Oregon Department of Forestry
Wet Season Road Use Monitoring Project
Final Report

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Wet Season Road Use Monitoring Report

BACKGROUND

Policy Recommendation
As part of the Oregon Plan for Salmon and Watersheds, a Forest Practices Advisory Committee (FPAC) was assembled to evaluate current forest practices and to make recommendations where needed to improve salmon habitat protection. The FPAC made ten recommendations for improvement of forest road management practices, including one recommendation for road surfacing. Specifically, the recommendation was to address wet-weather hauling by the development of two approaches:
1. Ensure that durable surfacing is placed on road segments that can deliver sediment to streams; and
2. Require operators to cease heavy truck traffic on roads when the road surface is "breaking down" (only for segments that are delivering sediment to streams). "Breaking down" would be defined by both depth of ruts and by depth of muddy fine sediment on the road.

This monitoring project was designed to better understand the wet season road use problem as it varies across forestlands in western Oregon. It was designed to help craft new Forest Practices rule language and the technical guidance for implementation of this new rule.

Objectives
This monitoring study was designed to identify factors that contribute to stream turbidity when forest roads are actively used during wet periods. Specifically, data were collected and analyzed to answer the following questions:
1. What are the rainfall conditions that result in road runoff entering streams and increasing turbidity?
2. How does road-surface aggregate (rock) depth, fines content, and durability affect stream turbidity?
3. How does road segment length draining to streams affect turbidity?
4. How does turbidity vary between no use, moderate use (under 10 trucks per day), and heavy use (10 or more trucks per day)?
5. How does wet season road use-associated turbidity change in a downstream direction?
6. How road-associated turbidity in small streams affect turbidity in larger streams?

Literature Review
The use of gravel-surfaced roads during wet periods has been documented as a major source of fine-grained sediment and associated stream turbidity (Reid and Dunne, 1984). A number of research and monitoring studies have investigated this issue. Forest practices designed to reduce road-associated sediment delivery to streams have also changed over the last 30 years.

Reid and Dunne (1984) conducted the first detailed study of wet season road use. They investigated delivery of fine sediment to streams from a road located in the Olympic peninsula of Washington and managed by the state. Surfacing material was crushed sandstone rock, which is generally considered a low durability material in the Pacific Northwest. One practice used at the time of this study is described as follows: "Ditches are usually cleaned out during road maintenance operations, with ditch material being spread out onto the road surface." This study found that a heavily used road segment on their study site contributed a sediment yield of up to 500 metric tons per kilometer per year, approximately 130 times as much sediment as an abandoned road.

Researchers working for Weyerhaeuser Company conducted a number of studies on road use, road maintenance, and sediment routing to and through streams (Bilby, 1985; Duncan and Ward, 1985; Bilby and others, 1989). These studies were conducted after Reid and Dunne (1984), also in Washington state. Road management practices included using crushed andesite (generally considered a durable surfacing material) on the mainline roads, and pit run marine basalt (less durable) on the secondary roads.

The Weyerhaeuser studies found a good correlation between rock hardness and sediment delivery. They also found that most of the sediment delivered to streams from the road surface was very fine (clay-sized particles). Thirty-four percent of the road segments drained to streams, with 66 percent draining to the forest floor. The wet season sediment yield was 26 metric tons per kilometer per year for the mainline road, and 10 metric tons per kilometer per year for the secondary road. For a typical site delivering sediment to streams, peak turbidity below the road was 110 nephelometric turbidity units (NTUs) while peak turbidity above the road was 40 NTUs. There were 46 instances where downstream turbidity was at least 3 NTUs above upstream turbidity (Bilby, 1985). Duncan and others (1987) found that less than 45 percent of fine sediment delivered to small streams during normal winter flows is transported to larger streams.

In the early 1990s, the USDA Forest Service conducted a number of studies of road surfacing quality, tire pressure, and sediment production (Folz, 1996). These studies were conducted in the Willamette National Forest near Eugene. (Folz, 1996) found that sediment production from marginal quality aggregate was four to seventeen times greater than sediment production from high quality aggregate surfacing, and also found log truck traffic increased sediment production between two to twenty-five times more than produced from roads with no heavy traffic.

Monitoring conducted in the mid-1990s shows that about one-third (29-39 percent) of active and inactive roads on state and private lands can deliver sediment to streams by ditch delivery (Skaugset and Allen, 1998; ODF, 1996). For the portions of the road network where sediment delivery is occurring, three major issues were identified:

1. There is a general lack of filtering of drainage waters near streams. A number of cases were observed where cross drainage structures were not in place to filter road runoff before the runoff reached stream crossings.
2. Steep-gradient roads tend to have cross drainage structures at wider spacing than lower-gradient roads. Under the current rules, road design and maintenance practices should result in steep-gradient roads having cross drainage structures with narrower spacing relative to lower-gradient roads.

3. There are inconsistencies in drainage practices between georegions, with special concerns in the Siskiyou georegion.

In summary, the literature shows that wet season road use can be a major source of fine sediment. It also shows that road surfacing and drainage practices have a very large effect on the delivery of sediment to streams. The following study focuses on these known effects and further identifies how turbidity from wet weather hauling can be minimized.

Monitoring Period Winter Conditions

Two winter seasons were monitored for this study: November 2000 to April 2001 (2001 winter) and November 2001 – April 2002 (2002 winter). The 2001 winter was unusually dry and many locations in Oregon were officially declared to be in drought conditions, while the 2002 winter represents average rainfall conditions. The average total precipitation for 18 western Oregon rain gauges was 18.5 inches for the period of November 1, 2000 to February 24, 2001. In contrast, the 2002 winter represents an average rainfall year. During the same time period, the average total precipitation was 46.6 inches for the same 18 rain gauges. The 2001 winter had only two days in which slightly more than 3 total inches of precipitation fell in the five days previous to storms. In contrast, the 2002 winter had 35 days with 3-6 total inches of precipitation in the five days previous to storms.

The contrasting weather conditions of the two winters allow for interesting comparisons of turbidity trends between years. There were no major deep freezing periods or subsequent rapid thawing periods during this study, so it was not possible to evaluate turbidity increases when roads are used during severe thawing periods.

METHODS

Site Selection

Study sites were focused segments of forest roads that were being used to transport logs (haul routes) during the monitoring period. These roads were on private industrial and state-managed forestlands. All roads were gravel-surfaced roads, and included both main haul roads and secondary roads accessing individual forest operations.

Based on information provided by forest landowners, specific study sites were selected in western Oregon on state and private forestlands. The low elevation areas were intentionally selected to minimize the likelihood that monitoring sites would be covered by snow or frozen for extended periods of time. Therefore the road segments were more likely to be affected by the combination of rainfall and road use. Individual landowners were asked for information on their road use plans, and these plans were reviewed with cooperating landowners using the following site selection criteria:

1. Only roads with active winter timber hauling
2. Landowners would provide some information on rock surface layer (source and quality) and winter hauling schedule for these roads
3. Roads cross small streams that flow all winter (data collection locations)
4. Sites reasonably close to survey personnel (Salem and Philomath) with an exception for roads in the Tyee Core Area (an area with a very limited supply of durable surfacing nearby)

5. There is a downstream confluence of larger fish-bearing streams near at least some of the selected roads

Study Sites

A total of 24 haul routes and 133 stream crossings were surveyed in the 2001 season. An additional eight haul routes and 41 stream crossings were surveyed in the 2002 season (Table 1). The data collected at these locations during each of these seasons is briefly described below and in more detail in Appendix A.

Table 1. Data collected in each of the two seasons.

Monitoring Element	Monitoring Period	
	2001	2002
Haul Routes	24	8
Crossings	133	41
Turbidity Pairs[1]	356	115
Pairs with Low, Medium, High Traffic[2]	-	46, 18, 17
Downstream Samples	-	138
ISCO® Samples Continuously Collected	-	155

[1]Consists of a sample each from above and below a crossing

[2]Low = 0 - 2 trucks/day, Medium = 3 - 9, High = > 10

Season One Data Collection: Winter 2001

The first winter data collection season (2001) focused on the immediate road's influence on the turbidity of small streams where they are crossed by the road. These data were used to identify road surfacing, drainage, traffic, or precipitation factors related to observed increases in turbidity.

At each road segment, the field crew measured a number of parameters to describe the road, road surface, and road drainage patterns. These parameters included: the road segment length draining to streams; the average grade of these road segments; ditch length (the length of road-side ditch without any filtering or buffering mechanisms and draining directly to the stream). The road surfacing was also evaluated, typically within 100 feet from the stream crossing. This evaluation included a description of the surface drainage paths, depth of the surfacing, and collection of a large sample of surfacing material.

Field personnel visited field sites throughout the 2001 winter season on days with the greatest precipitation. They made a number of additional measurements during these visits, including log truck traffic level, condition of the road surfacing (measuring ruts and mud depth), recent maintenance activity, and sources of sediment delivery to streams other than the road surfacing. Precipitation data for each site was compiled from the nearest available weather station. An attempt was made to measure streamflow. However, due to data quality concerns, streamflow data were not used in the analysis. The contribution of ditchflow to the stream was categorically and visually estimated as a percent of streamflow.

Two water samples were collected from the stream at each crossing. One sample was collected above the influence of the road and the second sample was collected below the influence of the road. The influence of the road included crossing fill or road drainage features. Turbidity levels of these samples were measured using a nephelometer. The difference in turbidity between the two samples (turbidity pairs, Table 1) was considered to be the influence of road-use and road-related factors.

Season Two Data Collection
Because data collection during the first winter season was limited in scope and by an exceptionally dry winter, a second season of data collection was added. For this second season (2002), data collection was conducted to assess changes in stream turbidity at road crossings over time, changes in stream turbidity moving downstream from road crossings, and influences of stream turbidity on turbidity of larger fish-bearing (Type F) streams that these sampled streams flowed into.

Along with the data described for the 2001 season, additional water samples were collected to address these issues. "Downstream Samples" (Table 1) consisted of samples collected at 200-foot increments downstream of road crossings, samples collected from Type F streams above and below the mouth of these crossed streams, and samples collected from Type F streams above and below the entire haul route.

Rock aggregate testing was conducted on samples from the stockpiles used on the roads where turbidity sampling occurred. The Oregon Department of Transportation (ODOT) materials lab conducted three tests: particle size gradation; sand equivalent; and Los Angeles abrasion on aggregate samples. These tests are used to determine the relative composition of fines in the aggregate and durability of the aggregate. Some of these tests are also commonly used by industrial landowners to determine suitability for road surfacing; others are more commonly used on public roads.

Quality Assurance and Control
A data quality assurance plan was implemented to ensure the accuracy of the turbidity measurements. However, adequate tests of measurement error were not conducted. Therefore, measurement error is assumed as described below.

