Wood Fiber Road Construction Influences on Stream Water Quality in Southeast Alaska

Michael D. Wolanek, *USDA Forest Service, Petersburg, Alaska*

A road segment using mill-generated bark and wood fiber as primary fill material was recently constructed on the Stikine Area of the Tongass National Forest in Alaska. Water-quality monitoring detected minimal effects of leachates from the road on the chemistry of three small streams that the road crosses. The parameter most affected is pH; increases of 0.5 to 1.5 pH units have been observed in the naturally acidic streams. Dissolved oxygen in the streams remains unaffected. All observed effects appear to be within the limits of Alaska water-quality standards.

A 4.5-km (2.8-mi) forest development road in the Stikine Area of the Tongass National Forest in Alaska was recently constructed using mill-generated waste bark and wood fiber as the primary subgrade material (see paper by Mullis and Bowman in these proceedings). One of the most significant issues arising from the use of bark and wood fibers in road construction is the potential effect of leachates from the road prism on water quality (*1–3*). Healthy stream systems support the valuable fishery resource vital to southeast Alaska's economy. Leachates could adversely affect the high-quality water of local streams and contend with the management goal of a sustained, productive fishery.

OBJECTIVES

A water-quality monitoring program was developed before construction of the road and included the following objectives:

1. Quantify surface and subsurface water quality and determine any changes associated with a wood fiber road. Intermediate and supporting objectives include the following:
   (*A*) Quantifying the salient physical and chemical properties of the bark and wood leachates over time,
   (*B*) Comparing the salient properties of the leachate with those of streams in the natural organic environment of southeast Alaska, and
   (*C*) Determining the distribution and concentration of the leachate in the streams and adjacent to the road.
2. Determine which Alaska water quality standards (WQS) are applicable and the extent to which they are affected or exceeded.

METHODS

Site Description

The road segment is located on Wrangell Island in southeast Alaska. The area receives 80 to 100 in. of annual precipitation, approximately half of which falls between September and December. The 50-year, 24-hr rain event is about 6 in.

The road traverses three small coastal watersheds and an area largely undissected by streams (a preventive design measure in case of adverse effects on fisheries). Table 1 displays characteristic data of the three drainages. Mean annual flow for Stream 3 is estimated to

TABLE 1 Characteristic Descriptions of Three Streams Crossed by Nemo Point Road

Parameter	Stream 1	Stream 2	Stream 3
Watershed Area, hectares, (acres)	26 (64)	78 (193)	1150 (2840)
Width at Road X-ing, meters, (feet)	1 (3.5)	1.5 (5)	7 (23)
Mean Gradient (%)	16	16	6 (Range 1-18)
Substrate	Cobble to small boulder	Cobble to small boulder	Gravel to small boulder
Fish	None	None	Resident Char and Trout[a]

[a] Species include Salvelinus malma and Oncorhynchus clarki

be 22 ft^3/sec. The 10-year peak flow is 670 ft^3/sec, and the 10-year, 7-day summer low flow is approximately 2 ft^3/sec.

Data Collection

Sampling stations each 46 m (150 ft) long were surveyed along the three streams. Stream 1 has four stations, and Streams 2 and 3 have six stations each. Stations upstream of the crossings provide monitoring controls, and the downstream stations provide the experimental data. Figure 1 shows the site layout on Streams 1 and 2.

Four geocomposite panels buried in the road serve as in situ leachate sampling devices. Two of the 58-m^2 (625-ft^2) panels, O1 and O2, were simply placed within the fill material and are subject to all water flows. In an effort to detect differences caused by groundwater flushing, two other panels, C1 and C2, were installed with vertical walls of plastic sheeting to minimize groundwater flux through the fill material above the panels.

Other data recorded to support analyses include depths to groundwater in shallow wells, groundwater chemistry, precipitation, stream stage and discharge measurements, and internal road temperature. Methods have been fully described by Wolanek (*4*).

Monitoring parameters (Table 2) reflect the compliance requirements of Alaska WQS (*5*). Total organic carbon (TOC) and chemical oxygen demand (COD), monitored periodically since construction began in 1992, indicate the potential of the leachates to utilize oxygen over time.

Statistical Analyses

At the time of this writing, statistical analyses of stream data sets are under way with assistance from statisticians with the USDA Forest Service Pacific Northwest Research Station. A general linear model approach is being used, with analyses of variance (ANOVAs) performed on three recognized sources of variance in the parameter data: time, treatment (wood road), and distance from the road. Comparisons of these sources with the variance in the control data will provide a clear pic-

FIGURE 1 Site map showing sampling design of Streams 1 and 2, Nemo Point, Wrangell Island, Southeast Alaska.

