ENVIRONMENTAL PROTECTION COSTS

IN LOGGING ROAD DESIGN AND CONSTRUCTION TO PREVENT INCREASED SEDIMENTATION IN THE CARNATION CREEK WATERSHED

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ABSTRACT

The Ritherdon Road extension project on the west coast of Vancouver Island was used in 1975 to study the relationship between logging road design and construction tasks, and stream sedimentation. A method of determining least cost logging road design and construction prescriptions to meet stream sedimentation standards is described using sample data.

RÉSUMÉ

Le projet d'extension de la route de Ritherdon sur la côte ouest de l'île de Vancouver fut utilisé en 1975 pour étudier la corrélation qui existe entre le design des chemis d'exploitation forestière et les travaux de construction, et la sédimentation des cours d'eau. L'auteur décrit, à l'aide de données-échantillons, une méthode pour determiner le design des chemins d'exploitation forestière au moindre coût et prescrire des techniques de construction correspondant aux normes de sédimentation des cours d'eau.

PREFACE

Public and private timber harvesting policies and procedures are periodically modified to maintain forest land values. It is possible to vary road design and construction practices to a large degree to comply with environmental constraints. To establish a basis for sound multiple-use forest management, public natural resource agencies and private firms need information about the relationships among timber harvesting damage, protective measures and damage prevention costs. However, not only is it difficult to quantify the values which are being conserved, but often the costs incurred are not known until after the constraints have been applied or until the road has been built.

In a case study of the Wilson Creek Forest Road in the Nelson Forest District, it was shown that the magnitude and distribution among design and construction tasks of the costs incurred to comply with a set of environmental constraints can be recorded. The realtionships between constraints and corresponding design and construction cost increases were determined using a modified and expanded cost accounting system. However, it was not possible to determine relationships between road cost increases and environmental quality indicators, such as stream sedimentation.

The Carnation Creek Watershed Project afforded an opportunity to investigate the relationship among environmental damage-prevention costs, and design and construction modifications, and resulting environmental quality. The Economics Unit of the Pacific Forest Research Centre was invited to participate in the multidisciplinary Carnation Creek Watershed Study in December, 1974.

The study objectives are to establish a benchmark set of observations of routine logging road design and construction practice, expenditures and stream quality response, and to demonstrate how these can be employed to determine least cost least sedimentation reducing prescriptions. The two major cooperators in this study were the Habitat Protection Directorate of the Fisheries and Marine Service and the Franklin Division of MacMillan Bloedel Ltd.

It is hoped that this report will be a help to public and private natural resource managers and researchers as a guide for formulating stream quality prescriptions and research projects.

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INTRODUCTION

Resource management agencies, particularly the British Columbia Fish and Wildlife Branch and the federal Fisheries and Marine Service, have been enforcing environmental regulations upon logging operations in British Columbia for many years. Some of these regulations require the forest industry to conduct timber harvesting operations in a way that prevents increased sediment levels in streams. Although these regulations serve to resolve somewhat the conflict between the logging industry and both the commercial and sport fisheries, the regulations impose additional costs for stream quality protection upon the logging industry. Therefore, although the regulations resolve some conflicts, they also create new ones.

Increases in logging costs which might result from complying with environmental regulations are borne not only by industry, but also by the general public through reduced forest revenues and increased forest product prices. Therefore, it is in the interest of both the public and industry to know more about which phases of forest harvesting are most damaging and which are most costly to modify. Economically efficient solutions to multiple-use conflicts require that the sum of the cost of preventing damage, the cost of rehabilitating damaged resource values and the residual damage suffered despite prevention and rehabilitation measures is minimized (Dales, 1968; U.S. Environmental Protection Agency, 1972; U.S. Council on Environmental Quality, 1972; Environment Canada, 1974).

Several major watershed studies are being conducted in the Pacific Northwest region of the United States to investigate the relationships among forestry practices, particularly harvesting, and forest hydrological factors (Hall and Lantz, 1969; Brown and Krygier, 1971; Frederickson et al., 1973; Harr et al., 1975; Swanson and Dyrness, 1975) and in British Columbia (Narver, 1974). Reports concerning modified road construction design and techniques are numerous (Rothwell, 1972; Adamovich et al., 1973; U.S. Environmental Protection Agency 1975). An accounting method to determine environmental costs and to provide cost control for logging road construction projects has been developed (Ottens, 1975). Unfortunately, none of these studies have determined the linkages among logging road design and construction practices and modification, modification costs and resulting fish habitat quality. The Carnation Creek Watershed Project afforded an opportunity to investigate these relationships.

The Carnation Creek Watershed Project is a long-term study initiated by the Fisheries and Marine Service in 1970 to investigate the effects of forest harvesting on salmonid fish populations. The overall objectives of the study are:

1. To develop a better understanding of how undisturbed coastal rainforest-salmonid stream ecosystems work in order,
2. To explain and quantify the impacts of timber production activities on stream environments and their capacity to produce salmonid fishes in sufficient detail,
3. To provide continuous input to the further development of integrated resource management guidelines. (Narver, 1974:2).

The project design is described in more detail in the Annual Report for 1973 (Narver, 1974).

In January 1975, the economic unit of the Pacific Forest Research Centre, Canadian Forestry Service, undertook a study, in cooperation with the Fisheries and Marine Service and MacMillan Bloedel Ltd., of the correspondence of road construction tasks with sedimentation. This information was to be used to estimate the additional cost of modifying road design and construction practices to reduce sedimentation to a level that would result in satisfactory stream gravel quality. The study was designed to produce results as compatible as possible with the chum salmon spawning gravel assessment portion of the project. The objectives of this portion of the project are:

1. To assess the effect of the current forest harvesting practices on spawning gravel composition, subgravel oxygen, and subgravel velocity.

2. To establish any relationships existing between spawning gravel composition, oxygen and velocity.

3. To assess the resultant effects on condition and weight of emergent fry. (Narver, 1974: 15).

The present studies of chum salmon spawning gravel quality allow for an assessment of the cumulative effects of the previous year's harvesting activities, but cannot provide a direct connection between construction tasks and gravel quality. However, if deterioration of spawning beds after road construction were detected, information from this study was to indicate specific construction tasks which caused most of the sedimentation under known hydrological conditions and what the probable damage prevention cost might be.

This report briefly describes the study road, the sediment sampling, the construction task observations and, with these observations, shows how the damage prevention cost might be determined for a given sedimentation standard.

The Study Road

The study road, comprised of the Ritherdon Road extension with branch roads, is located in the western part of the Carnation Creek Watershed. The watershed is located on Barkley Sound on the west coast of Vancouver Island and within Tree Farm Licence No. 21 of MacMillan Bloedel Ltd. (Figure 1). The climatic, vegetation and physical characteristics of the watershed have been described by Scrivener (1974) and Oswald (1975, 1974, 1973). It has a mild and wet west coast climate. Most of the 250 to 380 cm annual precipitation falls as rain (less than 5% is snow) during the months of October to March. The vegetation is characterized by an over-mature hemlock-amabilis fir-red cedar ecosystem and soils are shallow.