Calibration: The nephelometer was calibrated at the factory.

Accuracy Check: The accuracy of the nephelometer was checked prior to each analysis session following procedures and tools provided by the manufacturer.

Measurement Error: In general, turbidity sampling assumes the sediment particles being sampled are evenly distributed throughout the water column. However, because water-borne particles other than sediment affect turbidity, readings can vary depending on where in the water column the sample is collected. One way of evaluating this potential measurement error is to collect duplicate samples. This was not done for this project, so potential variability due to sample method cannot be quantified. Other turbidity monitoring projects indicate the typical variability in duplicate samples depends in part on background turbidity levels, and varies from 2 – 10 NTUs. For the purposes of this study, changes in turbidity between the range of 2 and 10 NTUs were not attributed entirely to truck traffic.

LIMITATIONS AND STRENGTHS OF THE STUDY

A random sampling design was not used to select the monitoring sites. Instead, roads were selected that were anticipated to have traffic during the wettest part of the season, and that crossed small streams. Additionally, water samples were collected during periods of heavy rainfall to increase the likelihood of observing increased turbidities. This design maximized the likelihood of observing increased turbidity as a result of hauling. During the second monitoring season, sites were added to further explore the influence of road-surface aggregate quality and quantity as well as downstream transport of road-related turbidity. Therefore, turbidity levels observed in this study can not be used to characterize an average water quality condition that results from wet-weather hauling in western Oregon, nor can the results be used to quantify the degree to which forest roads and road use contribute to stream turbidity statewide or year-round.

The strength of this study is the direct link with policy issues and road maintenance practices. The protocols were designed to collect data under conditions, locations, use, and timing that would provide the greatest insight into the factors that affect stream turbidity during wet season road use. Laboratory analyses of surface aggregate quality are used by private landowners, thereby increasing the operational applicability of results.

RESULTS

Data were collected over two winters, first from November 2000 to March 2001 (2001 monitoring period) and second from November 2001 to April 2002 (2002 monitoring period). The first winter was exceptionally dry, so results from that winter need to be evaluated with care. A total of 27 haul routes were sampled for this project in western Oregon over the two winter study periods (some routes sampled both years). Approximately 1600 stream turbidity samples were collected adjacent to these sites. The resulting data set was analyzed for two purposes: 1) identify forest road and use factors that can be related to increased turbidity in tributary streams crossed by roads; and 2) a synoptic evaluation of elevated turbidity effects downstream and on the larger streams. Results for these areas are reported in two sections below.

ROAD AND ROAD USE FACTORS THAT RELATE TO STREAM TURBIDITY INCREASES

The observed changes in turbidity included decreases, increases and no changes in turbidity that could be attributable to road use during wet weather. The following sections describe the observed changes in turbidity and which factors can be most clearly linked with roads and road use.

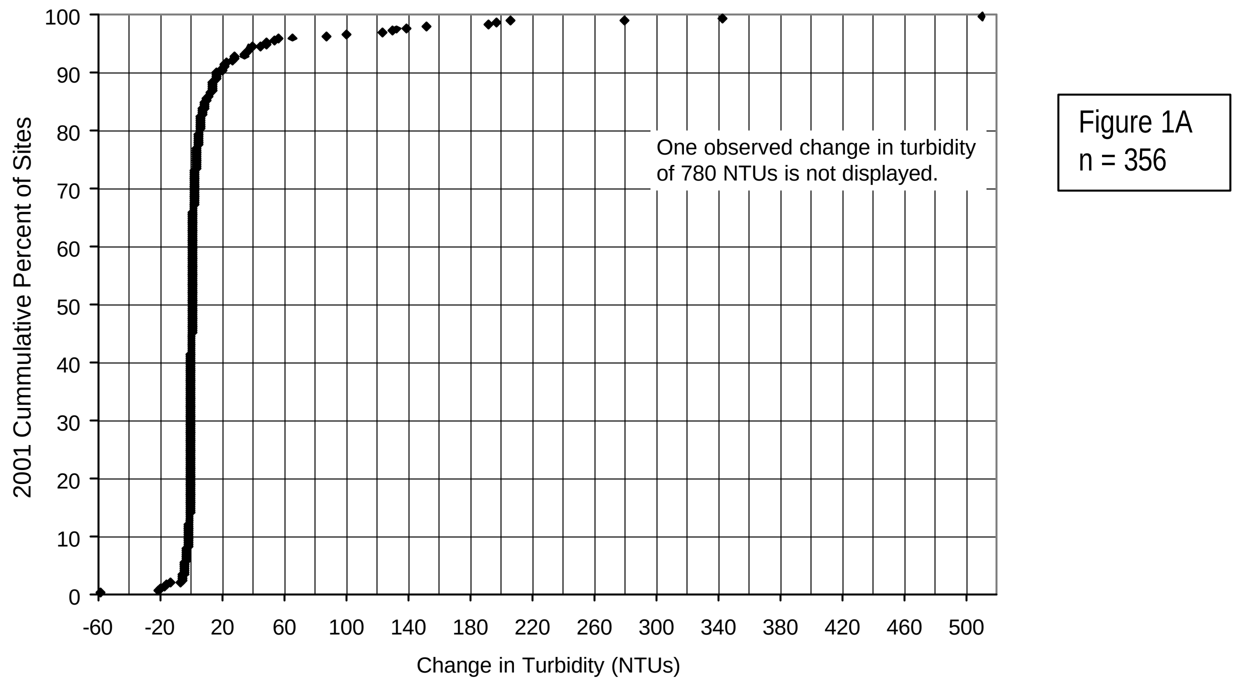
Observed Changes in Turbidity

The “change in turbidity” is defined as the difference in nephelometric turbidity units (NTUs) between a sample taken below all road and crossing influences and a sample taken above all road-crossing influences.

The distribution of 2001 and 2002 stream turbidity changes demonstrates a wide range of observations associated with both sampling periods and remarkably similar distributions (Figure 1A and 1B. For the 356 crossing samples conducted in the 2001 season, the change in turbidity averaged 12.5 NTUs. However, the median change in turbidity was only 0.6 NTUs, with values ranging from –58.3 to 780.6 NTUs. Twenty-eight percent of the crossing samples actually had a decrease in turbidity, 2% had no change, and 70% had an increase in turbidity. A change of 20 NTUs or less was observed on 90% of the sample pairs. The remainder of the observations ranged from an increase in turbidity of 20 to 520 NTUs. For 82 crossing samples conducted in the 2002 season, the change in turbidity averaged 9.8 NTUs. However, the median change in turbidity was only 2.5 NTUs, with values ranging from –11.5 to 171 NTUs. Eighteen percent of the crossing samples actually had a decrease in turbidity, 6% had no change, and 66% had an increase in turbidity. A change of 20 NTUs or less was observed on 89% of the sample pairs. The remainder of the observations ranged from an increase in turbidity of 20 to 171 NTUs.

As described in the quality assurance and control section of this paper, effects of wet weather hauling on changes in turbidity less than 10 NTUs, (either increases or decreases) cannot be distinguished from measurement error. The cause of decreased turbidity greater than 10 NTUs below a crossing was impossible to determine with these data and could only be theorized. It may be attributed to settling of materials between the two sampling points or poor mixing of suspended material throughout the sample reach. Increased turbidity greater than 10 NTUs below a crossing were attributed to road contribution and re-suspension of settled materials between the two sampling points.

The average change in turbidity was graphed versus each of the measured parameters (Appendix B). From this analysis, six factors showed potential to influence changes in turbidity associated with wet weather hauling. They were precipitation, depth of surfacing material, percent fines in surfacing material, durability of surfacing material, length of road ditch draining directly to stream, and traffic levels. Each of these factors is discussed individually in appendix B. In general, as precipitation, percent fines in surface material, ditch length, and traffic increased, road-associated turbidity increased. As depth and durability of surface material increased, road-associated turbidity decreased. However, due to the wide range in observed turbidity changes (-58 to 780 NTUs), and the skewed distribution (Figure 1), an analysis of averages may not be appropriate and is not statistically meaningful. Additionally, while the process of artificially isolating individual parameters may be conceptually helpful, it is important to recognize that stream turbidity is a function of multiple factors occurring simultaneously. Therefore the data were analyzed using stepwise multiple linear regression.



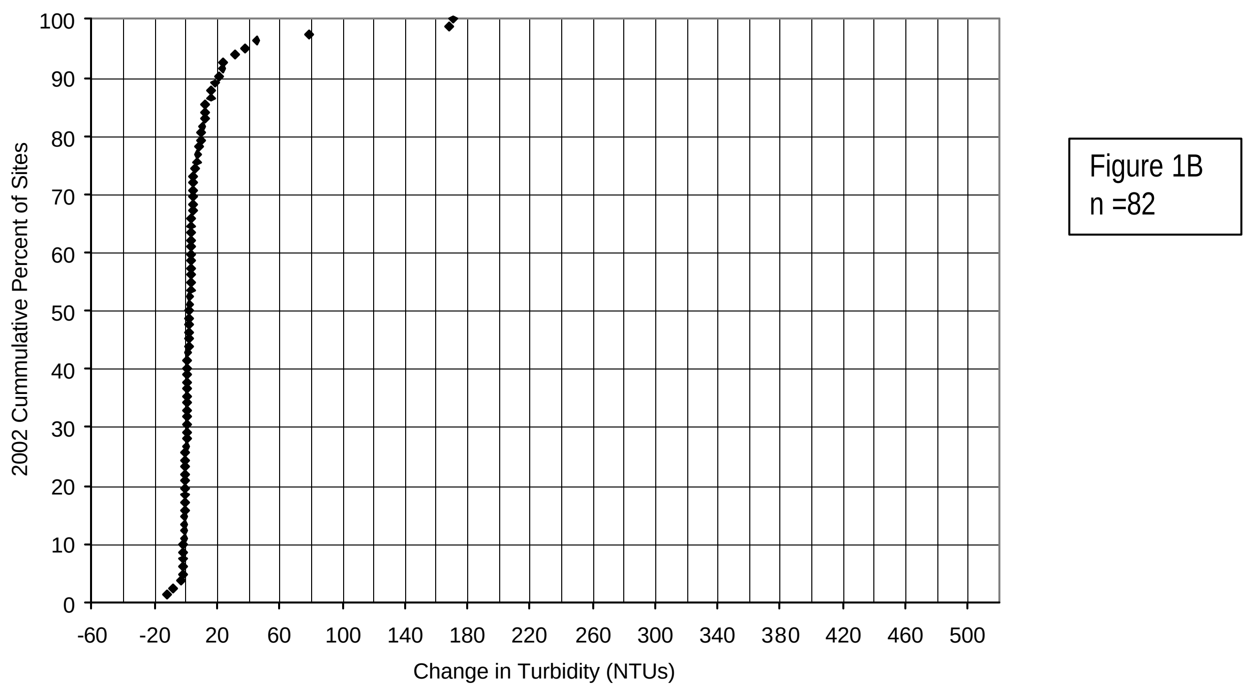


Figure 1A and 1B. Distribution of turbidity changes for 2001 (A) and 2002 (B) crossing samples. The change in turbidity is the difference in turbidity between upstream of all stream crossing influences and downstream of all stream crossing influences.