TABLE 2 Parameters Considered in Nemo Point Road Water-Quality Monitoring Project

1. Dissolved Oxygen (DO)	6. Total Dissolved Solids (TDS)
2. pH	7. Apparent Color
3. Temperature	8. Residues
4. Turbidity	9. Total Organic Carbon (TOC)
5. Electrical Conductivity (EC)	10. Chemical Oxygen Demand (COD)

ture of the mechanisms and magnitude of the leachate effects on the chemistry of receiving waters. As this analysis is incomplete, however, the following discussion utilizes initial statistical analyses on the data sets of individual sampling trips. This approach has some inherent flaws, but the tests shed some light on the trend and magnitude of differences between stations within each stream.

ANOVAs and Tukey multiple comparison tests (6) were used to evaluate trends in the samples collected from June 1992 to June 1993. The stations were compared independently, upstream to downstream, with the following null hypothesis:

> Ho: Woodwaste leachate does not affect water quality downslope of the road for the given stream and parameter.

If statistical tests detected significant differences in the data, the null hypothesis was rejected, concluding that leachates do affect that parameter. If no significant differences were observed, the null hypothesis was not rejected. Changes in leachate characteristics are observed and described through graphical analysis.

RESULTS AND DISCUSSION

The construction project began on June 1, 1992 (Day 0). Using this convention, Stream 1 was crossed (and leachate effects began) on Day 58, Stream 2 was crossed on Day 65, Stream 3 was crossed on Day 493, Panels 01 and C1 were installed in the road on Day 92, Panel 02 was installed on Day 456, and Panel C2 was installed on Day 533.

Leachate Characterization (Objective 1A)

Discharges from the four panels have been relatively minimal and erratic except during the wet fall months. Discharge volumes are variable and not always initiated by similar storm events.

TOC and COD are the best indicators of the potential of the leachates to reduce the oxygen dissolved in receiving waters. Results indicate rapid peak TOC concentrations of 1250 mg carbon/L in 01, 450 mg C/L in Cl, 1400 mg C/L in 02, and 840 mg C/L in C2 as shown in Figure 2. Similar rapid peaks of 5530 mg/L in 02 and 3600 mg/L in C2 were observed in COD results as shown in Figure 3. COD sampling did not begin until 1993, so no early data exist for 01 and C1. For both TOC and COD, concentrations appear to diminish almost exponentially after their peaks, approaching a low residual value.

Note that both "Open" panels (01 and 02) have higher peak TOC concentrations than C1 and C2 (Figure 2), which may reflect the greater flushing of 01 and 02 by groundwater, exporting greater quantities of partially decomposed wood and bark extractives from the road fill. Conversely, the increase in leachate COD from Panel C1 after 700 days may be the result of the delayed discharge of wood sugars, tannins, and other organic acids caused by reduced flow through the fill (Figure 3).

The peak "strength" of the leachate compares intermediately with that found in the literature. Vause (2), sampling leachate from a similar road collection device in western Washington State, reports TOC and COD peaks of about 320 mg C/L and 1500 mg/L, respectively. Econotech (7) reports TOC peaks of 1100 and 850 mg C/L for Douglas fir and western red cedar bark, respectively, and 8500 mg C/L for spruce/pine "hog fuel" from the interior of British Columbia. Relatively rapid declines in both TOC and COD concentrations are reported in the literature, and Nemo Point results appear to follow a similar trend.

Initial leachate discharges ranged from moderately acidic to neutral (Figure 4). For a period of time after the installation of each panel, from about 200 to 400 days, 01 and 02 leachates increased toward alkalinity, with pH peaks observed between 7.5 and 8.0. The pH of leachates from Panel C1 remained near neutral during this period. This trend was typically observed in the first, drier summer season after installation when discharge was minimal. Otherwise, pH returned to its in-