In general, the soils along the road routes are medium to coarsely textured, ranging from gravelly loam to loamy sand, and have developed on colluvial material or bed rock which is mostly of volcanic origin (Oswald, 1973). Oswald (1973) considers the erosion potential of those portions of road route located on sloping topography to be moderate to high.

Road construction generally results in increased sediment levels in adjacent streams through increased surface erosion and mass wasting or land slides. Examples of failures in current road beds due to these causes can be observed in adjacent areas (Oswald, 1973). As the organic layer and vegetative root masses, which are the primary binding agents holding the soil in place, are removed during excavation, intensive and rapid erosion can occur. Although mass wasting occurs relatively infrequently and during major storms, it is undoubtedly the cause of the most serious stream habitat degradation due to sedimentation. Mass wasting is probably not as important as surface erosion in contributing to sedimentation in the Carnation Creek Watershed.[1]

Route Selection

The study road was a 1.7-mile extension of the Ritherdon Road generally following the 200-foot contour, with 1.4 mile branch road (called Branch R-800) above it generally following the 500-foot contour (Figure 2). The route was selected to accommodate high lead logging, common to coastal

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[1] D. Toews, Forest Hydrologist, Habitat Protection Directorate, Fisheries and Marine Service, Vancouver, personal communication.

Figure 1. Location of the Ritherdon Road Extension

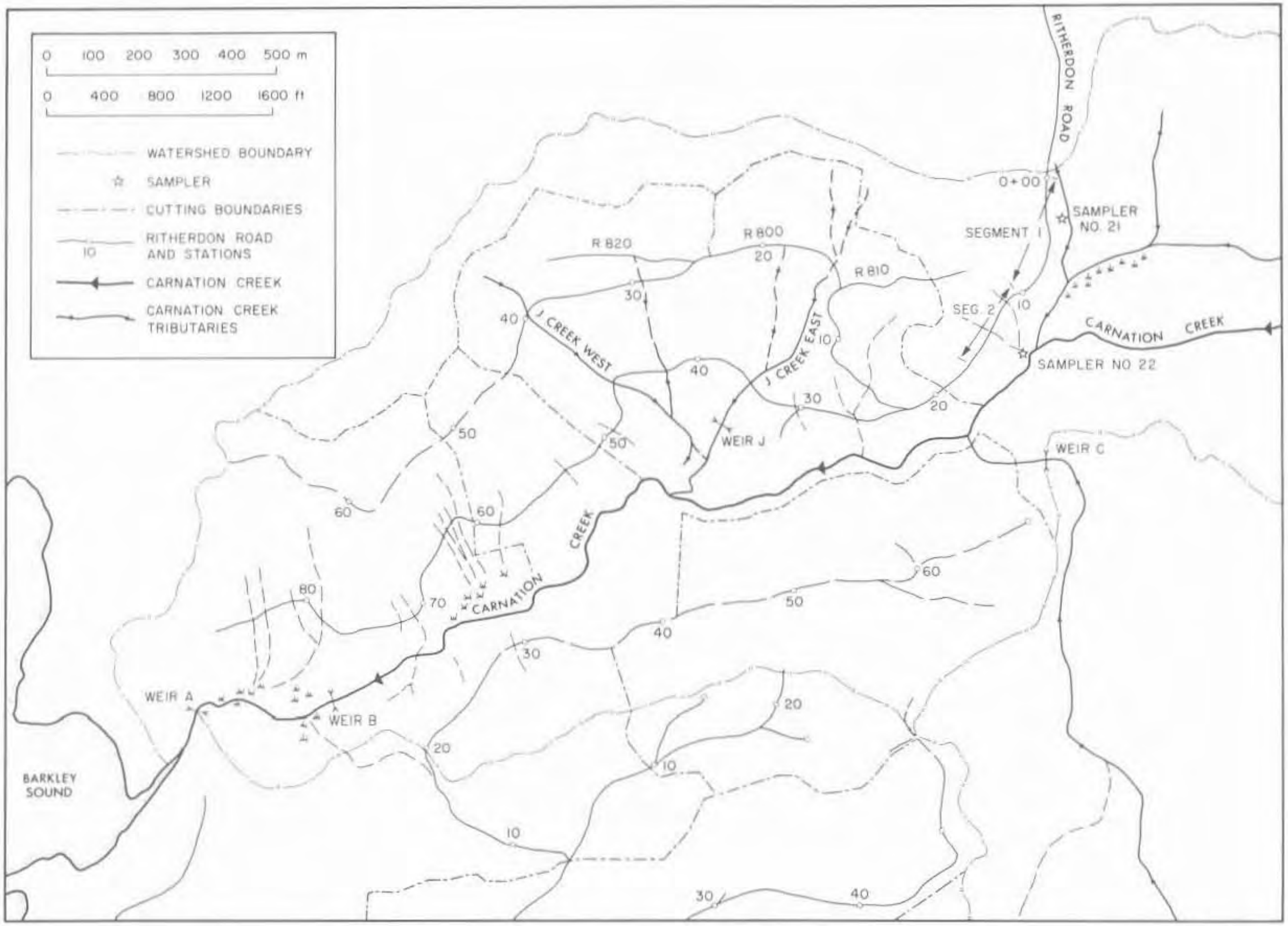

Figure 2. Ritherdon Road Extension and Sediment Sampling Installations

British Columbia, such that the road connects suitable landing sites. When it was not feasible to build main and branch roads directly to landing sites, spur roads were constructed. There was one 250-foot spur built from the main road. Two other spurs, named R-810 and R-820, and 950- and 1050-feet long, respectively, were built from branch road R-800. Other shorter spurs will be built as required at the time of logging.

Road Design and Construction Specifications

The construction project was conducted according to road specifications currently required in permits issued in the Vancouver Forest District. The conditions of these permits state the engineering specifications to which the road must be built and require prelogging of the right-of-way, disposal of all slash within the right-of-way by burning or burying, and excavation of reasonably stable cut banks. No specific stipulations for environmental or aesthetic purposes were made, other than general conditions concerning drainage, and spoil and borrow areas to prevent siltation of streams.

Route Description

The Ritherdon Road extension begins in a small pass at about 225-feet elevation on the north boundary of the watershed. It has a generally rolling grade with few pitches over 5%. Branch R-800 starting at station 22+50[2] on the main road, by contrast, has steeper grades. The first 3000 feet of branch R-800 has an average favorable grade[3] of 14%. Most of the rest of the branch has an average adverse grade of 6%, except for the sections from stations 30+00 to 33+00 and stations 61+00 to 72+00, which have rolling grades with few steep pitches. The study concentrated on the first portion of the extension road network, up to station 51+50 of the main road and station 45+50 of branch road R-800. These stations cross the 1975-76/1978-79 cutting boundary.