Factors that relate to observed increases in turbidity: Multiple Linear Regression

A multiple linear regression model assumes data are normally distributed and errors have constant variance. The 2001 and 2002 turbidity pairs (difference between upstream and downstream turbidity) were log-transformed to produce normal distributions. Log transformations cannot be applied to observed decreases in turbidity (negative numbers) or observations of no change in turbidity (zero). Thirty percent and 24% of the observations in 2001 and 2002, respectively, showed either a decrease in turbidity or no change in turbidity downstream of the road crossing and could not be included in the following analyses. Therefore the results of these analyses focus on observed *increases* in turbidity rather than observed *changes* in turbidity. The two data sets met the requirement of constant variance.

2001 MULTIPLE LINEAR REGRESSION MODEL

The 2001 Log-transformed turbidity increases (logNTU) were modeled as a function of the following variables:

- 3-day total precipitation (PPT)
- categorical ditch length draining to crossing (DITCHCLASS)
- combined length of road draining to crossing from both directions (ROADSEG)
- depth of road surfacing material at crossing (SURFACING)
- percent of surfacing material sample smaller than 0.5 mm (SEIVE #35)
- percent of surfacing material sample smaller than 0.15 mm (SEIVE #100)

The above variables with less than a 90% probability of influencing the logNTU were stepped (removed) from the model. The resulting model suggests that 3-day total precipitation (p-value <.001) and categorical ditch length draining to crossing (p-value = 0.019) each have a positive influence on observed increases in turbidity (N = 52, R-square = 0.66). The following model is proposed:

$$LogNTU = -3.474 + 5.9(precipitation) + 0.494(ditch\ length).$$

The model is highly significant (p<.001) and suggests that as 3-day precipitation and length of ditch draining to the stream increase, observed increases in turbidity from wet weather hauling will also increase.

2002 MULTIPLE LINEAR REGRESSION MODEL

The 2002 log-transformed turbidity increases (logNTU) were modeled as a function of the following variables:

- 3-day antecedent precipitation (PPT)
- log trucks over crossing on day of sample (TRUCKS)
- percent of surfacing material sample smaller than .425 mm (SEIVE #40)
- percent of surfacing material sample smaller than a .075 mm (SEIVE #200)
- LA abrasion results
- Sand Equivalent results

The road variables (percent fines, LA Abrasion, and sand equivalent) were modeled separately because these factors are not independent of each other. The variables with less than a 90% probability of influencing the logNTU were stepped (removed) from the model. The resulting model (n = 35, and R-squared = 0.29) suggests that the percent fines in the surfacing aggregate (p-value

=0.07) has a positive influence on turbidity increases at stream crossings. Surprisingly, 3-day antecedent precipitation has a negative influence on turbidity (p=value = 0.08). The following model is proposed:

$$\text{LogNTU} = -0.34 - 0.22(\text{3-day ppt}) + 0.23\ (\text{sieve \#200})$$

While the R-squared is very low, the model is highly significant (p-value = 0.005) and suggests that as the percent fines in the road surface aggregate increases the observed increases in turbidity increase. However, as precipitation increased the observed increases in turbidity decreased.

Overall, the 2001 and 2002 multiple linear regression results suggest that as both ditch length and percent fines in the surface aggregate increase, turbidity increases associated with wet weather road use will be elevated. The relationship between precipitation and turbidity was more complicated and is explored below.

Precipitation and Turbidity

The precipitation variable used for the above analyses is the amount of precipitation each site received in the three-day period prior to sampling (antecedent rainfall). The 2001 regression model suggests that turbidity from wet weather hauling increased as the antecedent rainfall increased. While the 2002 regression model results suggest the opposite. A possible reason for contradictory results attributed to a wetter year in 2002 that afforded more sampling across a broad range of heavier rainfall events. An evaluation of antecedent rainfall suggests that once the antecedent rainfall topped 1.5 inches, turbidity from wet weather hauling declined (Table 2 and Figure 2). The broader range of heavy rainfall, combined with a decline in turbidity changes during heavier rainfall events, explains the negative relationship in the 2002 regression model. The trend was further explored through t-tests of the differences between average LogNTUs associated with different antecedent rainfall levels.

For both years, an analysis of average LogNTU indicated that increases in turbidity were highest with moderate antecedent rainfall (1.0 –1.5 inches). Alternatively, there was no difference in turbidity increases between the heaviest and lowest antecedent rainfall events (Table 2). Specifically, in 2001 the greatest average increases in turbidity (LogNTUs = 3.50) were observed with moderate antecedent rainfall events of 1.0 – 1.5 inches. The average increases in turbidity were lowest with lower rainfall events of 0.5 - 1.0 (LogNTU = 0.96) ***and*** with heavier rainfall events greater than 1.5 inches (LogNTU = -0.640) (Table 2 and Figure 2).

Table 2. Statistically different average LogNTUs for three-day precipitation rainfall events.

Study Year	Log NTU for each Precipitation Class			
	0.05 – 1.0 inches	1.0 – 1.5 inches	1.5 – 3.0 inches	> 3.0 inches
2001	0.96 ↔	3.50 ↔	- 0.64	No observations
2002	0.52 ↔	2.04 ←	*NSS	→ 0.85

↔ = Statistically significant differences.

*NSS = No statistical differences between average Log NTU in the range of 1.5 inches to 3.0 inches of rainfall and other precipitation classes in 2002.

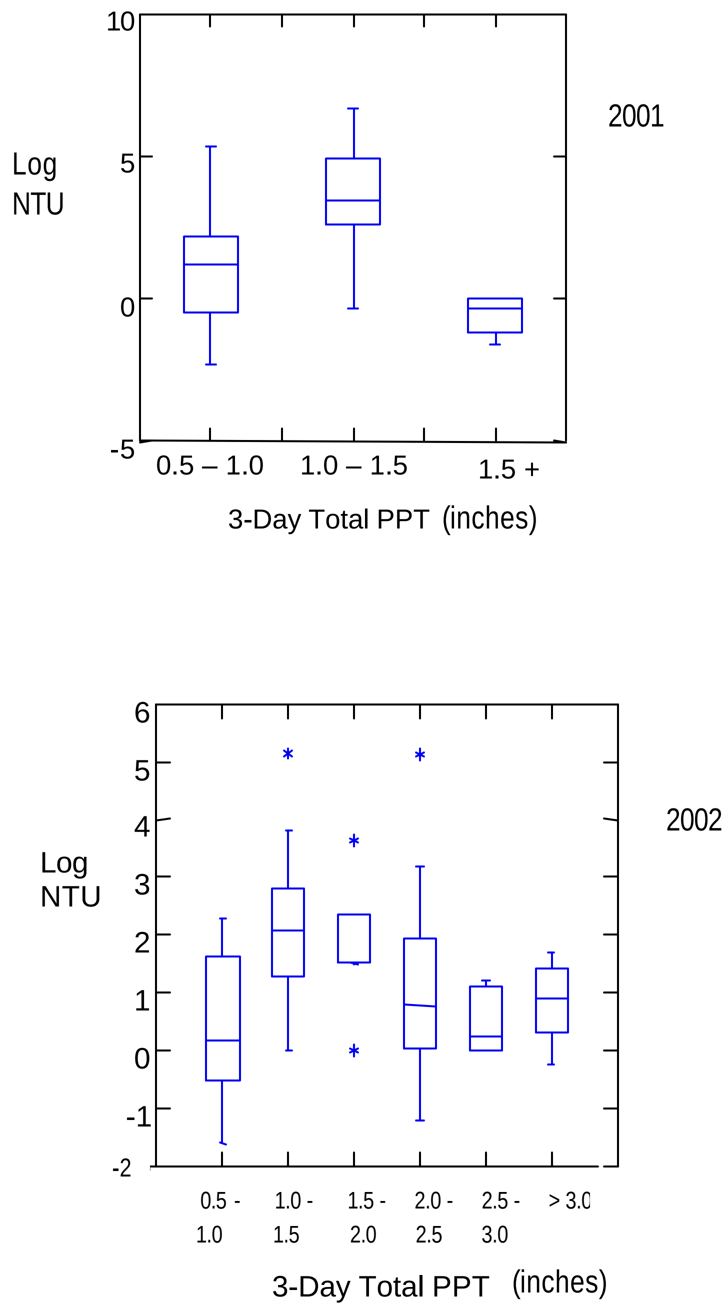


Figure 2. Average log of observed increases in turbidity (Log NTU) associated with 3-day precipitation (PPT) events in 2001 and 2002.

The same trend was observed in 2002. The greatest average increases in turbidity (LogNTUs = 2.04) were associated with the moderate antecedent rainfall events of 1.0 – 1.5 inches. The average increases in turbidity were lowest with both the lower rainfall events of 0.5-1.0 (LogNTUs = 0.52) ***and*** with heavier rainfall events greater than 3.0 inches (LogNTUs = 0.85) (Table 2 and Figure 2).

Note the generally lower turbidities observed in year two of this study, even though year two was much wetter than year one (Table 2). The high turbidities observed in 2001 may be related to accumulations of fine sediments between storms that were washed off the road surface during the few rainstorms that occurred during year one. Potential causes of lower turbidity increases with the heavier rainfalls can only be speculated. It may be related to similar processes that exhaust road-related sediment during the first moderate storms. Another possibility is that other sources of turbidity in the watershed may overwhelm the road signature as rainfall and streamflow increase.

Existing research has documented that flushing of sediment during an individual storm or throughout a season can result in varying suspended sediment concentrations at the same flow (Beschta 1978, Beschta 1987). Bilby et al. (1989) concluded that accumulated sediment was flushed rapidly from the road surface with precipitation, leading to a decrease in sediment concentrations in roadside ditches later in storms. In addition to these factors, turbidity is also sensitive to water-borne particles other than sediment. Therefore, it is likely that the same processes (storm and seasonal flushing) are influencing the relationship between turbidity and precipitation in this study. These results suggest that with respect to road-related increases in turbidity, the most critical time to monitor road condition and use may be during the first storms. However, precipitation alone does not drive the effects of wet weather road use on turbidity. The effects of percent fines in the surface aggregate and truck traffic also affect the potential for elevated turbidity as discussed below.

