Comparing Erosion Risks from Forest Operations to Wildfire

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Abstract - Wildfire and forest operations remove vegetation and disturb forest soils. Both of these effects can lead to an increased risk of soil erosion. Operations to reduce forest fuel loads, however, may reduce the risk of wildfire. This paper presents research and modeling results which show that under many conditions, carefully planned operations with adequate buffers, results in lower long-term erosion rates than experienced following wildfire, which is inevitable if fuel loads are not reduced. The effects of reducing fire-induced flood flows on forest stream systems, however, are unknown.

Keywords. Soil Erosion, Forest operations, Forest fires, WEPP

INTRODUCTION

Forests provide numerous benefits for society, including fiber, wildlife, and recreation. Forest managers are challenged to balance ecosystem health and societal needs. During the first half of the last century, public forest management emphasized the harvesting of forest resources. In recent years, the emphasis in public forest management has been shifted to long-term sustainability.

Fuel management is another issue that has recently become important. During most of the last century, fire suppression and timber harvest were the main fuel management practices. This has resulted in forests with an oversupply of fuels and diseased trees, leading to an increased risk of severe wildfires (Duncan 2001). Both fires and timber harvest increase soil erosion and sediment delivery from forest hillslopes.

Soil erosion is one of the major concerns in current forest management. Soil erosion reduces upland forest productivity. Sediment from eroding hillslopes adversely affects water quality in forest streams, impacting the viability of aquatic ecosystems and numerous endangered aquatic species. Currently, managers are seeking to minimize erosion by applying improved management practices for forest operations and fuel management. One of the questions managers are seeking to answer is whether frequent forest operations cause more or less erosion than less frequent wildfires.

The purpose of this paper is to compare erosion rates following forest disturbances to erosion rates following wildfires.

FOREST EROSION PROCESSES

In forests, soil erosion occurs from disturbances such as forest roads, timber harvesting, or fire. These disturbances have major affects on both the vegetation and the soil properties. Soil erodibility depends on both the surface cover and the soil texture (Elliot and Hall 1997). The soil erodibility on a skid trail is greater than in the areas between skid trails, and the erodibility following a wildfire is much greater than in an undisturbed forest (Robichaud et al. 1993).

Fire is a natural part of healthy forest ecosystems. In the past century, fire supression has resulted in reduced forest health, and an increase in fuel loads. Some managers suggest that this has resulted in an increase in high severity wildfires (Duncan 2001).

After a fire or operation, forests are highly susceptible to erosion in the following year. They do, however, recover quickly as vegetation regrowth is rapid when smaller plants do not have to compete with trees for sunlight, nutrients, and water. For example, figure 1 shows the reduction in erosion rates following a wildfire in Eastern Oregon dropped about 90 percent the first year, with no erosion observed in year 4 on any of the slopes.