Most of the extension road network was built on benches and in rocky terrain, and intercepted numerous minor collector streams and subsurface flows. The first 20 stations of the main road intercept small subsurface and surface flows which resulted in some muddy sections. The first 14 stations of branch road R-800 and stations 22+00 to 32+00 of the main road intercepted a diffuse drainage system which was concentrated in a small stream and crossed the main road at station 25+00. The largest drainage system intercepted by the remainder of the study road is concentrated in "J" Creek East and "J" Creek West. These streams flow into Carnation Creek within 100 feet of each other. "J" Creek East crosses branch road R-800 at station 14+00 and the main road at station 36+00. "J" Creek West consists of two branches that join in a deep ravine below the main road. The east branch crosses spur R-820 at station 4+50, road R-800 at station 29+50 and the main road at station 43+00. The west branch crosses road R-800 at 37+00 and the main road at station 46+00.

The road subgrade excavated in rock provided in-place ballast for most of the route. Only the muddy sections required quarried rock ballast. Muddy sections were encountered between stations 0+00 to 3+00 and 22+00 to 32+00 on the main road at the junction of branch road R-800 and spur R-810. Rock ballast was quarried at pits outside the study area, at station 14+00 on the main road and assorted smaller borrow pits.

The study road contains several portions with relatively high erosion potential.

On branch road R-800, a steep section from station 13+00 to station 22+50 was built on a fairly uniform sidehill consisting primarily of deep colluvial material through which notable subsurface

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[2] A station is a 100-foot segment along the centre-line of a road traverse.

[3] A road grade on which loaded trucks must haul downhill is referred to as a favorable grade. A road grade on which loaded trucks must haul uphill is referred to as an adverse grade.

seepage occurred. As of November 1975, ditches along these sections were inadequate so that water flowed over the road.

The main road from station 36+00 to 51+50 contains several portions with high erosion potential. The section between stations 36+00 and 39+00 was built through a steep side slope consisting of a deep, loose colluvial deposit. Excavation there has resulted in a long fill slope and a high cut bank. After the organic and vegetative layers were removed, the cut bank failed several times. From station 39+00 to 43+00, the road followed a bench. Although the road from station 43+00 to 51+50 required several deep rock cuts, the resulting subgrade contained a large proportion of loose colluvial material. The lack of solid rock in the fill created difficulty in securing two cedar culverts, one at station 43+00 and the other at station 46+00. The streams passing through these culverts join below the road to form "J" Creek West in a deep ravine. The large fill was required to cross the ravine. The culverts are situated near the top of this large fill and water is discharged directly onto the loose fill material. Insufficient rock material appeared to have been placed in the floor of the culverts, as evidenced by some erosion of the culvert floor and fill within a few months of installation. However, these road sections are situated well away from Carnation Creek. Furthermore, the hillsides in this portion of the valley do not slope directly to the Creek but onto a flat flood plain. Therefore, only a large landslide into a tributary stream would be likely to result in serious fish habitat damage.

Data Recording Methods

Road construction sediment sampling and time card data recording commenced in early January. Detailed field observations of construction tasks began on April 2, 1975.

Sediment Sampling

Sediment sampler operation and water sample analysis were conducted by personnel of the Habitat Protection Unit of the Fisheries and Marine Service.

The road was divided into segments in such a manner that the drainage from each section could be sampled in a single tributary, slightly downslope of the road. Road profiles, topographic maps and field observations were used to identify the topographic divides that formed the divisions between segments. Although activity at the ends of the segment might not result in sediment being transported to the sampled tributaries, the segments were treated as point sources because this affords a practical way 1) to treat moving and continuous sources of sedimentation, and 2) to use actual production data to estimate and compare costs per unit of road.

The samples were collected with an automatic, 24-bottle pumping sampler produced by Sirco Controls Limited. Samples of 500 millilitres were taken in separate bottles at 2-hour intervals.

The sediment concentration was measured in milligrams of sediment per litre of water, using filtering techniques. The samples were drawn through a millipore filtering apparatus, using a 18 p.s.i. vacuum and a 1.2 micron pore size membrane filter paper. Heavy samples (greater than 15 ppm) were filtered, using a glass fiber filter paper to prevent clogging. Approximately 1700 samples were collected and analyzed during the study.

The samplers measured sediment concentrations immediately downslope of the road. The concentrations were not necessarily the same as those entering Carnation Creek; some of the sediments were deposited as the tributaries traversed the flood plain adjacent to Carnation Creek.

The results of the analysis yield instantaneous concentration but do not indicate total sediment yield because stream flow was not measured in the tributaries.

Production Data

Production data were compiled initially only from time cards for road construction tasks by number of man- and machine-hours on specific road sections by Franklin Division personnel. It became evident at the beginning of March that production data from time cards would not permit the determination of exactly which practices caused sedimentation detected by the automatic sediment samplers. Following a revisional delay, field monitoring of road construction tasks by machine, crew, road location and time of day commenced on April 2, 1975. The construction project was monitored almost continuously until May 28, 1975. Time card data were compiled concurrently by Franklin Division personnel.

Tasks and Accounting Codes

Data collection forms were designed so that construction task data could be readily compiled by cost accounting categories (Appendix II). The categories permitted production data to be collected uniformly and to be coded to facilitate eventual computer data processing and conversion into monetary terms. The basic structure of the cost accounting system has been explained in an earlier report (Ottens, 1975). This accounting system is based on cost categories used by the B.C. Forest Service. It is structured to permit compilation of data at various levels of aggregation. To account for full work shifts, "Delay" and "Lunch" codes were added. The "Crew Moves" codes were added to account for machine time spent moving about on the site but not conducting usual construction tasks. Other codes were added to provide more detail about tasks within broader categories.

Field Production Observations

For each machine and crew, field notes are a record of their position on the road, the time, both start and finish, and a description of the task being performed. Every time, during a shift, that a piece of equipment changes task or position, these three pieces of information were recorded.

Two general difficulties were encountered in keeping the field notes accurate. The first was the problem of station markers either disappearing in the slash or being cut down by the fallers. The second was the result of the increasing distance between the ends of the mainline and branch R-800. As the work progressed, more time was spent by the observer commuting between work sites and thus short time interval tasks were missed.

Field notes were not kept for some crews because of a) night-shift work--work drilling crews; b) safety--right-of-way falling, blasting, and c) sporadic presence -- engineering, supervision. The information for these personnel was taken from the time sheets and is not as detailed as the information for the continuously observed crews.

Data Compilation

Data from time cards and field notes were compiled by segments, days and time periods, and by corresponding sediment levels and hydrological conditions (Appendix III[4]).

Sediment Discharge Level

Sediment discharge levels were compiled by the Fisheries and Marine Service for each sample location by time, stream flow and precipitation.

Hydrological variables, particularly precipitation and streamflow, are among the many var-

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[4] Only data used in the "Analysis" section of this report are presented. The balance of the data remains on file with the Pacific Forest Research Centre and the Operations Branch of the Fisheries and Marine Service.

iables that influence sediment levels in streams. Streamflow was used as a measure of prevailing hydrological conditions. Unfortunately, flow in the tributaries has not been measured. Therefore, the control stream hydrograph record from "C" wier was used to segregate sediment samples by whether flow was rising, stable or falling, and whether the flow was above or below storm runoff levels. The categories used:

1) rising - no storm flow
2) rising - storm flow
3) stable - no storm flow
4) stable - storm flow
5) falling - no storm flow
6) falling - storm flow

Samples were further qualified by total daily precipitation. Total precipitation was measured at Station "A" from 8:00 a.m. to 8:00 p.m.