Fines in the Aggregate Surfacing and Truck Traffic

Along with precipitation, fines in the aggregate surfacing influenced observed increases in turbidity. The 2002 multi-linear regression suggests that as the percentage of fine particles in the surfacing aggregate increased so did the turbidity that was associated with wet weather hauling. The regression analysis suggested that the finest particles (material passing through a number 200 sieve) are those most directly associated with the turbidity increases. A graphical display of the untransformed turbidity data, truck traffic, and precipitation versus percent fines is provided in Figure 3 to further illustrate the relationships. While truck traffic was not statistically significant, higher traffic levels do appear associated with overall increased turbidity.

The combined effect of high truck traffic and low quality rock results in elevated changes in turbidity observed in 2002. These results suggest that landowners should use surface aggregate with the minimum silt and clay-sized particles (passing a number 200 sieve, 0.075 mm and smaller) to bind the aggregate, at least around stream crossings. Figure 3 also illustrates the observed lower turbidity increases with higher antecedent rainfall levels. However, by analyzing antecedent rainfall simultaneously with truck traffic and percent fines, it is clear that rainfall alone does not explain the trends in turbidity changes.

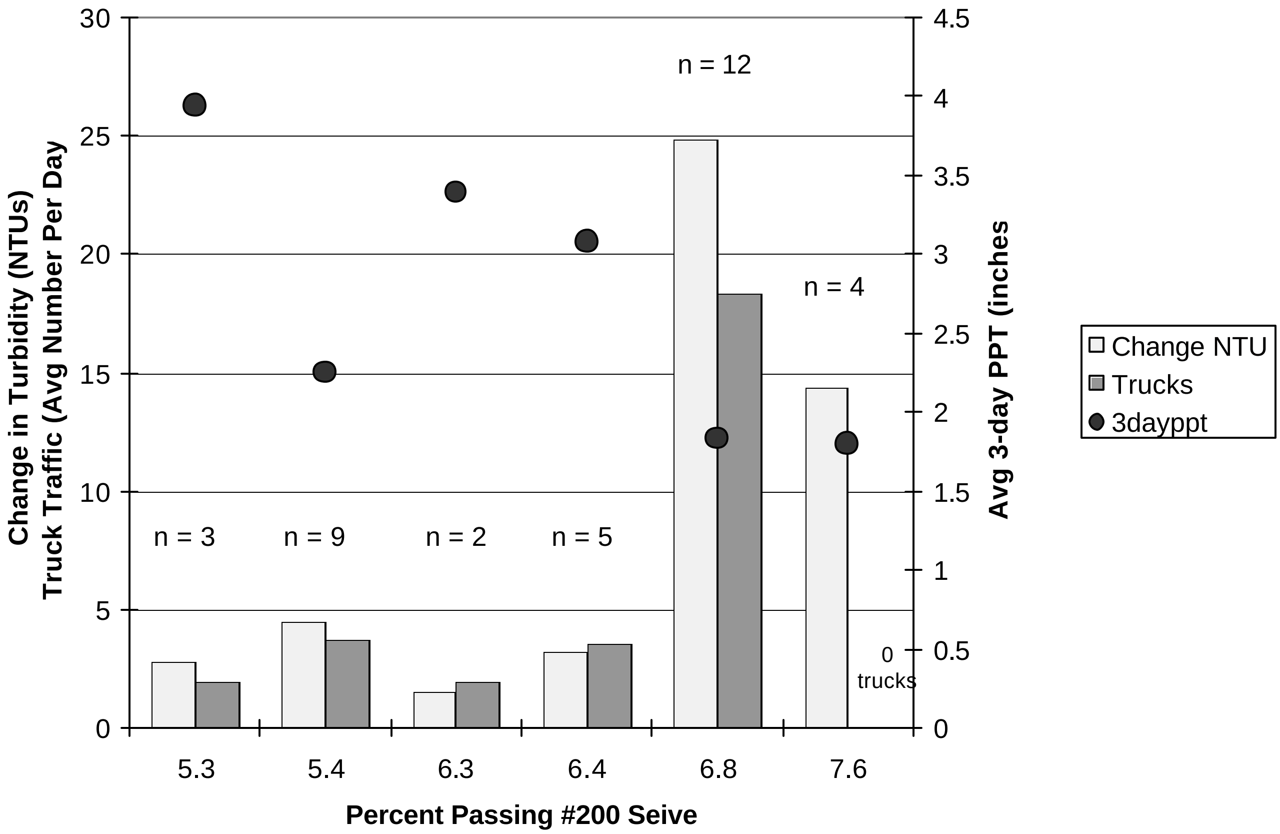


Figure 3. Influence of percent fines in the surface aggregate, truck traffic, and 3-day precipitation on changes in turbidity in 2002. Material passing a number 200 sieve has a diameter less than 0.074 mm). Sample size indicated on graph (e.g. n = 3) refers to sample pairs (i.e. samples upstream and downstream of crossing). Samples pairs included for this graph are those with changes in turbidity greater than 0 and 3-day rainfall amounts greater than 1.5 inches.

The relationship between turbidity and truck traffic was further explored by sampling turbidity changes at one crossing every 15 minutes for 2 hours during the hauling period (Figure 4). Rainfall levels were categorized and number of trucks were counted during the two hour period.The relationships in Figure 4 further illustrate that as truck traffic and rainfall increase so does turbidity.

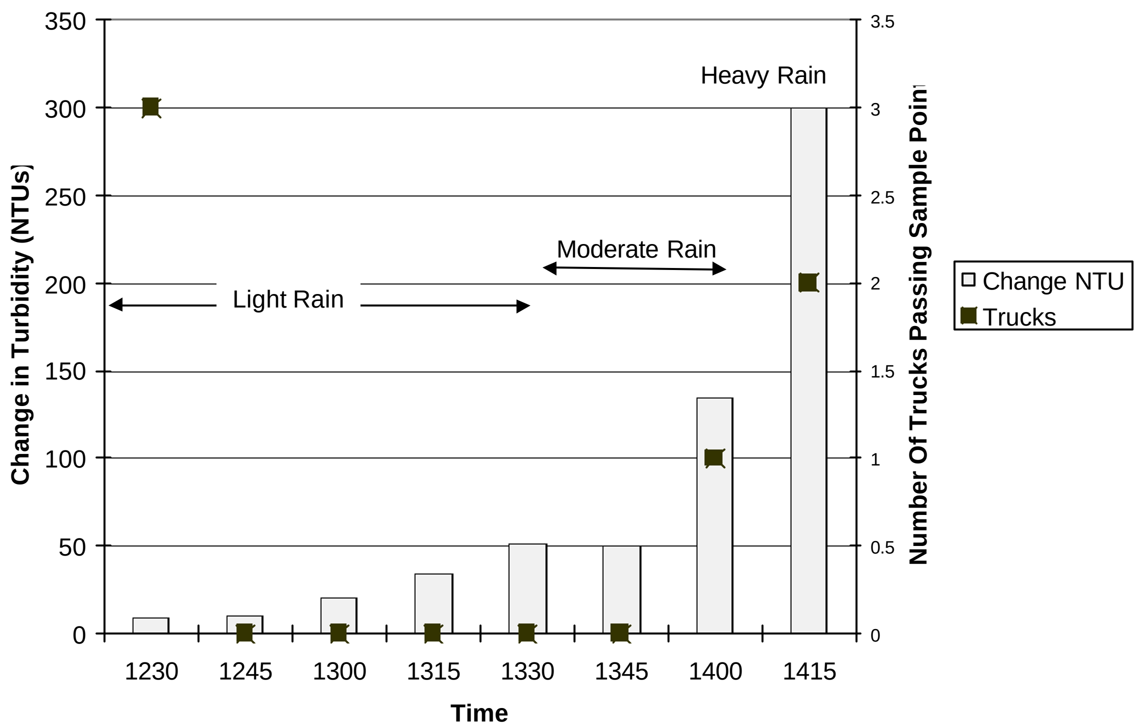


Figure 4. Changes in turbidity over time at a single crossing. Squares indicate the number of trucks that passed the crossing during each 15 minute interval. Rainfall levels were categorized as light, moderate, or heavy.

Ditch Length Draining Directly to Stream

The ditch length draining directly into the stream channel without buffering or filtering (ditch length) influenced observed increases in turbidity. The 2001 regression model suggests that as ditch length increases so do increases in turbidity from hauling. Graphical displays of the untransformed data are provided in Figure 5 to further illustrate the relationship. The average stream turbidity increases were higher for as ditch length draining directly into the stream increased (Figure 5). The 45 crossing samples with less than 250 feet of ditch length had an average turbidity increase of 13.7 NTUs. The 40 crossing samples with 250 to 500 feet of ditch length had an average turbidity increase of 48.2 NTUs. The 21 crossing samples with more than 500 feet of ditch length had an average turbidity increase of 70.5 NTUs. These results suggest landowners should minimize ditch length to less than 250 feet on sections draining directly to small streams.

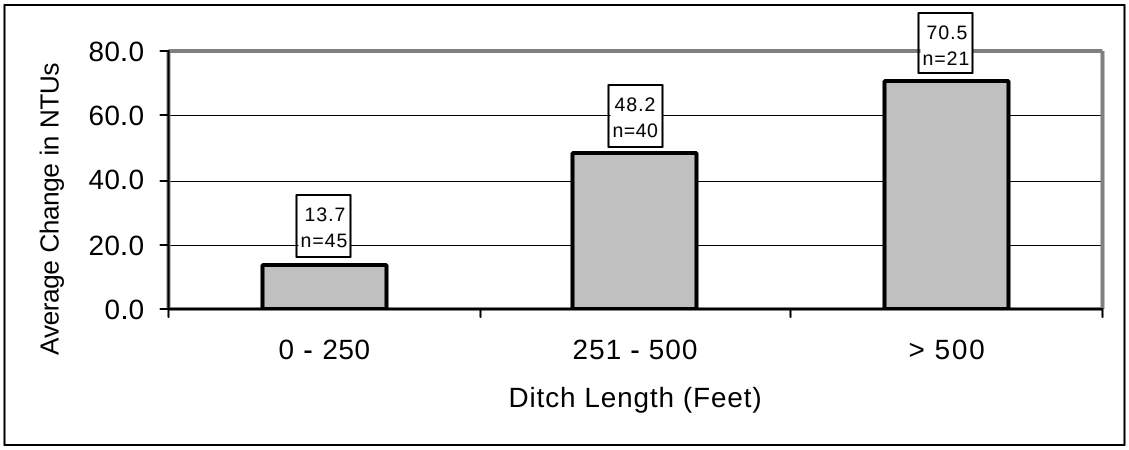


Figure 5. 2001 average change in stream turbidity vs. Ditch length draining directly into streams at crossings.

