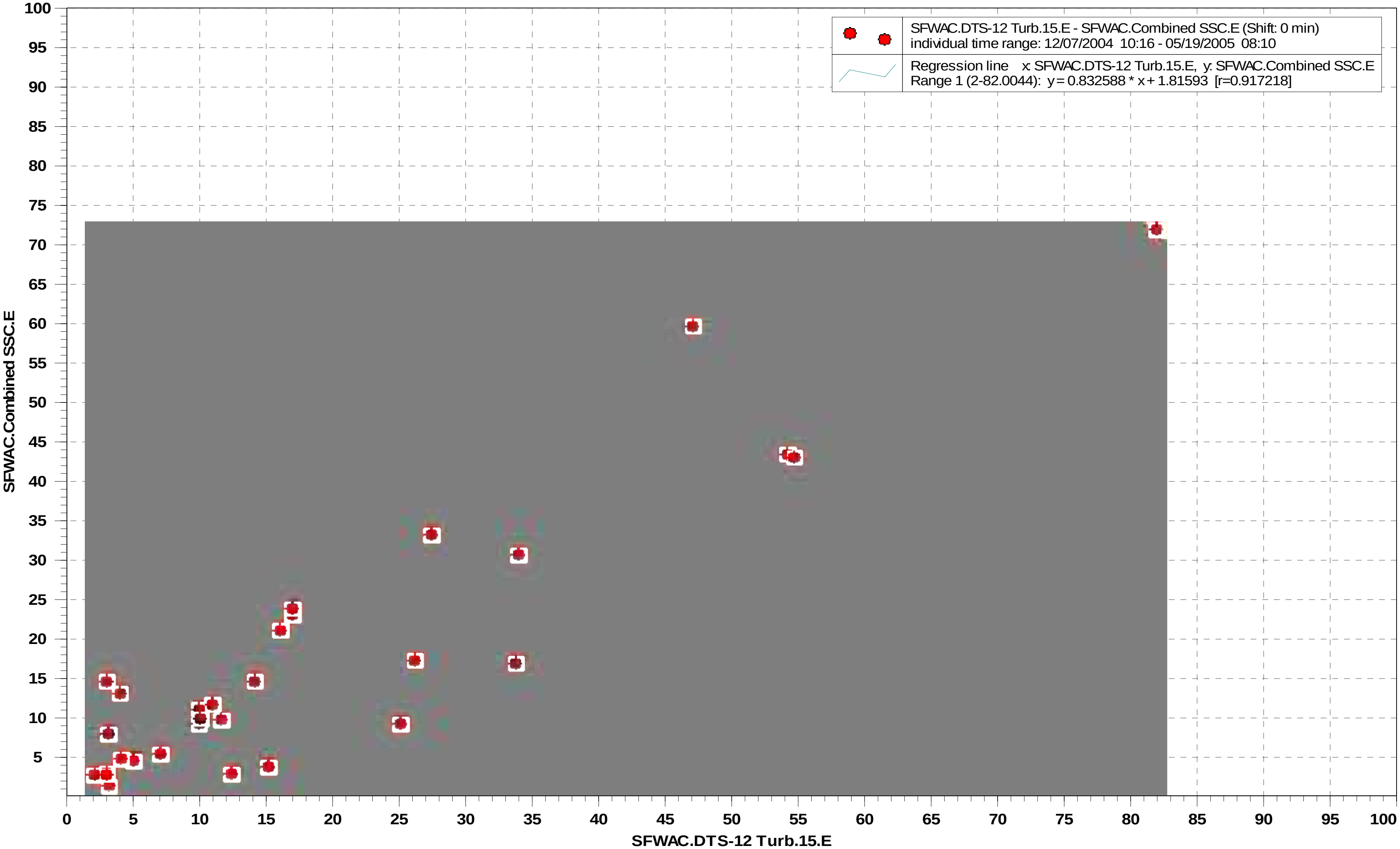
SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
DTS-12 Turbidity vs Depth-Integrated and Pump SSC