Time Card Data

As previously explained, time card data alone were used for right-of-way fallers, blasting crews, the night shift rock drilling crew, supervisors and engineers for reasons of safety and convenience.

Right-of-way fallers worked 6½-hour shifts, beginning at 7:30 a.m. and stopping at 2:30 p.m., with lunch from 11:30 a.m. to 12 noon. Call time of 2 hours was compiled for the segments within which the crew would have worked if weather had not prevented falling. The night-shift drilling crew worked from 4:00 p.m. to 12:30 a.m., with lunch from 8:00 to 8:30 p.m. Since it was unsafe to move the drill far during the night, this crew occasionally used two drills during one shift. The blasting crew worked the regular shift from 7:30 a.m. to 4:00 p.m., with lunch usually from 11:30 a.m. to 12:00 noon. Time sheet data were compiled within these shift schedules for the segments recorded. Delay or Crew Moves were not estimated for blasting.

Field Notes

Field note data along with time card data were used to compile activities of the remaining crews. These crews usually worked regular 7:30 a.m. to 4:00 p.m. shifts, with lunch from 11:30 a.m. to 12:00 noon. The number of man-hours determined from field notes were made consistent with those paid, primarily by means of Delay codes. Crews were often late starting and early stopping work. Time spent in activities such as Crew Moves, gravel "Hauling" and "Skidding" were assigned to segments by apportioning the time by distance covered within each segment. Time spent blasting by drill crews was confirmed by time sheet data. Right-of-way log hauling within the drainage was estimated by the Franklin Division. For each load, it was estimated that, on the average, it took 45 minutes to load the truck, 5 to 10 minutes to fasten the binders, and 5 to 10 minutes to drive the truck in and out of the drainage.

Analysis

The objective of the analysis was to illustrate how to estimate the damage prevention cost for the Ritherdon Road project. The sediment and production data were analyzed to determine which tasks caused the highest sediment levels under given hydrological conditions. The results were to have been used to determine which tasks needed to be modified to prevent high sediment discharges and to estimate the extra cost of doing so. However, the results of the analysis were inconclusive. One reason for these results was that few high sediment readings were recorded during the construction period. Construction was delayed for 8 working days in January and for 14 working days in February due to snow conditions. This prevented construction from progressing much beyond segments one and two before the wet season ended. The dry weather after March precluded the occurrence of high sediment discharge levels even at sensitive locations along the road. Relatively high sediment levels were recorded below segment one at sampler station 21 and segment two at sampler station 22 during January 22 to April 4, 1975. Except for the April 4 samples, the corresponding production data were based only on time card information. It is also possible that tasks alone were not responsible for high sediment levels. The degree of completion in which the subgrade was left before crews progressed along the route may have had more influence than tasks alone on sediment levels. Therefore, it is likely that the lack of completion of tasks rather than the manner in which tasks were performed may have caused high sediment discharge levels.

There were too few samples to determine a relationship between sediment levels and tasks by flow or precipitation. If this had been possible, the probability of significant sediment levels occurring as a result of road condition, hydrological factors, tasks performed and segment characteristics could have been estimated. From this relationship, the damage prevention cost could have been estimated. In lieu of such relationships, the information available from this study will be used to illustrate how to estimate the least cost preventive prescription to achieve a stream quality standard.

Damage from Sedimentation

The determination of a satisfactory standard of sediment discharge level from the road requires much more knowledge than is currently available. For illustrative purposes, all sediment discharge levels over 1000 ppm were arbitrarily assumed to be "significant" in contributing to damage to spawning and rearing grounds. Discharge levels less than 1000 ppm were assumed to be diluted and flushed through the stream system, or deposited in tributary stream beds and then flushed out of the stream system during winter freshets. To connect the instantaneous sediment sample values with continuous construction activity, it was assumed that significant discharge levels resulted from construction activities conducted within the 2-hour period preceding the time the sample was taken. It is probable that most high significant levels resulted from activity that occurred shortly before the sample was taken. Significant discharges occurred only from segments one and two during January, March and April (Appendix III).

Pre-, during- and post-construction sediment samples were available only for sampler stations 21 and 22. Respective average sediment levels recorded at station 21 below segment I were 9 ppm (57 samples), 57 ppm (213 samples) and 15 ppm (93 samples). Although average sediment levels increased during construction, levels exceeded 1000 ppm in only 2 of 213 samples, of 1% of the time. Both of these significant samples occurred during the afternoon of January 22. On that day, 4.63 cm of precipitation fell and flow at "C" weir was rising and at storm run-off level. Tasks performed were skidding right-of-way logs, subgrade excavation and rock drilling. The first 100 feet of the road had been ballasted on January 20 to fill a troublesome mud hole. However, surface and subsurface run-off resulting from both precipitation and snow melt made the road very muddy.

The average sediment level recorded during construction from segment two at station 22 was 525 ppm. Levels exceeded 1000 ppm in 31 of 238 samples, or 13% of the time. Significant levels were discharged during various flow characteristics and precipitation amounts. However, the average significant sediment level recorded was much higher when flow at "C" weir was at storm run-off level and falling. The significance of this observation can only be assessed in the context of all the sample data which were collected.[5] The main cause of sediment discharges from this segment was the movement through and operation in a pond on the road at station 14+00. This pond collected water flowing in a small stream interrupted by a road cut and a ballast rock quarry.

Damage Reduction Schedule

Given a desired level of sediment discharged from segments one and two combined, i.e. the whole road, a number of preventive prescriptions could have been followed to reduce sediment levels with varying degrees of success.

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[5] Further analysis of sediment levels in response to hydrological conditions is being conducted by the Fisheries and Marine Service.

A schedule of prescriptions and expected reduced damage comprise a damage reduction schedule. The question of what the least cost prescription is remains. A least cost method of reducing sedimentation to a desired level can be achieved if the extra cost of reducing the last unit of sedimentation is equal at each sediment source, i.e. the marginal cost of sedimentation prevention is equal at each segment.

A damage reduction schedule for the purposes of this report is a hypothetical schedule of reduced number of significant sediment discharges from both segments which can be achieved by various preventive engineering prescriptions during a given time period. Sample concentrations were not used to derive a hypothetical damage reduction schedule. It is now known how sediment levels of various magnitudes and durations affect habitat quality. Furthermore, since sediment levels were sampled at regular intervals while levels actually fluctuated randomly, the probability of certain average levels occurring under given conditions is more meaningful for deriving such a schedule. If sufficient information were available, the probability of the occurrence of a number of significant sediment discharges at sensitive portions of a road route could be estimated. In the study road, significant discharges occurred 1% of the time from segment one and 13% of the time from segment two. If, for a given time period, habitat deterioration increases with the number of significant sediment discharges, the pollution standard might be a maximum total number of significant discharges for a set time period from all point sources. The logging road engineer could then consider an array of sedimentation prevention measures of various expected degrees of effectiveness and cost for all sensitive portions of his route, in this case segments one and two (Table 1). His goal

Table 1. Hypothetical Damage Prevention Schedule.