Depth of Aggregate Surfacing

The depth of aggregate surfacing was not statistically significant, but it is discussed here to illustrate the practices applied at the monitoring sites, as well as the general relationship between rock depth and turbidity. The depth of surfacing aggregate at stream crossings and approaches influenced observed increases in turbidity (Figure 6). Turbidity changes associated with wet weather hauling were substantially greater for road segments with less than 6 inches of aggregate surfacing. The 59 crossing samples with at least 6 inches of surfacing rock had an average increase in stream turbidity of 26.0 NTUs. The average increase was nearly four times as large for the eight crossing samples with less than 6 inches of surfacing rock (99.1 NTUs). Note that in only 8 out of the 67 sample locations were roads surfaced with less than 6 inches of aggregate.

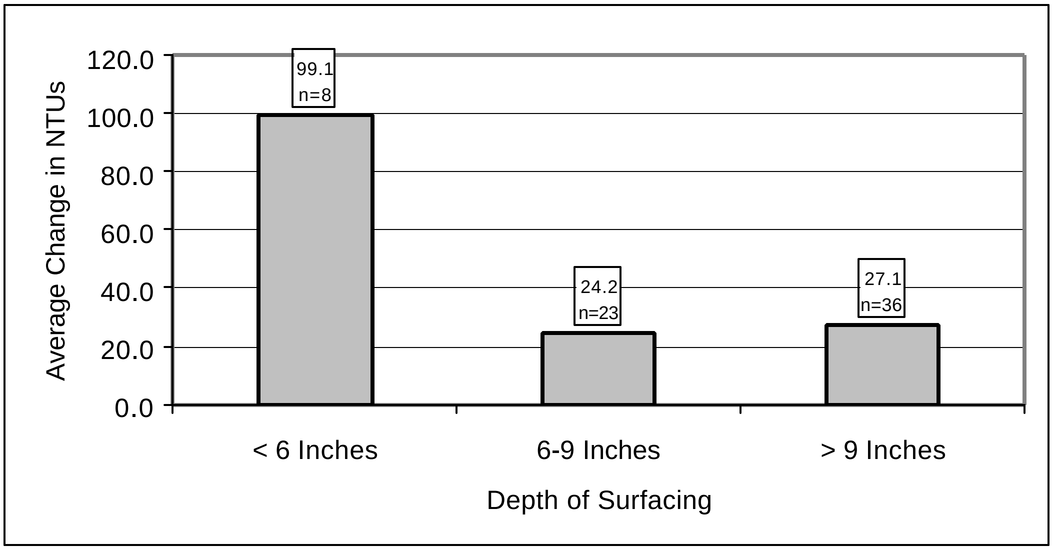


Figure 6. Average change in stream turbidity vs. Depth of road surfacing rock at crossings.

DOWNSTREAM TURBIDITY EFFECTS

The second purpose of this project was to evaluate the downstream fate of elevated turbidity observed at stream crossings. In 2002, water samples were collected every 200 feet downstream from crossings in small streams. Water samples were also collected at the junctions with these small streams and larger streams. Finally water samples were collected throughout an entire stream length adjacent to an active haul route. The results of several case studies using each of these approaches are detailed below.

Turbidity Changes Downstream of Crossings in Small Streams

In 2002, fifteen small non-fish-bearing streams were sampled to determine how turbidity levels changed downstream of a road crossing. Each stream was sampled immediately above the influence of the road and crossing, immediately below the influence of the road and crossing, and at 200-foot increments downstream until reaching a junction with another stream.

Results show highly variable downstream trends in turbidity changes. Turbidity increases declined on some streams, increased on others, showed no change on others, and increased then decreased on others. When the range of observed changes is considered, overall there were no differences in a downstream direction between 0 and 800 feet downstream of crossings (Table 3). Beyond 800 feet, the observed changes were within the range of expected measurement error, suggesting an inability to differentiate wet season road use effects on turbidity from other sources of turbidity or measurement error. However, the sample size is sufficiently small to preclude conclusions.

Table 3. Minimum, maximum and average changes in turbidity in a downstream direction from stream crossings. Change in turbidity is relative to the turbidity upstream of the road crossing.

Distance Below Crossing (number of sample pairs)	Minimum Change in Turbidity (NTU)	Maximum Increase in Turbidity (NTU)	Average Increase in Turbidity (NTU)
Immediately (n =15)	-3.0	48.6	9.3
200 ft. (n =15)	-9.6	30.6	6.3
400 ft. (n =15)	-14	30	0.5
600 ft. (n =2)	-3	21.6	9.3
800 ft. (n =2)	-0.5	8.6	4.1

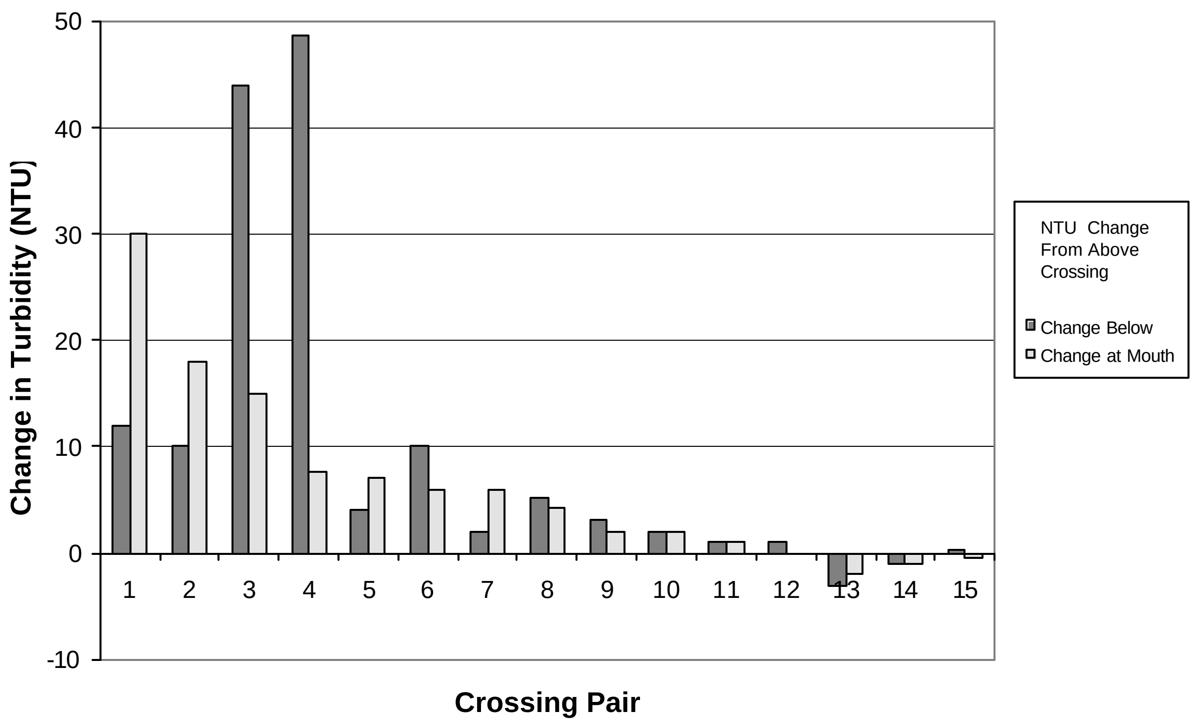


Figure 7. Change in stream turbidity downstream of road crossing and at the mouth of the tributary relative to upstream of road crossing for 14 water sample pairs.

Another way of evaluating the data is to compare the change in turbidity downstream of crossings with the change in turbidity at the mouth of the small stream just prior to its entry to a larger stream. These results are displayed in Figure 7. During the sampling period, five out of 15 pairs had increases in turbidity at or above the assumed measurement error of 10 NTUs associated with the stream crossing. On two streams (pairs 1 and 2; Figure 7), the turbidity increase was *higher* at the mouth than just below the crossing (i.e. an elevation above the assumed road effect). Conversely, on the three other streams, turbidity increases were *lower* at the mouth than just below the crossing (pairs 3. 4, and 6; Figure 7) (i.e. a dampening of the road-related effect).

These results illustrate the complexity of determining downstream fate of road-related increases in turbidity. The sample size is sufficiently small and the variability sufficiently high to preclude conclusions based on these results. This is a very important question from both a regulatory and an ecological perspective, since tributary junctions may provide important habitat for fish. Further research and monitoring is needed to better define the duration and levels of elevated turbidity downstream of a road-related increases, how those levels relate to other sediment sources in the stream, and to define the ecological effect of those increases. Part of the complexity of the fate of road-related sediment relates to the time it takes for the road-related sediment to reach downstream sections of these small streams. Road-related sediment may be getting stored in channel segments and thus delaying or preventing downstream transport at a given monitoring date. Factors that influence sediment routing include stream flow, channel morphology, channel gradient, wood loading and other sources of roughage in the channel. Future monitoring and research should adequately account for these factors in the study design.

Influence of Small Stream Turbidity Changes on Turbidity of Larger Streams

In 2002, a number of the sample sites included roads paralleling streams for long distances in the valleys of large streams. These roads had multiple crossings of small streams that quickly delivered to a larger stream. At times, there were other sources of turbidity along these roads, including landslides unrelated to the roads and, in a few cases, slash treatment activities. Therefore, the following results need to be reviewed with caution, since there may be other sediment sources that affect stream turbidity and that were not accounted for. Attempts were made to go downstream of a visible plume caused by the small tributary, but the question of proper mixing poses another challenge when monitoring the influence of small stream inputs to large stream turbidity.

Twelve stream junctions were sampled to evaluate the influence of small tributary streams on the large fish-bearing (mainstem) streams that they drained into. Each of these tributary streams drained into a mainstem stream 200 to 1200 feet downstream of the road crossing. Water samples were collected in the mainstem stream above and below the tributary junction to assess the influence of the tributary stream.

The changes in the turbidity of the mainstem streams at tributary junctions are shown in Figure 8. The change is the turbidity downstream of the tributary relative to the turbidity upstream of the tributary. Results indicate that contributions of these small tributaries to mainstem turbidities may be less than 2 NTUs. The change in mainstem turbidity ranged from 2.0 to –5.0 NTUs and averaged –0.4 NTUs. This is likely less than the measurement error associated with the sampling methods of this study.