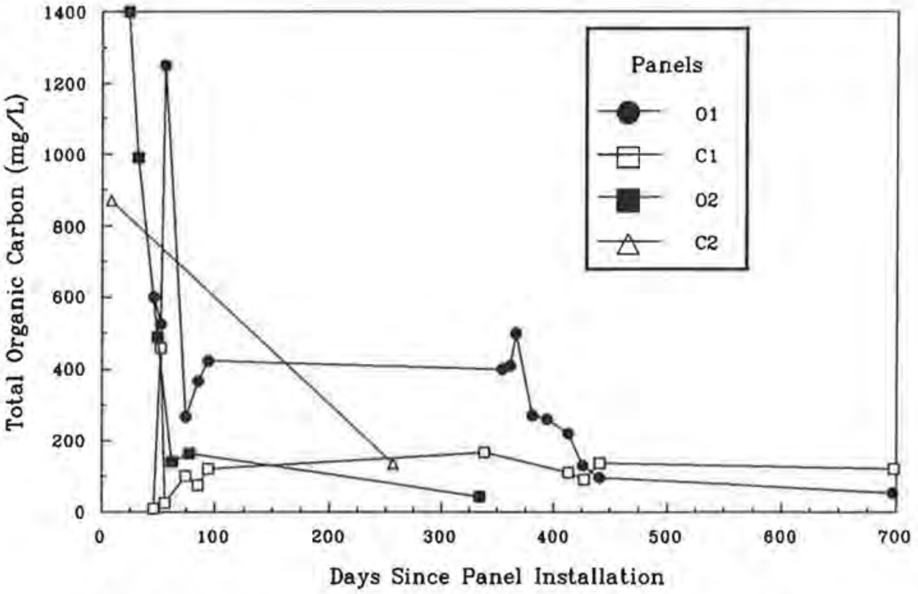

FIGURE 2 Total organic carbon of leachates obtained from geocomposite collection devices within Nemo Point Road.

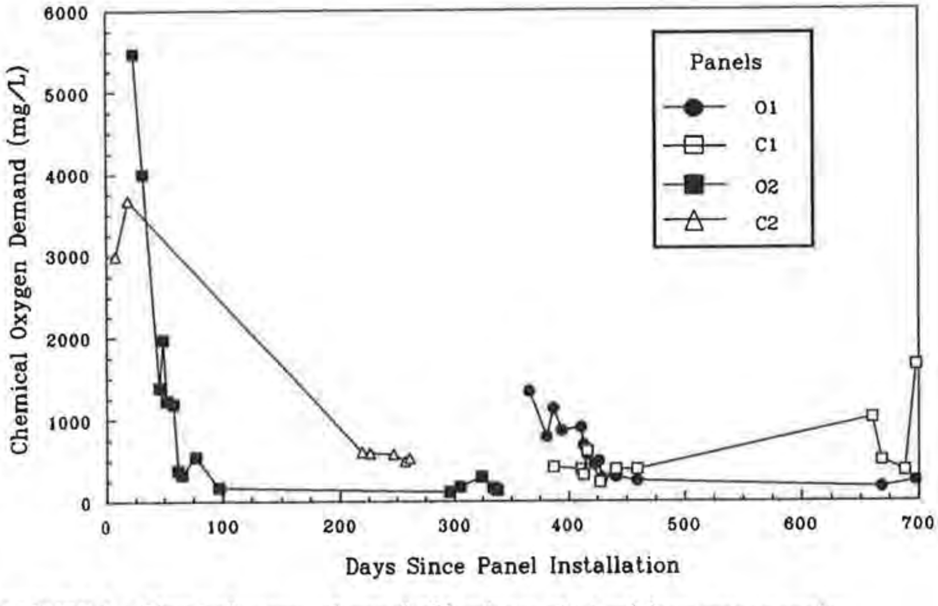

FIGURE 3 Chemical oxygen demand of leachates obtained from geocomposite collection devices within Nemo Point Road.