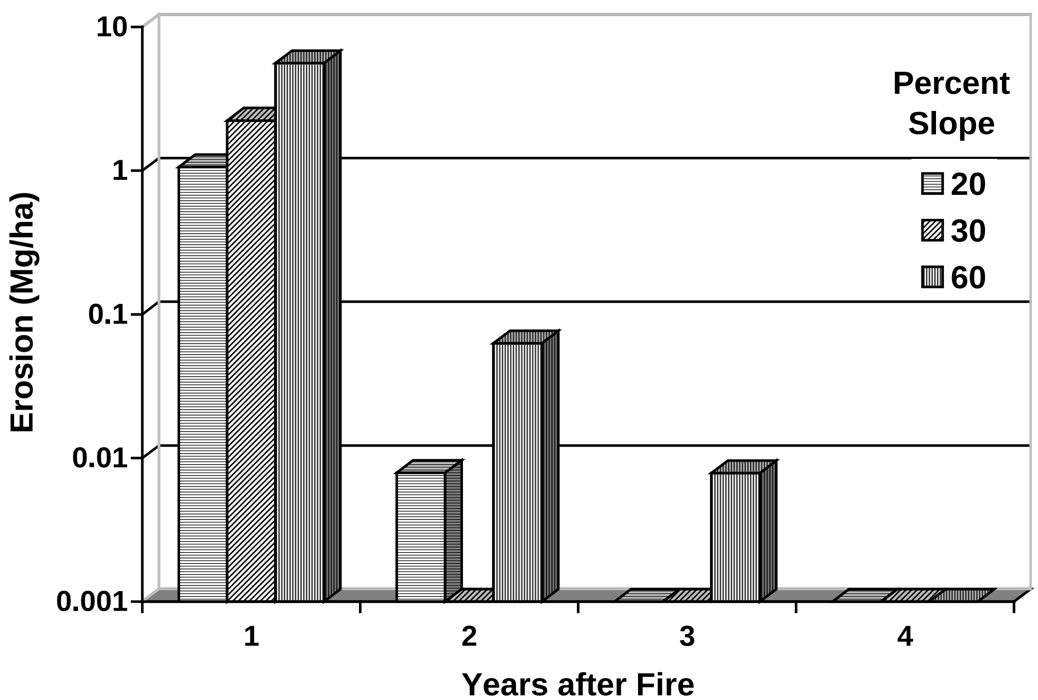


Figure 1. Erosion rates measured following a wildfire in Eastern Oregon. Note log scale on y-axis (Robichaud and Brown 1999).

Erosion in forests is highly variable, driven by a few extreme events each decade. Field data collected during years without events are likely to be well below "average" erosion rates, and data collected during a year with an event are likely to be well above the "average" rate.

Eroded sediments are frequently deposited in stream channels where they may remain for years to decades, slowly moving through the stream system in response to high runoff events (Trimble 1999). Thus, the scale at which sedimentation is measured becomes important. Smaller scales will show large variations in erosion rates as disturbed sites recover, whereas watershed scale observations will tend to reflect long-term trends in erosion rates, with large sedimentation events associated with infrequent watershed disturbances or flood events.

Managers and the public tend to focus on the erosion that may occur immediately following a disturbance, and fail to consider medium- or long-term impacts of short-term disturbances.

EROSION PREDICTION

Prediction of soil erosion by water is a common practice for natural resource managers for evaluating impacts of upland erosion on soil productivity and offsite water quality. Erosion prediction methods are used to evaluate different management practices and control techniques. One of the prediction tools recently developed is the Water Erosion Prediction Project (WEPP; Flanagan and Livingston 1995). WEPP is a physically-based soil erosion model, and is particularly suited to modeling the conditions common in forests. Forest templates were developed for the model (Elliot and Hall, 1997) and later, a user-friendly suite of Internet interfaces called FS-WEPP (Elliot et al. 2000). Included with these interfaces is a database of typical forest soil and vegetation conditions. These databases were populated with values determined from rainfall simulation and natural rainfall field research by scientists within our organization and elsewhere.

Cover is one of the most important factors in determining soil erosion rate. The WEPP model does not have a cover value for an input, but instead calculates the amount of cover each day as a function of vegetation growth and residue decomposition values in response to the climate.

In the WEPP model, the hillslope can have a complex shape, and can include numerous soils and vegetation types along the hillslope. Each unique combination of soil and vegetation is called an overland flow element (OFE) (Figure 2). This feature allows users to describe disturbed forest conditions with undisturbed forest buffers.

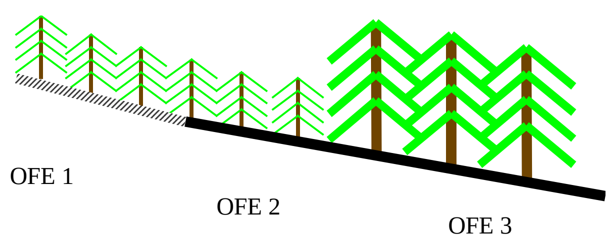


Figure 2. Overland flow elements (OFEs). OFE 1 has soil 1 and management 1, OFE 2 has soil 2 and management 1, and OFE 3 has soil 2 and management 2.

FS WEPP INTERFACES

Two Internet interfaces have been developed for WEPP for forest conditions (Elliot et al. 2000). One is for a number of road scenarios (WEPP:Road), and the other for disturbed forest conditions (Disturbed WEPP).

A complementary interface (Rock Clime) assists the user in selecting an appropriate climate from a large climate database, or to customize the mean monthly precipitation amounts, number of wet days per month, and monthly mean maximum and minimum temperatures (Scheele et al. 2001).

Disturbed WEPP. We are developing Disturbed WEPP for forest conditions including prescribed fires, wild fires, and young and mature forest. Disturbed WEPP currently allows two

OFEs (Figure 2) so that users can study numerous combinations of uphill and downhill disturbances, such as a harvest area above a buffer zone.