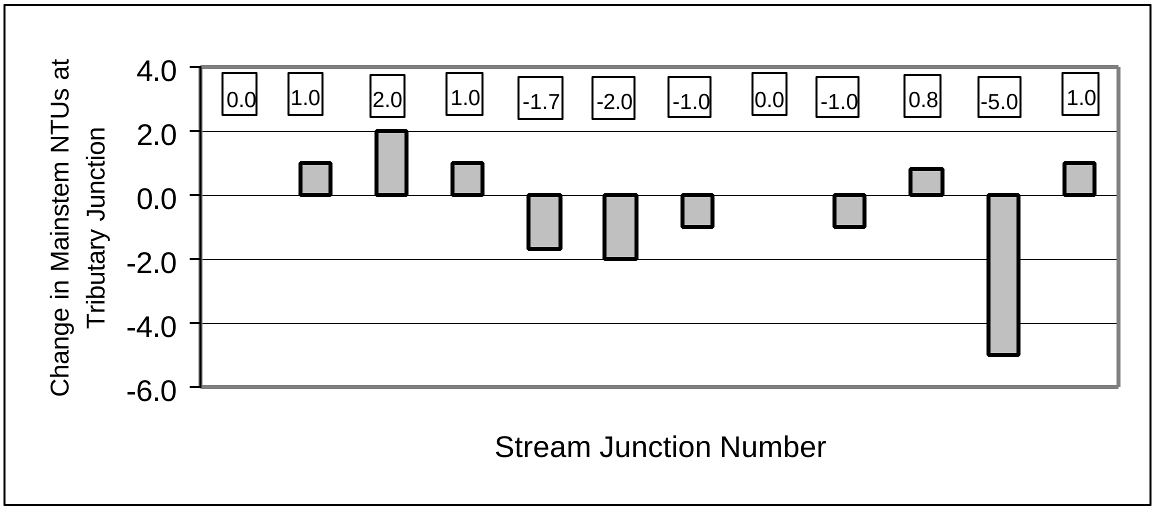


Figure 8. Mainstem turbidity change at junctions with tributary streams.

These results suggest effects of small streams on larger stream turbidity were not detected in this study. However, in two cases a visible sediment plum at the junction suggested water quality at the junction itself may have been impaired. The previous section on downstream fate of road-related sediment describes the challenge of linking these observations with road-related sediment. Future monitoring should focus on the small streams and relationships to plume turbidities.

Mainstem Streams Parallel to Haul Routes

In 2002, turbidity samples were also collected from mainstem streams that flowed along the haul routes. Samples were collected from above and below the entire hauling reach along the stream, generally several miles, between about 2 and 16 miles. The turbidity above the haul route, turbidity below the haul route, and difference between the two is shown in Figure 9 and Table 3. Because of the many factors involved (many other streams entering the channel, natural erosion, other roads, etc.), changes in turbidity between these samples cannot be attributed only to hauling. Therefore, this table shows the worst-case scenarios under current practices, since much, but not all, of the turbidity changes might be attributed to the road surfacing. Statistical tests were not performed due to the nature of the dataset, so the statistical significance of the observed changes cannot be described. Turbidity increased in a downstream direction on all streams. The turbidity increase ranged from 0.3 NTUs to 33 NTUs.

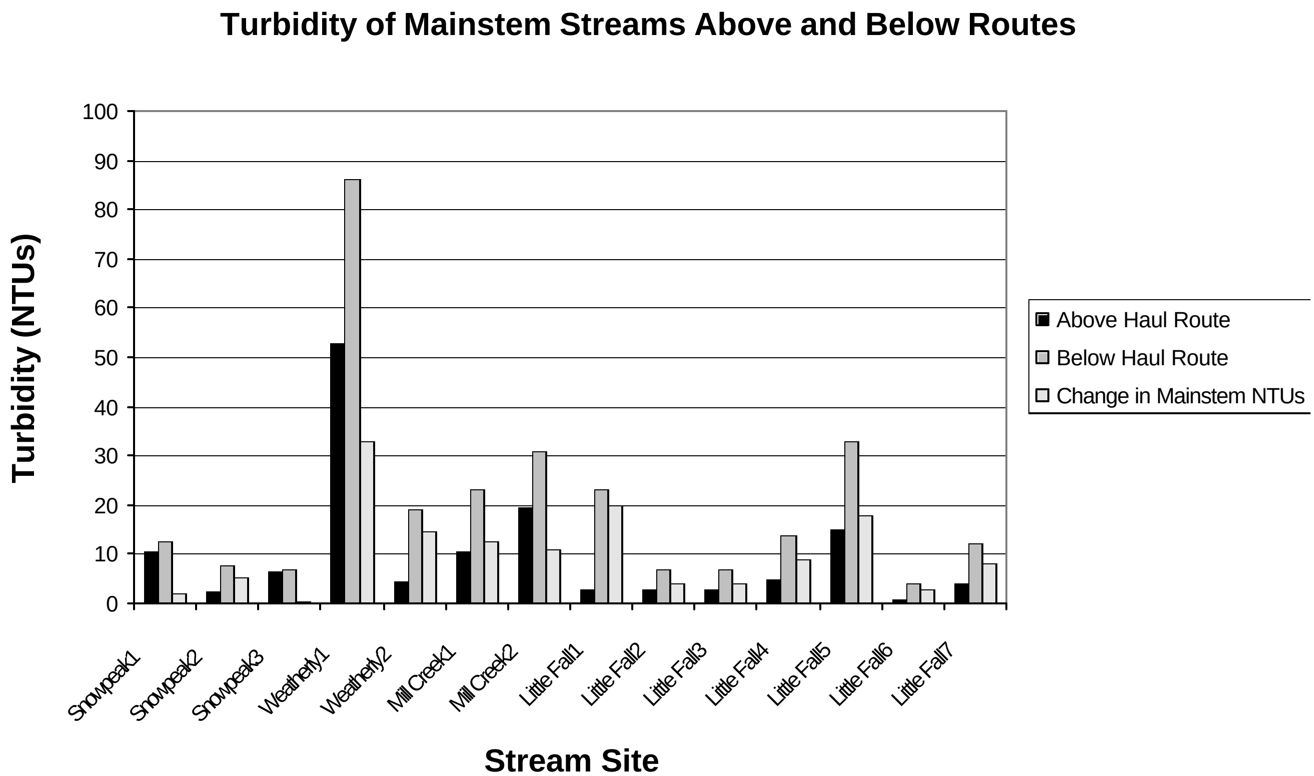


Figure 9. Turbidity of mainstem streams above and below haul routes (2002).

Table 4. Turbidity of mainstem streams above and below haul routes.

Haul Route/Visit	Snowpeak1	Snowpeak2	Snowpeak3	Weatherly1	Weatherly2	Mill Creek1	Mill Creek2	Little Fall1	Little Fall2	Little Fall3	Little Fall4	Little Fall5	Little Fall6	Little Fall7
Mainstem NTUs Above Haul Route	10.4	2.6	6.5	53.0	4.5	10.5	19.7	3.0	3.0	3.0	5.0	15.0	1.0	4.0
Mainstem NTUs Below Haul Route	12.4	7.7	6.9	86.0	19.2	23.3	30.8	23.0	7.0	7.0	14.0	33.0	4.0	12.0
Change in Mainstem NTUs	2.0	5.1	0.4	33.0	14.7	12.8	11.1	20.0	4.0	4.0	9.0	18.0	3.0	8.0

FINDINGS AND CONCLUSIONS

Currently available literature shows that wet season road use can be a major source of fine sediment. Road surfacing and drainage practices can have a very large effect on the delivery of sediment to streams. This study focuses on these known effects and provides information on how turbidity from wet weather hauling can be minimized.

Two winter seasons were monitored for this study: November 2000 to April 2001 (2001 winter) and November 2001 – April 2002 (2002 winter). The 2001 winter was unusually dry and Oregon was officially declared in drought conditions while the 2002 winter represents average rainfall conditions. The data sets were analyzed for three purposes:
1) to determine the current practices being used by forest landowners to surface wet season use roads;
2) to identify forest road and use factors that can be related to increased turbidity in tributary streams crossed by roads; and
3) a general evaluation of elevated turbidity effects downstream and on the larger streams.

Landowners participating in this monitoring project are currently using at least 6 inches of aggregate to surface roads used during the wet season. This aggregate surfacing is produced from igneous rock sources. This aggregate generally contains less than 15 percent of material passing the number 40 sieve, and less than 10 percent passing the number 200 sieve. Cross drains are almost always installed within 500 feet of stream crossings and, in 40 percent of cases, are within 250 feet of the stream crossing.

A wide range of changes in turbidity was observed during the two winters of field monitoring. Thirty percent of the sample pairs showed no change or a decrease in turbidity downstream of road crossings. Ninety percent of the sample pairs showed a change of 20 NTUs or less. The remaining 10% of the observations ranged from an increase in turbidity of 20 to 520 NTUs.

Increases in stream turbidity levels at stream crossings during periods of wet weather hauling appear to be impacted by several factors including precipitation, surfacing material, drainage design, and traffic factors. Below are six specific conditions identified as relating to the most significant turbidity increases.

Statistically significant turbidity increases from wet season road use were associated with

- Three-day precipitation totals between 1.5 - 3.0 inches
- Size distribution of surfacing material with more than 7 percent silt sized and smaller particles (a number 200 sieve).
- Over 250 feet of road ditch flow draining directly to stream channel

Increases in average turbidity from wet season road use without statistical significance were associated with:

- Depth of surfacing material less than 6 inches
- Durability of surfacing material of less than a 17 Los Angeles abrasion rating (none of the study areas used very poor rock)
- Traffic levels of 10 or more log trucks per day

Attempts to track the fate of road-related sediment illustrated the complexity of the issue. The sample size was sufficiently small and the variability sufficiently high to preclude conclusions. This is a very important question from both a regulatory and an ecological perspective. Future monitoring and research should adequately account for sediment routing factors in the study design.

RECOMMENDATIONS FOR FOREST ROAD MANAGERS

1. Use aggregate containing the minimum percentage of fines needed to bind and pack and seal the surfacing. Where there are excess fines; screen aggregate to reduce the percentage of fines in the rock and lower sediment delivery.
2. Use at least a six to ten inch minimum depth of aggregate produced from sound igneous or metamorphic rock (use more where the subgrade is soft).
3. Reduce the length of road segments that deliver to streams to less than 250 feet by adding cross drain culverts or other drainage structures.
4. Prioritize inspection of wet weather active operations during the first moderate rainfalls (3 day total = 1.5- 3 inches) to determine if immediate repairs are needed or if ceasing road use is necessary.

In summary, there are cases where there are practicable measures to better comply with the Department of Environmental Quality turbidity and sedimentation water quality standards. While the practices used by cooperating landowners on the surveyed roads seem to result in no significant non-compliance with the turbidity and sedimentation water quality standards, this is in part because current practices employed by these forest managers exceeded the current forest practices requirements in place at that time. The information was to modify the forest practice rules for road drainage, and to develop a new rule for wet season road use. This new rule became effective on January 1, 2003, with a gradual phase-in period to allow landowners to improve their roads during the summer of 2003.