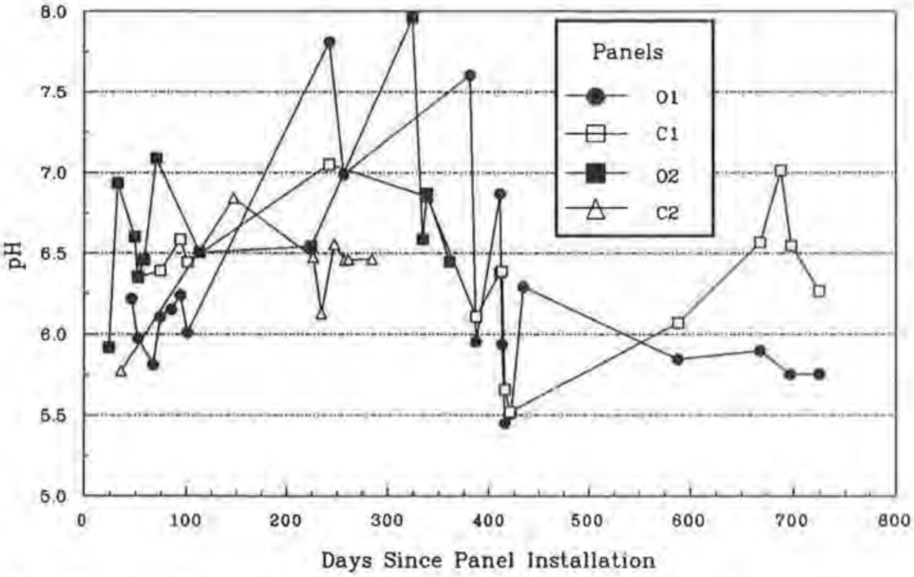

FIGURE 4 pH of leachates obtained from geocomposite collection devices within Nemo Point Road.

itial range. The lowest pH value to date is about 5.5, observed in both 01 and C1 leachates.

Leachate pH, with the exception of the alkaline spikes, is in the range of pH observed in the literature for a variety of wood species (7,2). Econotech's extensive study of leachates, including leachates from pulping wastes, reported consistently alkaline leachates only from the stored waste of one kraft bleaching operation. No pulp waste was used on this project.

Control versus Treatment Analysis of Water Quality (Objective 1B)

The overall null hypothesis that wood fiber road construction does not affect stream water quality was rejected if (*a*) postconstruction ANOVAs consistently rejected the null hypothesis that there is no difference between any station means and (*b*) Tukey multiple comparison tests and graphical analyses indicated the development of consistent trends with regard to control versus treated stations. If neither criterion was met, the conclusion was not to reject the null hypothesis. Table 3 summarizes the results of the analyses to date.

The conclusions show that pH, electrical conductivity (EC), and total dissolved solids (TDS) are affected by wood fiber road construction. EC and TDS populations were significantly different because data sets were tightly grouped with minor variability, but actual increases in means were quite small. The following discussion therefore focuses on pH and considers dissolved oxygen (DO) as well.

pH

Results of the ANOVA and Tukey multiple comparison tests indicate that pH was the parameter most affected by bark and wood fiber road construction at this site. Mean pH data from Stream 2 stations are presented in Figure 5 for four representative points in time. The July 1992 data were obtained before road construction, the October 1992 data reflect conditions near the beginning of observable leachate influences, the December 1992 data were obtained during heavy rains in a late fall storm, and the October 1993 data were selected to show the maintenance of leachate effects after 1 year.

In each stream, statistically significant differences were commonly detected between maximum and minimum station means in the preconstruction data sets (e.g., Figure 5, July 1992). The data sets for each stream showed a change in the trend of station means within sampling trips beginning in October 1992, about 2 months after the road crossed the streams. From that point, the ANOVAs detected consistent significant increases in pH below the road (Figure 5, October 1992). The degree of this increase varied between trips but remained statistically significant. A marked increase in pH from 4.6 to 6.1 from Station 21 to Station 25 in December 1992 was among the largest increases seen in a stream on any one trip (Figure 5). Overall, pH increased

TABLE 3 Results of ANOVA and Tukey Multiple Comparison Tests for Each Parameter in Streams 1 and 2

Parameter	Test[a]	No. Tests	Overall Test Results[b]	
			Stream 1	Stream 2
pH	AT	17	Reject	Reject
D.O.	AT	17	DNR	DNR
E.C.	AT	16	Reject	Reject
TDS	AT	15	Reject	Reject
Turbidity	AT	15	DNR	DNR
Temperature	AT	17	DNR	DNR
Apparent Color	AT	10	DNR	DNR
Residues	V	25	DNR	DNR
TOC			N/A	N/A
BOD			N/A	N/A

[a] Test Type:
AT = ANOVA/Tukey Multiple Comparison Test
V = Visual Observations/Conclusions Made Each Trip
[b] Test Conclusions:
"Reject" = Reject Null Hypothesis Given Under Methods
"DNR" = Do Not Reject Null Hypothesis
"N/A" = Tests Incomplete, or Not Enough Data

from upstream to downstream of the road by about 0.5 pH units on Stream 1 and by 0.3 pH units on Stream 2.

Dissolved Oxygen

Preliminary results indicate that oxygen in these streams was not affected by leachates from bark and wood fiber road construction, although this was initially one of the greatest concerns of the project. Figure 6 gives an example of DO data from four selected sampling trips on Stream 3. As with pH, statistically significant differences were occasionally observed among stations with the maximum and minimum DO, even before construction, on all streams. However, the primary difference was a seasonal one, with cooler fall temperatures enabling a greater concentration of oxygen to remain dissolved in the streams (e.g., Figure 6, November 1993).