The user can select the climate and soil, the vegetation type and surface cover on the two OFEs, and the topography for each OFE. To aid users in ensuring the desired amount of cover, Disturbed WEPP allows the user to calibrate WEPP to achieve the desired cover on each OFE. The output presents the probability associated with years with exceptionally high runoff and erosion as well as a mean annual erosion rate that would occur in a year with an "average" climate.

A recent validation study (Elliot and Foltz 2001) found that when parameterized for forest conditions, the Disturbed WEPP model was able to predict soil erosion following prescribed and wildfire and disturbed forests (Tables 1 and 2).

VALIDATION RESULTS AND DISCUSSION

We have completed a number of studies on erosion following prescribed and wildfire, and have identified several studies of erosion following forest operations. For our validation, we used the Rock:Clime interface to describe a climate as close to the reported weather as we could. We used as much soil and topographic data as we could determine from each reference.

Erosion After Fire. Table 1 summarizes studies on hillslope erosion rates following fire. Elliot et al. (1996) reported an erosion rate between 0.5 and 1 Mg ha^{-1} following a prescribed fire in central Idaho. The site had experienced a low severity prescribed fire and had a skid trail at the bottom of the slope. It appeared that most of the sediment was generated from this short width of skid trail. The predicted values were similar to the observed.

On a prescribed fire study in Montana, Robichaud (1998) observed very low erosion rates the year following the prescribed fire, but a greater rate the second and third years. The first year (1995) was a year of low snowfall, likely the reason for the low erosion rate. The second year was a particularly wet year, resulting in increased erosion even though the vegetation had recovered. The third year, the effects of increased vegetation were apparent with the decreasing erosion rate. After specifying the cover for a different vegetation class and increased cover, Disturbed WEPP predicted values similar to the observed values in years 2 and 3.

The predicted erosion rates following wild fire reported in Robichaud and Brown (1999) were within the confidence limits of the field observations (Elliot and Foltz 2001). The reason that lower erosion rates were predicted on the 30 percent slope plots was that the plots were only half the length of the plots on the other treatments. A nearby climate station recorded below average precipitation for the first year of the study, which is likely the reason for the overprediction based on an "average" climate for the area. Although not shown in Table 1, the predictions in the years of recovery were similar to the observed values (figure 1) as well. Table 1 shows the predicted erosion rates for the wildfire in Robichaud (2000) were similar to the observed values.

Nonfire Erosion Rates. Disturbed WEPP is capable of modeling any natural vegetation condition if users select the appropriate input values for vegetation type and cover. Most publications present watershed erosion rates that include erosion from both roads and other forest disturbances. Table 2 provides three of these studies. Patric (1976) provided a literature review from eleven southeastern states. The range of predicted erosion rates for typical hillslope lengths and southeastern climates is similar to the observed erosion rates. Because much of

Patric's (1976) data came from watersheds where channel deposition may have been a factor, the higher predicted rates are to be expected.

Table 1. Comparison of observed erosion rates and predictions from the Disturbed WEPP interface following fire.

Reference	Comments	Observed Sediment (Mg ha^{-1})	WEPP prediction (Mg ha^{-1})	Comments for WEPP
Elliot et al. 1996	Payette NF. Harvested and Rx burned, skid trail at bottom, 45% slope	Estimated 0.5 to 1.0	1.2	Warren, ID climate, Tall grass on slope with skid trail at bottom
Robichaud, 1998	Bitterroot NF 50% slope, 70% cover Rx burn	0.004 yr 1, 0.04 yr 2, 0.03 yr 3	0.66 yr 1, 0.05 yr 2, 0.01 yr 3	Adjusted Stevensville, MT climate,
Robichaud and Brown, 1999	Twin Lakes in eastern OR, loam soil, 28% cover first year, 20, 30, and 60 % slopes	1.1 on 20% slope 2.2 on 30% 2.5 on 60%	1.6 on 20%, .82 on 30%, 4.01 on 60%	Adjusted Wallowa climate for elevation, 30% plots were half the slope length of other plots
Robichaud, 2000	Chelan WA, sandy loam, 40% high severity, Year 1 veg cover 50%, Year 2 veg cover 75%	0.75 to 1.1 0	0.76 to 1.5 0.01 to 0.02	60% slope, 50% cover

Rice (1979) presented a number of erosion rates for disturbed and regenerating watersheds in Northern California. His erosion rates included some landslide sediment and the movement of some sediment in the stream channel from earlier disturbances, so some of his observed values are greater than predicted values. Table 2 shows that the predicted erosion rates were similar to the erosion rates estimated by field observations during the first four years following the disturbance. The simulations showed that majority of this erosion occurred during the first two years following the disturbance, similar to the declining rates shown in figure 1 following wildfire.