REFERENCES

Beschta R.L. 1987. Conceptual Models of Sediment Transport in Streams. In: Sediment Transport in Gravel-bed Rivers. Edited by C.R. Thorne, J.C. Bathurst and R.D. Hey. John Wiley and Sons Ltd.: 387-419.

Beschta R.L. 1978 Long-Term Patterns of Sediment Production Following Road Construction and logging in the Oregon Coast Range. Water Resources Research. Vol. 14, No.6: 1011-1016.

Bilby, R.E. 1985. Contributions of road surface sediment to a western Washington stream. Forest Science. 31:827-838.

Bilby, R. E., K. Sullivan, and S. H. Duncan. 1989. The Generation and Fate of Road-Surface Sediment in Forested Watersheds in Southwestern Washington. Forest Science. Vol. 35, No.2: 453-468.

Duncan. S.H. and J.W. Ward, 1985. The influence of watershed geology and forest roads on the composition of salmon spawning gravel. Northwest Science. 59:204-212.

Folz, R.B, 1996. Traffic and No-traffic on an Aggregate Surfaced Road: Sediment Production Differences. paper presented at FAO seminar on Environmentally Sound Forest Road and Wood Transport, Sinaia, Romania

ODF Forest Practices Monitoring Program. 1996. Road Sediment Monitoring Project Report: Survey of Road Drainage in Western Oregon. Final Report to the Department of Environmental Quality.

Reid, L. M., and T. Dunne. 1984. Sediment Production from Forest Road Surfaces. Water Resources Research. Vol. 20, No. 11: 1753-1761.

Skaugset, A.R. and M.M. Allen, 1998. Forest Road Sediment and Drainage Monitoring Project Report for Private and State Lands in Western Oregon. Unpublished Report, Forest Engineering Department, Oregon State University.

Wellman, R.E., J.M. Gordon, and R.L. Moffat. 1993. Statistical summaries of streamflow data in Oregon: Volume 2--Annual low and high flow, and instantaneous peak flow. USGS Open File Report 93-63. Portland, OR. 406 pp.

APPENDIX A
DATA COLLECTION PROTOCOL SUMMARY

Initial site data

a. Road segment length (draining to stream) (add both sides if crossing at sag point) in feet
b. Road grade in percent, (repeat measurements for vertical curves)
c. Filtering length (minimum, in feet)
d. Identify nearby rain gauge(s)

Initial surfacing data: Collect at location 100 feet from stream crossing, unless drainage length less than 100 feet. In this case, collect at midpoint between the stream crossing and the cross drain.

a. Surface drainage paths: Crown, inslope, outslope, or down ruts. Make a photo record.
b. Depth to subgrade, average measured in wheel tracks, in inches
c. Separate sample of capping rock where appropriate

Durable Surface

Rock testing will be conducted on samples from the stockpiles used on the roads or that are easily available to the landowners. The Oregon Department of Transportation (ODOT) materials lab will conduct the tests.

Wet-use Data: Measurements made at same location where initial data collected.

a. Water Sample:
   - ❑ Collect upstream and downstream of any road influence.
   - ❑ Do not contaminate sample by disturbing bed and banks or placing muddy foot in the stream.
   - ❑ Collect sample where water column is well mixed
   - ❑ Triple rinse collection vile prior to collection
   - ❑ Analyze within 24 hours
b. Trucks per day in categories: Low (0 to 3), Moderate (3 to 10), High (10 to 20), Heavy (over 20). Landowners provided daily truck traffic logs.
c. Number of trucks passing site during field visit
d. Rut depth in inches, to nearest half inch (average of both ruts), measured with a yardstick
e. Slop depth in inches, to nearest tenth of an inch
f. Thawing present (depth to frozen layer in inches) "0" value indicates no thawing
g. Graded since last visit: (yes or no)
h. Spot rocking since last measurement: (yes or no)
i. Other sources of sediment (not road surfacing): cutslope; raw ditch; other (note conditions)

Downstream Effects

Downstream sampling will be conducted to measure turbidity after mixing in a Type F or Type D stream, and to measure turbidity as it changes over time. This will be done on a case study basis, since every site is different. In some cases, an entire day may be spent on one site, evaluating how turbidity changes over time. The focus will be on changes over a significant length of stream channel.

a. <u>Downstream Trends</u>: Collect water sample every 200 feet downstream of select crossings

b. Tributary Junction with Larger Stream: Collect water sample at the outlet of the small stream, upstream of the junction and downstream of any visible plume from the small stream.
c. Above and below haul routes

Office Data

a. Antecedent Precipitation Index or prior 24 hours rainfall, from nearest rain gauge, adjusted by state precipitation maps
b. Compile and summarize rock test results
c. Turbidity of water samples with nephlometer within 24 hours of collection. Perform accuracy check on the nephlometer prior to each analysis session.
d. Basin area in acres
e. Rock unit: Tyee; fine sedimentary (non-Tyee); intrusive; basalt flow; altered flow or pyroclastic
f. Summarize recommended aggregate test values from ODOT

APPENDIX B
INDIVIDUAL ROAD PARAMETERS AND NON-TRANSFORMED TURBIDITY DATA: DISCUSSION AND GRAPHICAL DISPLAYS

Results for all factors, other than precipitation, are reported for crossing samples with a three-day antecedent precipitation total of at least 0.5 inches. This was identified to be the point at which road-related factors generally began to have a measurable effect on stream turbidity.

Precipitation and Turbidity

The amount of precipitation each site received in the three-day period prior to sampling (antecedent) was a strong indicator of observed increases in turbidity at a stream crossing. In general, turbidity from wet weather hauling increased as the three-day precipitation increased. However, once the three-day precipitation reached 2.5 inches, turbidity from wet weather hauling declined sharply.

The 2001 results show that increases in stream turbidity rose steadily for each three-day precipitation range up to 1.5 inches, and declined sharply beyond that (Figure B-10). The average turbidity change was an increase of 1.8 NTUs for the 250 crossing samples with less than 0.5 inches of precipitation. The average turbidity change increased to 9.9 NTUs for the 59 crossing samples with 0.5 to 1.0 inches of precipitation over three days, and rose to 83.9 NTUs for the 41 samples with 1.0 to 1.5 inches. The turbidity increase dropped to 0.5 NTUs for the six crossings samples with just over 1.5 inches of three-day precipitation.

The 2002 results show a similar pattern as those from the first season, with turbidity increases peaking with 1.0 to 1.5 inches of three-day precipitation (Figure B-11). The average turbidity increase was less than 2 NTUs for all crossing samples with less than 1.0 inches of precipitation. Turbidity increases peaked at 15.4 NTUs for crossing samples with 1.0 to 1.5 inches of three-day precipitation, and remained above 10 NTUs for samples with 1.5 to 2.0 inches and 2.0 to 2.5 inches of three-day precipitation. The average turbidity increase dropped back to below 1 NTU for crossing samples with more than 2.5 inches of precipitation. This trend is further described in the multiple linear regression section later in this paper.

Note the generally lower turbidities observed in year two of this study, even though year two was much wetter than year one. The high turbidities observed in year one may be related to accumulations of fine sediments between storms that were washed off the road surface during the few rainstorms that occurred during year one. Also, note that in both years, the maximum increases in turbidity associated with the road crossings occurred at a 3-day precipitation of between 1.0 and 1.5 inches.

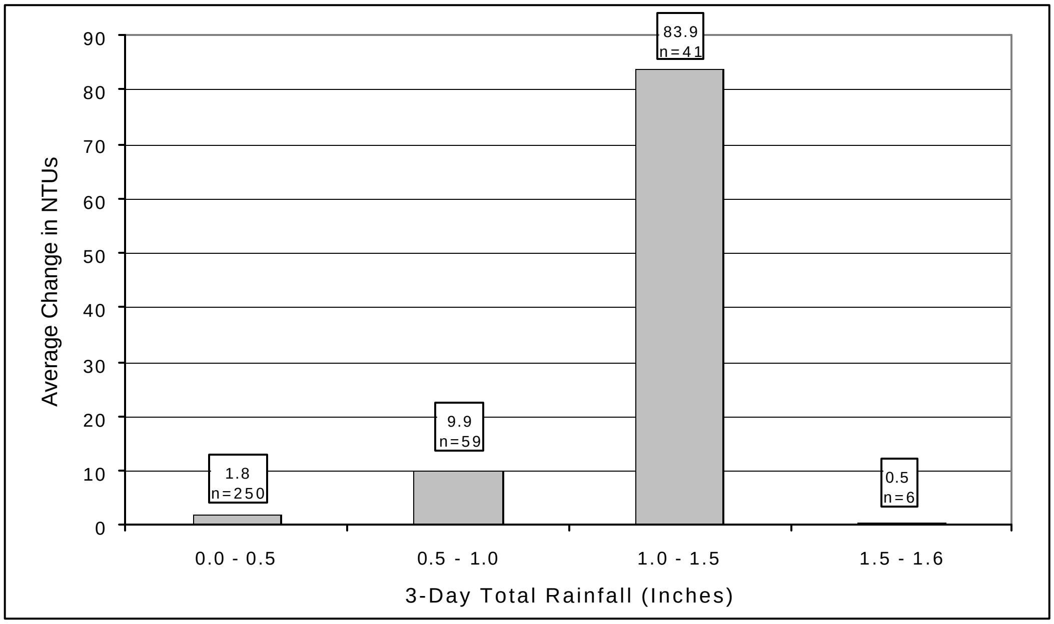


Figure B-10. Average change in stream turbidity vs. 2001 3-day precipitation totals.