Prescriptions	Damage Prevention Cost		Expected Number of "Significant" Sediment Discharges Reduced
	Total Cost $[1]	Marginal Cost $/Discharge	
Segment 1			
Nil	Nil	Nil	Nil
Ditch	X_1	X_1	1
Ditch, culvert	Y_1	Y_1-X_1	1.5
Ditch, culvert, ballast	Z_1	Z_1-Y_1	2
Segment 2			
Nil	Nil	Nil	Nil
Ditch and culvert	W_2	W_2	5
avoid quarry at station 13+50	X_2	W_2-X_2	12
avoid quarry at station 13+50 and ditch and culvert	Y_2	Y_2-X_2	20
avoid quarry at station 13+50 and ditch, culvert, and ballast	Z_2	Z_2-Y_2	23

1 Where $W<X<Y<Z$

would be to choose a set of prescriptions which are likely to meet the pollution standard at the lowest possible cost.

Least Cost Damage Reduction

The cost per number of significant sediment discharges avoided for a given standard will be lowest for both segments combined when the extra cost of the last discharge avoided is equal for both segments. This can be demonstrated graphically by adapting a model used by Kneese and Bower (1968) (Figure 3). They showed that in the case where two or more firms were polluting the same water body, least cost abatement would be achieved in response to a uniform pollution charge. Each firm would reduce its discharges until the additional cost of reducing the last unit of discharge was equal to the charge C. At charge C, 80 units of pollutants would still be discharged by both firms combined, 55 units by firm 1 and 25 units by firm 2, at a total cost of $a_1 + a_2$[6/]. Any other combination of pollution reduction to achieve a standard of 80 units would be more costly. If both firms were required to reduce their discharges by 60 units, the total cost $(a_1 - b_1) + (a_2 + b_2)$ is more than $a_1 + a_2$. If an effluent standard of 80 units were set instead of an effluent charge C, and if the firms could negotiate or if the firms were owned by one owner, the least cost solution could be achieved. In the road sedimentation case, since one firm controls all point sources, the least cost solution to meeting the standard would not require inter-firm negotiation. The solution could be determined until the target number of significant discharges were achieved at least cost (Figure 4).

If the standard were ten significant sediment discharges during the construction period, the least abatement cost would be $s_1 + s_2$. Between one and two probable significant sediment discharges would be reduced from segment one, and 20 from segment two. The least cost prescription would, of course, add the least amount to the cost of the road.

Conclusions and Recommendations

Although the data gathered for that study were insufficient to derive definite relationships between sedimentation from logging road construction and damage prevention costs, the information and experience gained may serve to illustrate a possible approach to achieving least cost sedimentation prevention and the critical data gaps. The possibility that the road was designed and constructed so that very little sedimentation occurred during the study period should not be ignored in developing guidelines.

The insufficient number of significant observations indicate that either long-term study in a single watershed or a study encompassing more than one study area, or both, are required to gain sufficient information to develop biologically significant sedimentation standards, and least cost and effective road design and construction remedies. It is not enough to study sedimentation only during the construction phase. It is important to determine the sedimentation caused by the degree of completion that the road is left in after completion of construction. This will yield a two-part analysis that should contribute toward linking road design and construction effects on stream habitat quality during complete years or the life cycle of salmon. It is well recognized that much hydrological and biological information remains to be acquired. There is also a need to conduct more work to determine efficient measures of preventing sedimentation from roads and their costs. More detailed cost accounting on road projects using special categories for environmental design and practices will, if supplemented with sedimentation monitoring, aid in determining effective and least cost remedies for meeting sediment standards.

6/ Since marginal cost function is the first derivative of total cost, the area beneath the marginal cost curve is equal to the total cost.

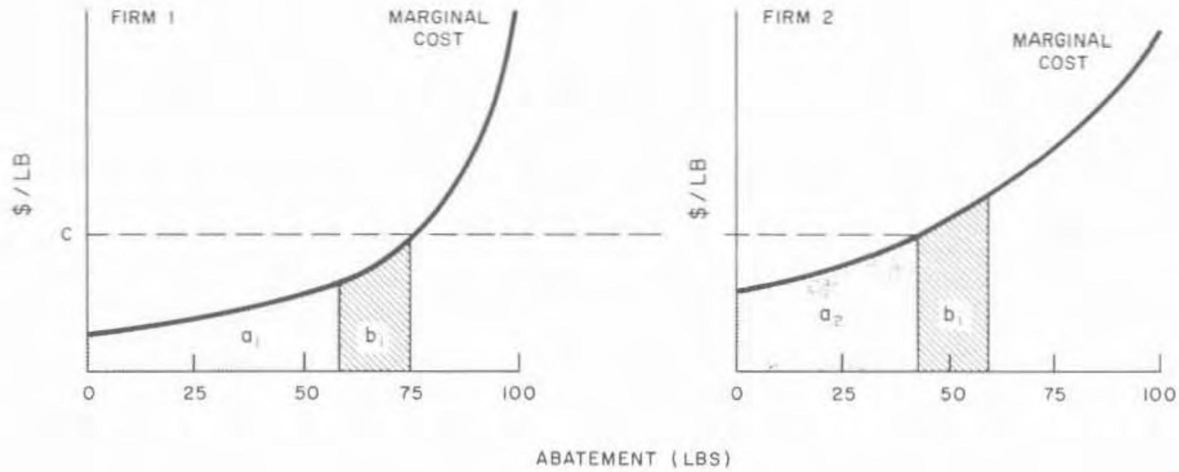

Figure 3. Abatement Cost with Effluent Charge (Kneese and Bower 1968)

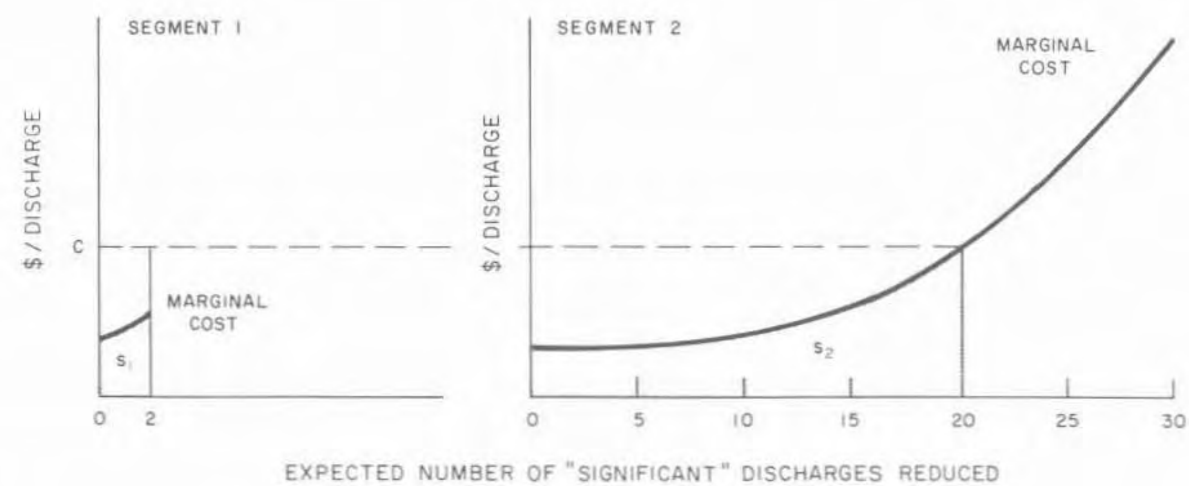

Figure 4. Least Cost Reduction of "Significant" Sediment Discharges from Segments One and Two