Yoho (1980) reported watershed erosion rates from a number of studies. There were insufficient data to make detailed comparisons with reported values, but the predicted rates were of similar magnitudes to the values Yoho reported if we assumed "typical" topographic, climatic and disturbance values.

COMPARING MANAGEMENT STRATEGIES

We were sufficiently encouraged from these validation results to have the confidence to use the Disturbed WEPP interface to compare erosion rates following wildfire to rates following forest operations and prescribed fire. We considered two different ecosystems for this comparison as described in Table 3. The Montana conditions assumed a relatively dry forest with a 40-year fire cycle, and an 80-year harvest cycle, with 30 percent slopes and tractor logging. The Oregon conditions assumed a 200-year fire cycle, a 40-year harvest cycle, with 60 percent slopes and a cable logging system. The Disturbed WEPP interface has the ability to describe many other management scenarios, but we felt these two systems would demonstrate the utility of the prediction tool and the erosion risks associated with fuel management and harvest activities.

Table 2. Comparison of observed erosion rates and Disturbed WEPP predictions following forest operations or other vegetation conditions.

Reference	Comments	Observed Sediment (Mg ha^{-1})	WEPP prediction (Mg ha^{-1})	Comments for WEPP
Patric, 1976	Literature review of SE US forested areas	.01-.3	.03 - .62	Matched climate and disturbances for each study
Rice, 1979	Caspar Cr nr Ft Bragg, CA, Total erosion for 4 years	18 - 93	27 - 49	Adjusted for climate and cover during 4-yr recovery
Yoho, 1980	Lit review of practices in South	0.74 -17.6 annual burn,	3.7	Rx burn
	"Careless" clearcut:	3.03	0.93	Careless clearcut: 40% disturbance,
	"Careful" clearcut:	0.13 - 0.38	0.08	careful: 8%

Figure 3 shows the results of these simulations assuming an average climate. Figure 3a is for the wetter climate in the Oregon Cascade range, and figure 3b for the drier climate in the Bitterroot Mountains in Montana. There are several striking features on these two figures. On both graphs, the vertical axis is logarithmic. The erosion following wildfire is more than 2 magnitudes greater than before the fire, and more than a magnitude greater than following a major forest operation with a buffer. Also, the erosion rate in the Cascades is about two magnitudes greater than the erosion rate in the Bitterroots, even though the difference in precipitation is only about a factor of 2. The majority of the precipitation in the Bitterroots comes as snow, and snowmelt rates (typically 1 mm h^{-1}) are generally much lower than rainfall rates (typically up to 25 mm h^{-1}).

Figure 3a shows that if we assume that thinning exposes about 15 percent of the mineral soil on a site, then the erosion rate due to thinning is similar to the erosion rate due to harvesting. Figure 3b shows that the erosion rate following a prescribed fire, assuming a 15 percent mineral soil exposure, is similar to the erosion rate following a harvest operation.

Figure 3 shows the sediment yield values assuming that every year had average weather. The year following a fire or other disturbance may be wetter than normal, increasing sediment yields considerably, or may be drier than normal, so that sediment yields are low to none. Table 4 shows the probability that the sediment yield will be nonzero, the sediment yield for an average year's weather, and the sediment yield that may occur if the year following the disturbance is the wettest year in 5. There is a much greater likelihood that there will be sediment delivered in the Cascade scenario, and sediment delivery rates are much higher, as shown in figure 3. In both scenarios, there is a 20 percent chance that the sediment yield following wildfire will be 50 percent greater than the sediment yield in an average year.