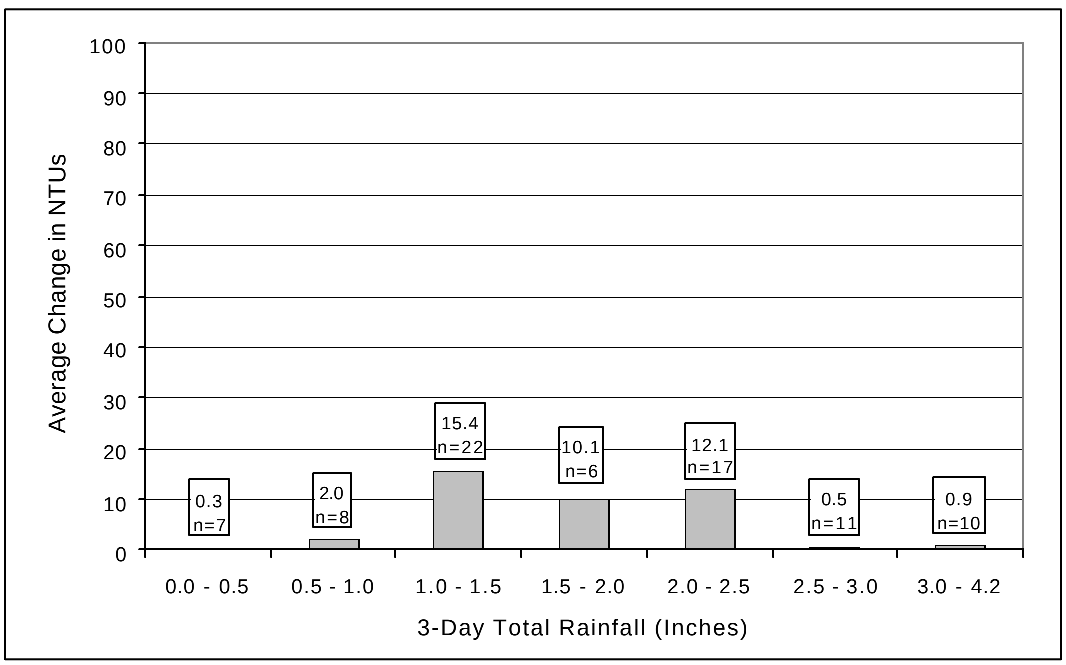


Figure B-11. Average change in stream turbidity vs. 2002 3-day precipitation totals.

Fines in the Aggregate Surfacing
The quality of road surfacing rock at stream crossings and approaches influenced observed increases in turbidity. In general, as the percent fines increased, so did the turbidity that was associated with wet weather hauling. The measurements of road surfacing aggregate quality used in this study are surfacing particle gradation (#35 and #100 sieves) and testing for resistance to mechanical wear**.**

The average change in stream turbidity for percent of surfacing material passing through a #35 sieve (material smaller than 0.5 millimeters, or 0.02 inches) is shown in Figure B-12. For the 56 crossing samples with 5 to 10% of the road surfacing material smaller than 0.5 millimeters, the average change in turbidity was an increase of 33.7 NTUs. The average change rose slightly to 39.1 NTUs for the 31 crossing samples with 10 to 15% of the road surfacing material smaller than 0.5 millimeters, and rose to 61.4 NTUs for the 15 crossings with more than 15% of the material in this category.

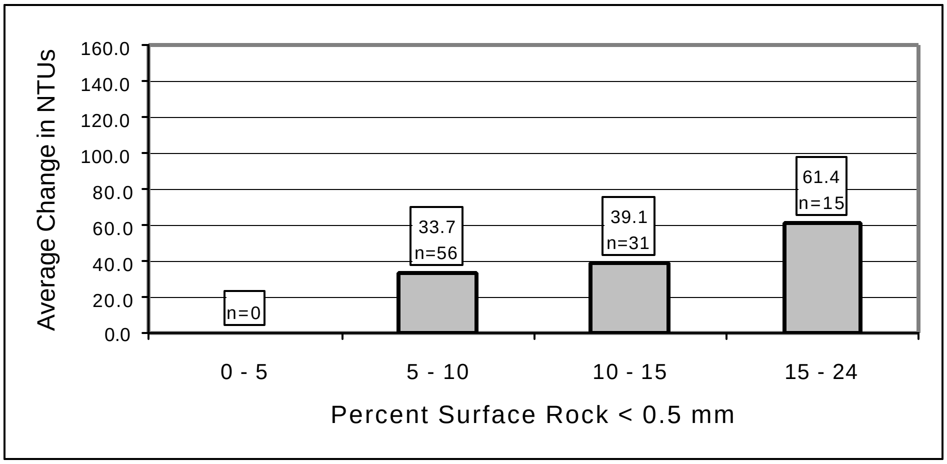


Figure B-12. Average change in stream turbidity vs. Percent of materials < 0.5 mm.

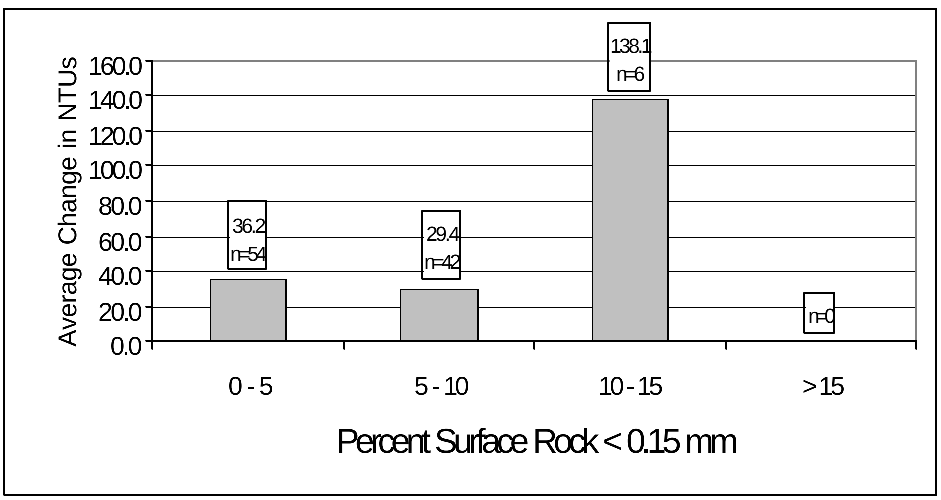


Figure B-13. Average change in stream turbidity vs. Percent of materials < 0.15 mm.

The average change in stream turbidity for percents of surfacing material passing through a #100 sieve (material smaller than 0.15 millimeters, or 0.006 inches) is shown in Figure B-13. For the 96 crossing samples with less than 10% of the road surfacing material smaller than 0.15 millimeters, the average increase in turbidity was 33.2 NTUs. The average change was an increase of 138.1 NTUs for the six crossing samples with more than 11% of the road surfacing material smaller than 0.15 millimeters (note the sample size is only six).

Durability of Surfacing Material

The durability of surfacing aggregate at stream crossings and approaches influenced observed increases in turbidity. Less durable surfacing was associated with greater turbidity increases at stream crossings. The average change in stream turbidity related to the abrasion testing is shown in Figure B-14. Higher abrasion test rating results indicate less durable material. The 43 crossing samples with an abrasion rating greater than 17 had an average stream turbidity increase of 11.3 NTUs. The 31 crossing samples with an abrasion rating of less than 17 had an average stream turbidity increase of 2.5 NTUs.

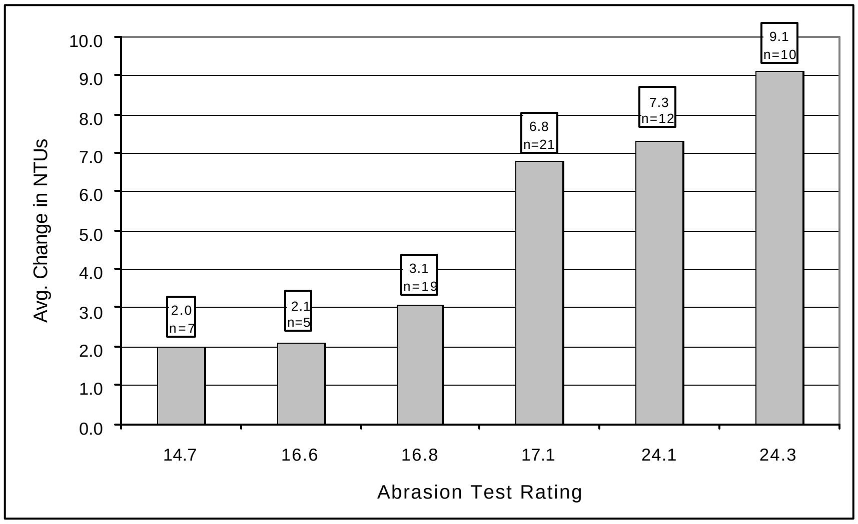


Figure B-14. Average change in stream turbidity vs. Abrasion test rating.

The percent of fines in the road surfacing material was not a reliable indicator of durability. Figure B-15 compares the percent of surface material smaller than 0.6 millimeters to the Los Angeles (LA) abrasion rating of all road surfacing samples which were given both tests. No clear relationship existed between the percent of surfacing material smaller than 0.6 millimeters and the durability rating of that material.

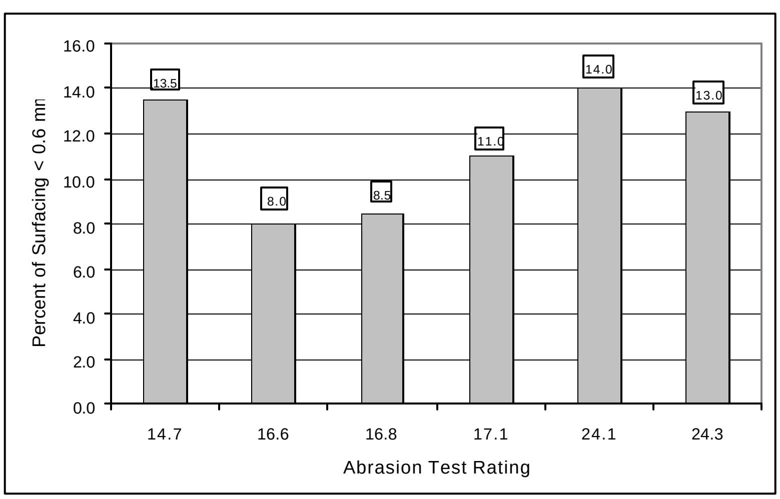


Figure B-15. Percent fines versus the LA Abrasion test rating.

APPENDIX C
GLOSSARY OF TERMS

***Antecedent Rainfall*:** For the purposes of this study, antecedent rainfall refers to the total precipitation that fell during the 3-day period prior to sampling.

***Change in Turbidity*:** For the purposes of this study, the change in turbidity refers to the difference between turbidity measured above the road crossing or haul route and the turbidity measured below the crossing or haul route.

Ditch Length: The length of road-side ditch draining directly to the stream without any filtering or buffering mechanisms,

Durable surfacing is any material of sufficient thickness, hardness, and lack of loose fines to resist deep rutting and rapid formation of fine sediment during wet season road use.

Heavy truck traffic includes repeated log truck, rock truck, or low-boy type road use.

Turbidity is defined as the optical property of a water sample that causes light to be scattered and absorbed. Since water-borne particles other than sediment can scatter light (e.g., fine organic matter, plankton, microscopic organisms), *turbidity is not a direct measure of sediment in the water column*. The relationship between suspended sediment and turbidity can vary greatly between sites. However, in general, turbidity levels are influenced by the same factors as suspended sediment with the additional complication of turbidity's sensitivity to water-borne particles other than sediment.

Wet season is that time of year when rainfall or thawing normally occurs. In western Oregon, this includes the period from October through April.