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APPENDIX I

Road Segments and Corresponding Sediment Samplers

ROAD SEGMENT			SAMPLERS		
No.	Road	Stations	No.	Location on Ritherton Road	Sampling Period 1975
1	Main	0+00 - 10+50	21	3+00	Jan. 7 - Mar. 23
2	Main	10+50 - 17+00	22	13 + 75	Mar. 2 - Apr. 5
12	R810	2+00 - 10+00	22		
3	Main	17+00 - 31+00	23	25+00	Mar. 23 - Mar. 25
	Main spur	0+00 - 2+50	23		
	R800	0+00 - 13+00	23		
7	R810	0+00 - 2+00	23		
	R800	13+00 - 15+50	23		
8	R800	15+50 - 25+00	24	36+00-"J" east	Mar. 30 - May 26 Aug. 27 - Nov. 15
	R820	0+00 - 3+00	24		
4	Main	31+00 - 36+00	24		
9	R800	25+00 - 32+50	25	Below jnctn. 43+00 + 46+00 - "J" west	Apr. 10 - May 26 Aug. 27 - Nov. 18
13	R820	3+00 - 10+50	25		
10	R800	32+50 - 38+00	25		
11	R800	38+00 - 61+00	25		
5	Main	36+00 - 51+50	25		
8	R800	15+50 - 25+00	26	Below no. 24 on "J" east	Aug. 27 - Nov. 1
	R820	0+00 - 3+00	26		
4	Main	31+00 - 36+00	26		

APPENDIX II

Cost Accounting Codes

Code	Description
100	Construction
110	Site Preparation
112	Right of way logging
112.1	Falling and bucking
112.11	Falling and backing call time
112.2	Skidding
112.3	Loading and trucking
112.4	Delays
112.5	Crew moves ("equipment walks")
115-118	Pioneer subgrade construction
115-118.1	Crew moves
115-118.2	Delays
120	Excavation
121	Solid rock
121.1	Drilling
121.11	Drilling
121.12	Crew moves
121.13	Delays
121.2	Blasting (excl. stumps and quarries)
121.3	Rock movement
121.31	Crew moves
121.32	Delays
122	Other material
122.1	Crew moves
122.2	Delays
130	Gravelling
131	Quarrying
131.1	Drilling and blasting
131.2	Loading
131.21	Delays
133	Hauling
133.1	Delays
134	Spreading
134.1	Delays
160	Installation
161	Culverts
161.1	Metal
161.2	Wooden
161.3	Delays
161.4	Crew moves

Code			Description
	170		Materials
		171	Culverts
		172	Explosives
400			Overhead
	410		Supervision
		411	Engineer
		412	Grade foreman
		413	Bullbacker
		414	Logging foreman
	430		Surveying
		431	Route surveys and plans
		433	Right of way marking
		434	Design
600			Lunchbreaks

APPENDIX III

SELECTED CONSTRUCTION AND SEDIMENTATION DATA

Sampler No. 21

Date	Sediment Level	HYDROLOGICAL CONDITIONS Total Daily Precipitation	Flow	Time of Sample	Time of Construction Tasks	Stations where tasks performed	Crew	Tasks Performed	Task Code	Daily Road Condition of Segment
	ppm	(cm)	(1)	(2)	(3)	(3)	(4)		(5)	(6)
SAMPLER PS21										Pioneered St. 3+00 to 5+50
Jan 22		4.63			730 - 1130	3+00-5+50	E24	Excavation, om	122	Subgrade to station 3+00
						0+00-5+50	Clark 668	Skidding R/W logs	112.2	Ballast to station 1+00
					1130 - 1200	0+00-5+50	E24	Lunch	600	No ditching or culverts
						0+00-5+50	Clark 668	Lunch	600	
	4250		2	1447	1200 - 1447	3+00-5+50	E24	Excavation, om	122	
						0+00-5+50	Clark 668	Skidding R/W logs	112.2	
						5+50	No 9	Drilling rock	121.11	
	1628		2	1651	1447 - 1600	3+00-5+50	E24	Excavation, om	122	
						0+00-5+50	Clark 668	Skidding R/W logs	112.2	
						5+50	No 9	Drilling rock	121.11	
SAMPLER PS22										Pioneer to station 16+00
March 3		Nil			730 - 904	16+00-17+00	E24	Excavation, rock	121.3	Subgrade to station 13+00
						16+00	No 9	Drilling rock	121.11	No ballast, ditches, culverts
	4052		6	1104	904 - 1000	16+00-17+00	E24	Excavation, rock	121.3	
						16+00	No 9	Drilling rock	121.11	
					1000 - 1104	16+00-17+00	E24	Excavation, rock	121.3	
						16+00	No 9	Drilling rock	121.11	
						16+00	Blasters	Blasting rock	121.2	

	8382		6	1307	1104 - 1130	16+00-17+00	E24	Excavation, rock	121.3	
						16+00	No 9	Drilling rock	121.11	
						16+00	Blasters	Blasting rock	121.2	
					1130 - 1200	16+00-17+00	E24	Lunch	600	
						16+00	No 9	Lunch	600	
						16+00	Blasters	Lunch	600	
					1200 - 1307	16+00-17+00	E24	Excavation,	121.3	
						16+00	No 9	Drilling rock	121.11	
						16+00	Blasters	Blasting rock	121.2	
	6906		6	1511	1307 - 1511	16+00-17+00	E24	Excavation, rock	121.3	
						16+00	No 9	Drilling rock	121.11	
						16+00	Blasters	Blasting rock	121.2	
	5872		6	1714	1511 - 1600	16+00-17+00	E24	Excavation, rock	121.3	
						16+00	No 9	Drilling rock	121.11	
						16+00	Blasters	Blasting rock	121.2	
					1600 - 1714	16+00	No 9	Drilling Rock	121.11	
	4798		6	1918	1714 - 1918	16+00	No 9	Drilling Rock	121.11	
	3298		6	2121	1918 - 2121	16+00	No 9	Drilling Rock	121.11	
	2834		6	2325	2121 - 2325	16+00	No 9	Drilling Rock	121.11	
					2325 - 2400	16+00	No 9	Drilling Rock	121.11	
March 4										
		Nil			2400 - 0030	16+00	No 9	Drilling rock	121.11	Subgrade to Station 16+00
	1983		6	0128						No ballast, ditches, culverts
	3034		6	925	730 - 925	17+00-18+00	E24	Pioneering	115-118	
						17+00-18+00	No 9	Drilling rock	121.11	
						16+00	Blasters	Blasting rock	121.2	