Table 3. Assumptions for two example harvesting systems

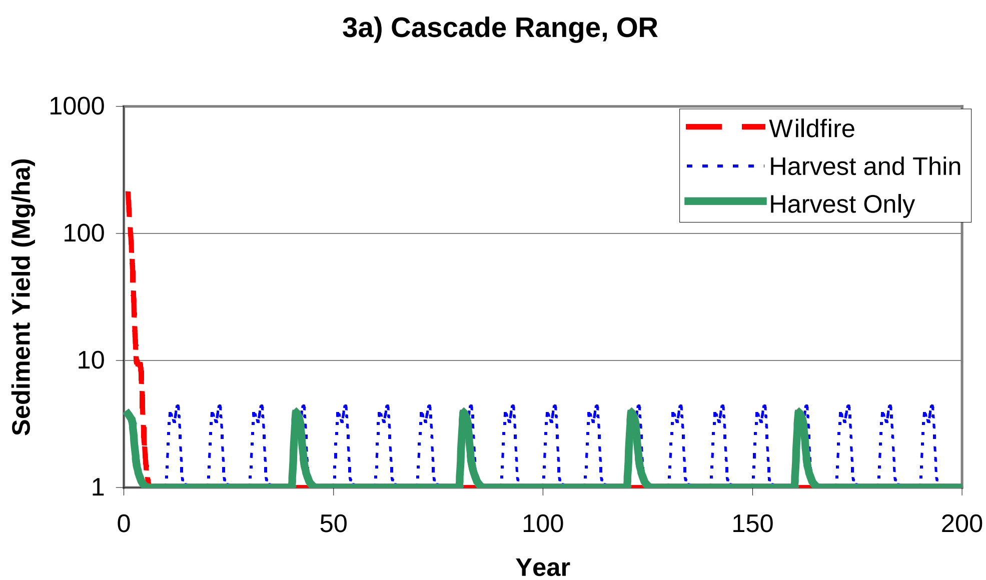
Site	Bitterroot Range, Montana	Cascade Range, Oregon
Annual precipitation (mm)	1548	2816
Wild fire cycle (yrs)	200	40
Thinning Cycle (yrs)	20	10
Prescribed fire cycle (yrs)	20	20
Harvest frequency (yrs)	80	40
Slope steepness (%)	60	30
Buffer width (m)	30	60
Harvesting system	Tractor	Skyline
Harvesting disturbance assumptions	85 % cover on harvested area in year 1, increasing to 100 percent in year 5	2-m wide skid trails every 24 m* up and down the slope. 85% total cover with bare skid trails in year 1, increasing to 100 percent in year 5.

* LeDoux and Butler 1981

In the Bitterroot Range, we predict that there is only an 8 percent chance that there will be any sediment yield in the year following a forest operation. The average sediment yield is greater than the 5-year sediment yield because the "average" value include the large rates predicted for very wet years, skewing the distribution of possible sediment yields. This means that if a study is set up to measure sediment yields following a forest operation, there is only an 8 percent chance that any sediment will be collected, and a 92 percent chance that there will be no observed sediment yield. In the wetter and steeper Cascade Range Scenario, there is an 80 percent chance that there will be sediment delivered across a buffer in the year following the disturbance.

DISCUSSION

Figure 3 and table 4 raise a number of issues for further discussion. Erosion from wildfire is a natural phenomena, which has driven the development forest ecosystems. High upland erosion rates and large sediment yields play an important role in shaping landscapes and introducing fresh material into our stream systems. In the last century, scientists found that fire was important for ecosystem health, and that fire exclusion resulted in a decline of the health of many forests. Will we find that the exclusion of wildfire and the large runoff and erosion events that follow will also lead to a decline in the health of our hydrologic and aquatic ecosystems? This question requires some significant interdisciplinary research to answer.