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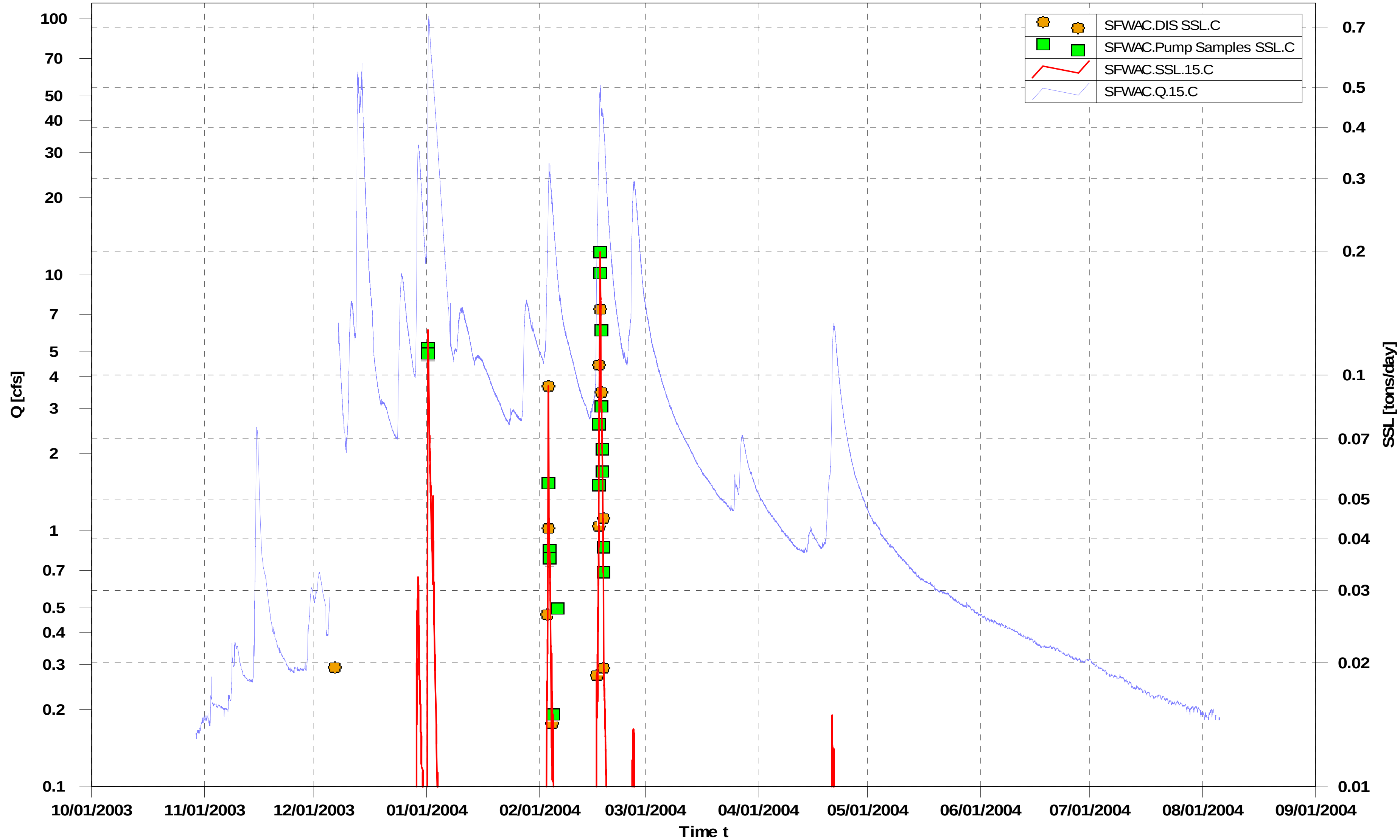
APPENDIX

B-9b

SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
Discharge versus Suspended Sediment Load



PROJECT:

SOUTH FORK WAGES CREEK
STREAMFLOW AND SEDIMENT TRANSPORT MONITORING

GMA
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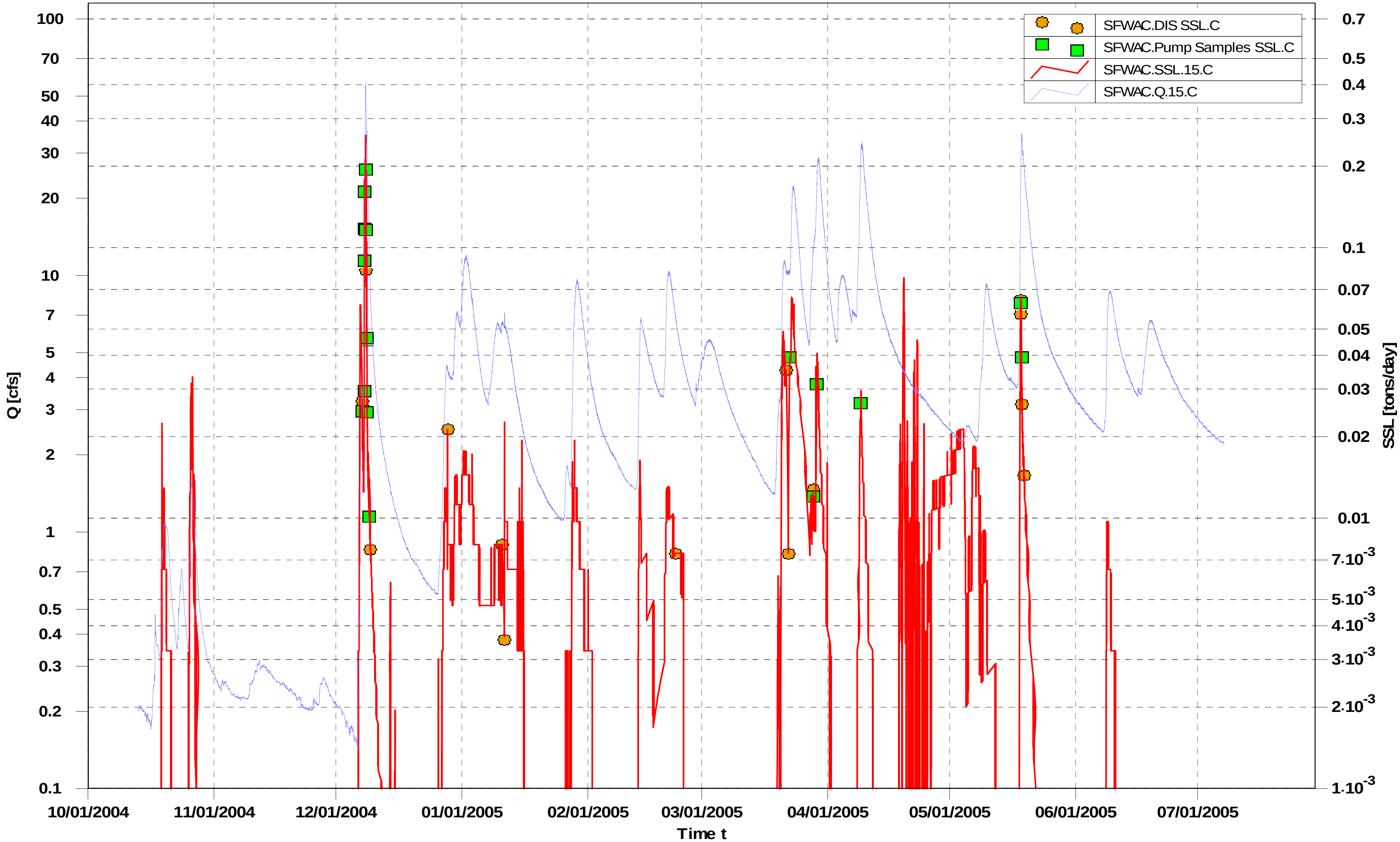
WY 2004
APPENDIX

B-10a

SOUTH FORK WAGES CREEK ABOVE CENTER GULCH
Discharge and Suspended Sediment Load



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