				925 - 1000	17+00-18+00	E24	Pioneering	115-118	
					17+00-18+00	No 9	Drilling rock	121.11	
					12+00	Blasters	Blasting rock	121.2	
				1000 - 1034	17+00-18+00	E24	Pioneering	115-118	
					17+00-18+00	No 9	Broken	121.13	
					12+00	Blasters	Blasting rock	121.2	
4031		6	1234	1034 - 1130	17+00-18+00	E24	Pioneering	115-118	
					17+00-18+00	No 9	Broken	121.13	
					12+00	Blasters	Blasting rock	121.2	
				1130 - 1200	17+00-18+00	E24	Lunch	600	
					17+00-18+00	No 9	Lunch	600	
					12+00	Blasters	Lunch	600	
				1200 - 1234	17+00-18+00	E24	Pioneering	115-118	
					17+00-18+00	No 9	Broken	121.13	
					12+00	Blasters	Blasting rock	121.2	
				1234 - 1600	17+00-18+00	E24	Pioneering	115-118	
					17+00-18+00	No 9	Broken	121.13	
					12+00	Blasters	Blasting rock	121.2	
				1600 - 2000	17+00-18+00	No 9	Drilling rock	121.11	
				2000 - 2030	17+00-18+00	No 9	Lunch	600	
				2030 - 2400	17+00-18+00	No 9	Drilling rock	121.11	
March 5	Nil			2400 - 0030	17+00-18+00	No 9	Drilling rock	121.11	Pioneered to Station 18+00
				730 - 1130	18+00-19+00	E24	Pioneering	115-118	Subgrade to station 17+00
					19+00	No 9	Drilling rock	121.11	No ballast, ditches, culverts
				1130 - 1200	18+00-19+00	E24	Lunch	600	
					19+00	No 9	Lunch	600	

					1200 - 1319	18+00-19+00	E24	Pioneering	115-118	
						19+00	No 9	Drilling rock	121.11	
						19+00	Blasters	Blasting rock	121.2	
	1224		5	1519	1319 - 1519	18+00-19+00	E24	Pioneering	115-118	
						19+00	No 9	Drilling rock	121.11	
						19+00	Blasters	Blasting rock	121.2	
					1600 - 2000	12+00	No 9	Drilling rock	121.11	
					2000 - 2030	12+00	No 9	Lunch	600	
					2030 - 2400	12+00	No 9	Drilling rock	121.11	
March 6										
		Nil			2400 - 0030	12+00	No 9	Drilling rock	121.11	Pioneered to station 19+00
	3874		5	900	730 - 900	16+50	E24	Delay	121.32	Subgrade to station 17+00
						19+00	No 9	Blasting rock	121.2	No ballast, ditches, culverts
					900 - 1130	18+00-19+00	E24	Excavating rock	121.3	
						20+00	No 9	Drill	121.11	
					1130 - 1200	18+00-19+00	E24	Lunch	600	
						20+00	No 9	Lunch	600	
					1200 - 1230	18+00-19+00	E24	Excavating rock	121.3	
						20+00	No 9	Drilling rock	121.11	
					1230 - 1600	18+00-19+00	E24	Excavating rock	121.3	
						20+00	No 9	Broken	121.13	
March 7										
		Nil			730 - 1130	20+00	No 9	Drilling rock	121.11	Pioneered to station 20+00
					1130 - 1200	20+00	No 9	Lunch	600	Subgrade to station 19+00
					1200 - 1300	20+00	No 9	Drilling rock	121.11	No ballast, ditches, culverts
					1300 - 1600	20+00	No 9	Blasting	121.2	

March 8, 9 (Weekend)										
March 10										
		Nil			730 - 815	16+50	No 9	Broken	121.13	Pioneered to station 20+00
	1211		1	1015	815 - 1015	16+50	No 9	Broken	121.13	Subgrade to station 19+00
	1012		1	1219	1015 - 1130	16+50	No 9	Broken	121.13	No ballast, ditches, culverts
					1130 - 1200	16+50	No 9	Lunch	600	
					1200 - 1212	16+50	No 9	Broken	121.13	
					1212 - 1600	16+50	No 9	Broken	121.13	
					1600 - 2000	20+00	No 9	Drilling rock	121.11	
					2000 - 2030	20+00	No 9	Lunch	600	
					2030 - 2340	20+00	No 9	Drilling rock	121.11	
	1865		5	0040	2340 - 2400	20+00	No 9	Drilling rock	121.11	
March 11										
		0.71			0000 - 0030	20+00	No 9	Drilling rock	121.11	Pioneered to station 20+00
	1530		3	854	730 - 854	18+00	No 9	Drilling rock	121.11	Subgrade to station 19+00
					854 - 1101	18+00	No 9	Drilling rock	121.11	No ballast, ditches, culverts
	1106		3	1301	1101 - 1130	18+00	No 9	Drilling rock	121.11	
					1130 - 1200	18+00	No 9	Lunch	600	
					1200 - 1301	18+00	No 9	Drilling rock	121.11	
					1301 - 1600	18+00	No 9	Drilling rock	121.11	
					1600 - 1711	18+00	No 9	Drilling rock	121.11	
	1204		3	1911	1711 - 1911	18+00	No 9	Drilling rock	121.11	
					1911 - 2000	18+00	No 9	Drilling rock	121.11	
					2000 - 2030	18+00	No 9	Lunch	600	
March 11										
					2030 - 2118	18+00	No 9	Drilling rock	121.11	Pioneered to station 20+00
	1159		3		2118 - 2318	18+00	No 9	Drilling rock	121.11	Subgrade to station 19+00

					2318 - 2400	18+00	No 9	Drilling rock	121.11	No ballast, ditches, culverts
March 12										
		0.03 cm			2400 - 0030	18+00	No 9	Drilling rock	121.11	Pioneered to station 20+00
	1611		1	732	730 - 732	18+00	No 9	Drilling rock	121.11	Subgrade to station 19+00
					732 - 1100	18+00	No 9	Drilling rock	121.11	No ballast, ditches, culverts
					1100 - 1130	18+00	No 9	Drilling rock	121.11	
					1130 - 1200	18+00	No 9	Lunch	600	
					1200 - 1300	18+00	No 9	Delay	121.13	
	1992		1	1504	1300 - 1600	18+00	No 9	Drilling rock	121.11	
March 13										
		Nil			730 - 1130	18+00	No 9	Drilling rock	121.11	Pioneered to Station 20+00
					1130 - 1200	18+00	No 9	Lunch	600	Subgrade to station 19+00
					1200 - 1600	17+00-18+00	No 9	Drilling rock	121.11	No ballast, ditches, culverts
					1600 - 2000	16+00-17+00	No 9	Drilling rock	121.11	
					2000 - 2030	16+00-17+00	No 9	Lunch	600	
					2030 - 2400	16-00-17+00	No 9	Drilling rock	121.11	
March 14										
		Nil			2400 - 0030	16+00-17+00	No 9	Drilling rock	121.11	"
March 15										
	1330	1,73 cm	2	203						"
	1992		2	507						"
March 16 (Sunday)										
March 17 (No activity)										
March 18										
		?	?		730 - 930	16+00-19+00	No 9	Drilling rock	121.11	Pioneered to station 20+00
					930 - 1200	16+00-19+00	No 9	Blasting	121.2	Subgrade to station 19+00
					1200 - 1230	16+00-19+00	No 9	Lunch	600	No ballast, ditches, culverts