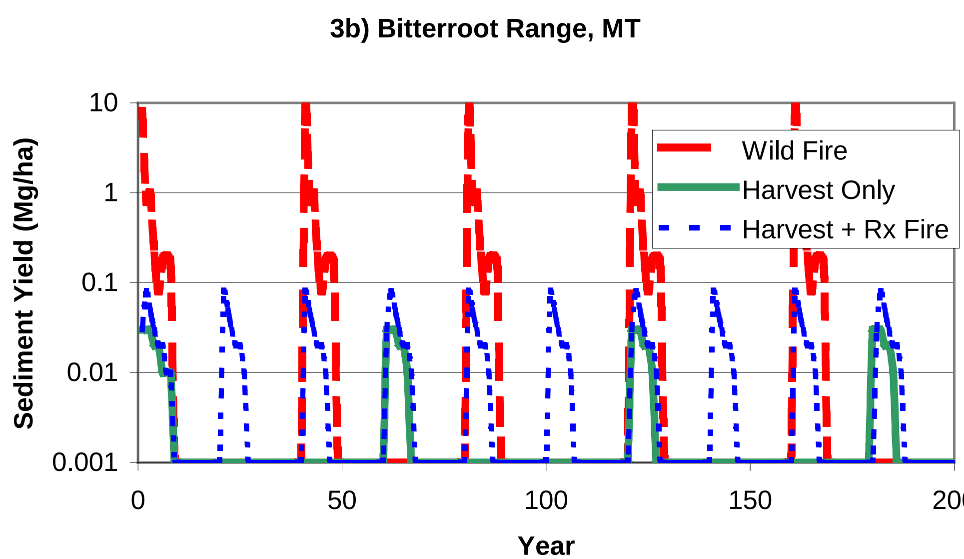


Figure 3. Hillslope sediment yield for an "average" weather pattern versus year for different management conditions for the two scenarios described in Table 3. Note the log scales on the vertical axes, and the difference in scales between the two graphs.

Forest roads contribute sediment to stream systems most years. Forest operations, as shown in figure 3, may contribute low levels of sediment to stream systems more frequently than the natural wildfire cycle. Sediments from both roads and operations are likely to be finer, and less likely to contribute to the cobbled stream beds that are preferred by many aquatic organisms. How important are large runoff events following fires for flushing these fine sediments through the stream system?

Table 4. Sediment yields the year following a disturbance if the first year has average weather, and if it experiences the most erosive year in 5.

	Bitterroot Range	Cascade Range
Precipitation (mm)		
Average	1548	2816
Greatest in 5 years	1702	3046
Sediment Yield first year after harvest (Mg ha^{-1})		
Probability > 0 (%)	8	80
Average	0.03	4.5
Greatest in 5 years	0.0	9.9
Sediment Yield first year after wildfire (Mg ha^{-1})		
Probability > 0 (%)	100	100
Average	8.1	203.6
Greatest in 5 years	12.6	339.8

Another issue arises in figure 3 and table 4 is about the validity of using an average erosion rate. Following a forest disturbance, the overwhelmingly greatest amount of sediment is delivered in the first year, and after several years, the delivery is near zero. The amount of sediment delivered is highly dependent on the climate that first year, as shown in table 4. Watershed managers require an understanding of risks associated with different levels of sediment yield. They must then use that understanding to develop management strategies. Currently, the Disturbed WEPP interface is the only technology that provides such an analysis. Technologies based on the Universal Soil Loss Equation with an average climate factor do not lend themselves to such an analysis.

Table 5 shows the sediment yield rates presented in table 4 and figure 3 averaged over the 200-year period. If a manager's goal is to simply reduce the sediment delivery to the stream systems, then the management strategies analyzed may achieve that goal. However, one must also include the erosion from roads, which was not included in this analysis, to estimate the total impact of management activities (Conroy 2001). As previously discussed, managers need to exercise caution when dealing with average values, as variability and outliers frequently dominate hydrologic processes.

SUMMARY

We have collected field data following both prescribed and wildfires and used that information to parameterize the WEPP model. We have shown that the Disturbed WEPP interface can predict erosion rates following forest disturbances. We then used the Disturbed WEPP interface to compare the sediment yields from forested hillslopes following wildfire to sediment yields from the same slopes following forest operations. Sediment yields following forest operations are much lower than following wildfire both the year following the disturbance, and when averaged over two centuries. We are not sure, however, if reducing the large sediment yields that follow wildfire will result in improved watershed health in the long term.

Table 5. Average annual erosion rates over 200 years for the scenarios presented in Table 3 and Figure 3.

	Average annual delivery rate during 200 years (Mg ha^{-1})	
	Bitterroot Range	Cascade Range
Wild fire	0.27	2.4
Harvest Only	0.003	1.15
Harvest with thinning	0.007	1.22
Harvest with prescribed fire	0.011	1.51

CONCLUSIONS

From our field work and our modeling results, we conclude the following:

- The Disturbed WEPP interface can predict sediment delivery following forest fires or other disturbances.
- Sediment delivery following forest operations and prescribed fire with forested buffers are a magnitude or more lower than following wildfire.
- The increased number of disturbances from active forest management result in lower long-term average sediment delivery rates than would occur following less frequent wildfire disturbances.
- Increased research is needed to determine the long term effects of forest operations on watershed health.

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