Distribution of Leachates Adjacent to Road (Objective 1C)

The sampling design was intended to detect water-quality recovery with increasing distance downslope of the road, as shown in Figure 1. However, trends show that pH (Figure 5) and EC in Stations 24 and 25 were often significantly higher than in Stations 22 and 23. Likewise, Stations 13 and 14 were noted to have readings for various parameters elevated above those in Station 12.

Supplemental data collected from small tributary rills draining road ditches indicate that they are likely significant contributors to the parameter changes observed. Comparing ditch data with rill data indicates that leachates primarily influence rill water downslope of the road (i.e., not in the ditches). These rills transport water very slowly, without the dilution and mixing effect of stream cascades. Similar observations were made regarding overland flow on organic soils (bogs) near Stream 2 during saturated conditions. The bogs and rills serve as alternate routs for leachates around the streams and account for much of the increase in pH from Stations 23 to 24 observed in the December 1992 data (Figure 5). These observations indicate the importance of depressions, swales, and rills in concentrating and transporting leachates downslope.

Comparison of Water Data and WQS (Objective 2)

Table 4 briefly summarizes Alaska WQS affected by this project (*5*) and compares the mean, maximum, and minimum values of each parameter on Streams 1 and 2. Stream 3 data are omitted for brevity.

The Alaska WQS (*5*) set a range in pH from 6.5 to 9.0 for waters where fish and wildlife are the primary beneficial uses. An additional clause states that pH should not vary more than 0.5 units from natural conditions. In these streams pH typically remains below the minimum standard but exceeds the variance-from-natural criterion. The significant differences detected for pH after road construction should be considered in the light that ANOVAs also detected significant differences

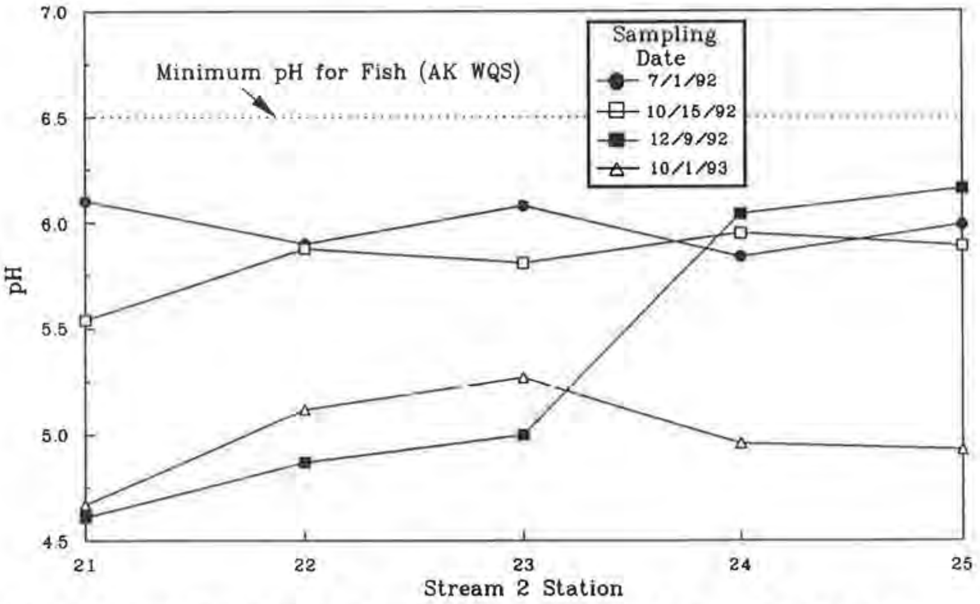

FIGURE 5 Influence of leachates from bark and wood fiber in Nemo Point Road on Stream 2 pH and its relationship to Alaska WQS.

before construction because of the natural variation in stream pH. Notably, increases detected actually elevated pH toward the minimum standard, as shown in Figure 5.

DO WQS for nonfishery streams range from a minimum of 5 mg/L to maximum of 17 mg/L (5). The minimum DO for fish rearing is 7 mg/L. Station means are well above these minimums and easily within the maximum (Table 4, Figure 6).