					1230 - 1300	16+00-19+00	No 9	Delay	121.13	
					1300 - 1600	16+00-19+00	No 9	Blasting	121.2	
						19+00-21+00	E90	Excavating, rock	121.3	
March 19										
	3106	1.07cm	2	937	730 - 937	16+00	No 9	Drilling rock	121.11	Pioneered to station 21+00
						15+00-21+00	E90	Excavating rock	121.3	Subgrade to station 19+00
						15+00-18+00	Blasters	Blasting rock	121.2	No ballast, ditches, culverts
					937 - 1130	15+00-18+00	No 9	Blasting rock	121.2	
						15+00-18+00	Blasters	Blasting rock	121.2	
						15+00-21+00	E90	Excavating rock	121.3	
					1130 - 1200	15+00-18+00	No 9	Lunch	600	
						15+00-18+00	Blasters	Lunch	600	
						15+00-21+00	E90	Lunch	600	
					1200 - 1600	15+00-18+00	No 9	Blasting rock	121.2	
						15+00-18+00	Blasters	Blasting rock	121.2	
March 20										
	8647	2.46 cm	6	815	730 - 815	21+00	No 9	Blasting quarrie	131.1	Pioneered to station 21+00
						15+00-18+00	E90	Excavating rock	121.3	Subgrade to station 19+00
					815 - 1023	21+00	No 9	Blasting quarrie	131.1	No ballast, ditches, culverts
						15+00-18+00	E90	Excavating rock	121.3	
	6457		6	1223	1023 - 1130	21+00	No 9	Blasting quarrie	131.1	
						15+00-18+00	E90	Excavating rock	121.3	
					1130 - 1200	21+00	No 9	Lunch	600	
						15+00-18+00	E90	Lunch	600	
March 20										
					1200 - 1223	21+00	No 9	Blasting quarrie	131.1	Pioneered to station 21+00

						20+00-21+00	E90	Excavating rock	121.3	Subgrade to station 19+00
						20+00-22+00	S13	Excavating, om	122	No ballast, ditches, culverts
					1223 - 1400	21+00	No 9	Blasting quarrie	131.1	
						20+00-21+00	E90	Excavating rock	121.3	
						20+00-22+00	S13	Excavating, om	122	
					1400 - 1600	21+00	No 9	Drilling quarrie	131.1	
						20+00-21+00	E90	Excavating rock	121.3	
						20+00-22+00	S13	Excavating, om	122	
					1600 - 2000	21+00	No 9	Drilling quarrie	131.1	
					2000 - 2030	21+00	No 9	Lunch	600	
					2030 - 2400	21+00	No 9	Drilling quarrie	131.1	
March 21										
		?			2400 - 0030	21+00	No 9	Drilling quarrie	131.1	"
March 22, 23 were Saturday and Sunday										
March 24										
		Nil			730 - 942	15+00-22+00	E90	Excavating rock	121.3	Pioneered to station 22+00
						22+00	No 9	Blasting rock	121.2	Subgrade to station 20+00
	1488		5	1142	942 - 1130	15+00-22+00	E90	Excavating rock	121.3	No ballast, ditches, culverts
						22+00	No 9	Broken	121.13	
						18+00	Blasters	Blasting quarrie	131.1	
					1130 - 1142	15+00-22+00	E90	Lunch	600	
						22+00	No 9	Lunch	600	
						18+00	Blasters	Lunch	600	
					1142 - 1200	15+00-22+00	E90	Lunch	600	
						22+00	No 9	Lunch	600	
						18+00	Blasters	Lunch	600	

					1142 - 1200	15+00-22+00	E90	Lunch	600	
						22+00	No 9	Lunch	600	
						18+00	Blasters	Lunch	600	
					1200 - 1349	15+00-22+00	E90	Excavating rock	121.3	
						22+00	No 9	Broken	121.13	
						18+00	Blasters	Blasting quarrie	131.1	
	2042		5	1549	1349 - 1400	15+00-22+00	E90	Excavating rock	121.3	
						22+00	No 9	Broken	121.13	
						18+00	Blasters	Blasting quarrie	131.1	
					1400 - 1549	15+00-22+00	E90	Excavating rock	121.3	
						22+00	No 9	Drilling rock	121.11	
						18+00	Blasters	Blasting quarrie	131.1	
			5	1753	1549 - 1600	15+00-22+00	E90	Excavating rock	121.3	
						22+00	No 9	Drilling rock	121.11	
						18+00	Blasters	Blasting quarrie	131.1	
					1600 - 1753	19+00	No 9	Drilling quarrie	131.11	
					1753 - 2000	19+00	No 9	Drilling quarrie	131.11	
					2000 - 2030	19+00	No 9	Lunch	600	
					2030 - 2400	19+00	No 9	Drilling quarrie	131.11	
March 25										
					2400 - 0030	19+00	No 9	Drilling quarrie	131.11	
April 4										
		0.38 cm			730 - 1054	15+00-Seg. 3	Ballast	Ballasting	131,'2,133,134	Subgrade to station 22+00
	2916		2	1254	1054 - 1130	15+00-Seg. 3	Ballast	Ballasting	131.2,133,134	No ballast, ditches, culverts
					1130 - 1200	15+00	Ballast	Lunch	600	
					1200 - 1254	15+00-Seg. 3	Ballast	Ballasting	131.2,133,134	

1544	2	1438	1254 - 1458	15+00-Seg. 3	Ballast	Ballasting	131.2,133,134
			1458 - 1600	15+00-Seg. 3	Ballast	Ballasting	131.2,133,134

NOTES

1. Hydrograph record from C-wier:
   1. rising - no storm flow
   2. rising - storm flow
   3. stable - no storm flow
   4. stable - storm flow
   5. falling - no storm flow
   6. falling - storm

2. Water sample taken every two hours. Three minutes were required to take a sample and reset mechanism to be ready to take the next sample.

3. Estimated from time card data. Stations reported by crews on daily time cards.

4. Crews were as follows:
   E24 - a D-9 bulldozer with operator and swamper
   Clark 668 - a rubber-tire skidder with operator and one or two chokermen
   No 9 - a track-mounted compresser - rock drill with operator and helper
   blasters - a powderman with one helper
   E 90 - Terex 82-40 bulldozer with operator and swamper
   S13 - a Poclain HC 300 with operator and swamper
   Ballast - a Catterpiller 950 front-end loader, TD20C bulldozer (for spreading), 2 or 3 15-cubic yard gravel trucks and operators.

5. See Appendix II.

6. Estimated from time card data.

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