In no case do parameter values exceed the limits set by the standards as a result of road construction and the generation of leachates (except for a temporal peak in turbidity during installation of drainage structures). However, pH and apparent color naturally exceed these standards. With the exception of the acidic pH and organic-stained color, these standards verify the high quality of water found downslope of the road. The ex-

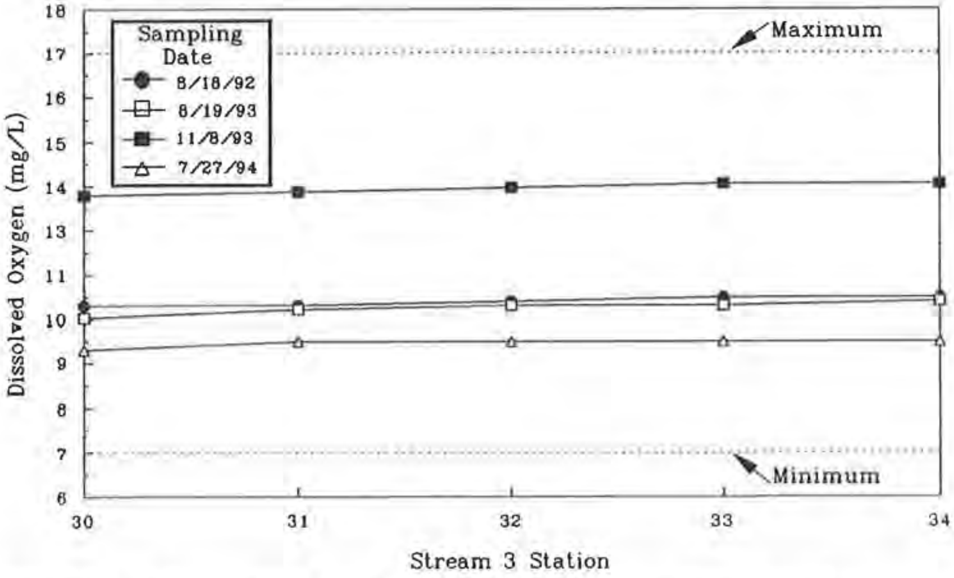

FIGURE 6 Influence of leachates from bark and wood fiber in Nemo Point Road on Stream 3 dissolved oxygen and its relationship to Alaska WQS.

TABLE 4 Comparison of State of Alaska Water-Quality Standards with Control and Treated Water Chemistry Data for Streams 1 and 2

Parameter (Units)	Water Quality Standards (WQS)	Stream 1			Stream 2		
		Mean	Max	Min	Mean	Max	Min
		First row of data is control; Second row of data is treated.					
DO (mg/L)	Fish: 7 to 17; Non-fish: 5-17; Interstitial gravels: >5; Never >110% saturation.	10.8	13.8	8.4	11.0	14.1	8.1
		11.5	13.9	8.0	11.9	14.4	8.6
pH	Minimum: 6.5; Maximum: 9.0; Effects +/- 0.5 unit from natural.	5.8	6.6	4.0	5.5	6.2	4.1
		5.7	6.7	4.3	5.3	6.4	4.2
Turbidity (NTUs)	Effects <25 above natural.	6	56	0	2	9	0
		13	331	0	7	76	0
Temperature (°C)	Maximum: 20; Egg & fry maximum: 13; Weekly averages maintained; no nuisance organisms.	10.2	14.1	1.8	10.6	14.6	1.1
		8.2	14.2	1.9	7.3	13.5	1.3
TDS (mg/L)	Maximum: 1500; No effects exceed 1/3 natural.	<10	10	<10	<10	<10	<10
		16	47	<10	<10	23	<10
Apparent Color (platinum color units)	No reduction in depth of photosynthetic activity; Maximum: 50.	58	173	21	52	107	23
		74	203	23	65	140	23
Residues	No films or sheens on water surface. No sludge, solid, or emulsion deposited on surface or substrate.	None observed			None observed		
		None observed			None observed		

[a]Data collected from June 1992 through September 1994.

ceptions are attributed to the organic soils of these two small watersheds.

CONCLUSIONS

Water-quality monitoring from June 1992 through September 1994 indicates minimal effects on stream water quality downslope of bark and wood fiber road construction. The parameter most often affected is pH, increasing significantly by 0.2 to 1.5 pH units. This trend is, in all instances observed, an increase toward the minimum pH of 6.5 set by the Alaska WQS for the protection of a stream's beneficial uses (fisheries). No significant differences in DO levels were detected. Results demonstrate that from a water-quality approach on similar terrain, bark and wood fiber road construction is an environmentally sound method.

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