

# Road Alignment and Haul Routing in Estimating Sediment Delivery to Streams

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## Abstract

The operational and environmental impacts of a conventional and a long-span yarding approach to forest management were simulated and compared in T12N R14E in the Ahtanum valley West of Yakima, WA. The conventional approach produced higher revenues at lower costs as expected, but delivered no more sediment to the stream than the long-span, no-new-roads approach. The explanation for this counter-intuitive result can be found in the density of the road network and its proximity to the stream. The road network produced a tenfold sediment increase over background levels, which might suggest a program of elimination and/or surfacing of existing roads. Analysis of this case, however, suggests that the construction of a ridge-based road network will be both environmentally and economically superior. This approach of integrating cumulative environmental impacts into the landscape scale harvest and transportation planning appears promising for identifying management options for reducing salmonid habitat degradation.

## Introduction

The Washington Department of Natural Resources (DNR) entered into an agreement with the federal government relating to the compliance with the federal endangered Species Act (16 USC 1531 et seq). As part of that agreement DNR developed a Habitat Conservation Plan (HCP) which would provide the framework for the management activities of its trust lands (DNR, 1997). Significant changes to timber sales requirements resulted. Rather than commit to a definite, upper limit on road densities, DNR agreed to provide for a comprehensive landscape-based road network management process. The major components of that process includes the minimization of the active road density and a site specific assessment of alternatives to new road construction such as extending yarding distances and their use where consistent with conservation objectives (DNR, 1997).

Impacts on salmonid habitat or water resources in general are influenced by activities in any one of the six general phases of road system development: planning (yarding distance – road densities/locations), design, construction, use, maintenance, and decommissioning. (Everest, et al. 1987). The planning aspect includes the trade-off of yarding distance – road densities and within this general framework the location of roads based on the particular topographic and geologic conditions. A clear understanding of a total and true cost accounting of the road transportation system has to include aspects of sediment generation and sediment delivery to the stream network.

The overall goal as stated in the HCP is to reduce road densities based on the assumptions that this is one of the significant factors that affect salmonid habitat. Road density reduction would be achieved through a combination of increased yarding distances and an aggressive road-decommissioning program. Both options (increased yarding distance, road decommissioning) have costs associated with them and both strategies will result in decreased road densities. However, as will be shown,

neither strategy alone, or in combination may reduce the true agent of salmonid habitat degradation; sediment delivery.

What is needed is an integrative approach to road system development including new road construction. What is not quite clear are the cumulative effects of either or what a combined strategy has on the natural resources and habitat of sensitive species. Any comparative analyze should attempt to quantify road use patterns (and with it the economic trade-off) and include sediment budgets as the true agents of salmonid habitat degradation

## **Objectives**

The objective of this study was to develop a framework for comparing the economic and environmental costs of conventional harvest systems versus a road minimizing option using a combination of long-reach skylines, helicopters, ground-based systems. Each management plan would be assessed based on the economics and the resulting sediment budgets.

1. Analyze the impacts and trade-offs of long-span yarding systems and reduced roading on total costs and revenues.
2. Assess the impacts of roads on sediment generation and delivery to salmonid habitat.

## **Approach**

The project was organized along the two activities in order to address the issues mentioned earlier. First, the operational and economic parameters for a harvest and transportation plan comparison of a portion of the Ahtanum watershed were developed. Its purpose was to develop a long-span yarding alternative with the resulting road system and compare the results (revenues and road densities) with the current harvest and transportation plan that had been developed by DNR harvest planners using conventional yarding systems and yarding distances. The second activity centered on developing the resulting sediment budgets for each alternative based on road use pattern and traffic loads (sediment generation and delivery).

## **Harvest Scheduling and Road Network Analysis**

The Ahtanum is characterized by its checkerboard ownership pattern where various other landowners are involved, each with different land management goals. To reduce those impacts a township was selected for further analysis where DNR had substantial (although no exclusive) ownership. The original harvest and transportation plan developed by DNR harvest planners was adjusted to reflect the new planning boundaries. However, the stated goals and harvest volume targets were used in the adjusted areas (Figure 1).

The long-span management plan had as its stated goal the reduction of overall road densities. This could be achieved by extending the yarding distances beyond the conventional reach ( $> 610$  m (2000 feet)) and/or by not allowing any new road construction. We chose to use both goals. In order to approach the extremes of

extending conventional yarding distances beyond 610 m (2000 feet) we specified that any setting not currently served by an existing road would be harvested by helicopter (Figure 2).

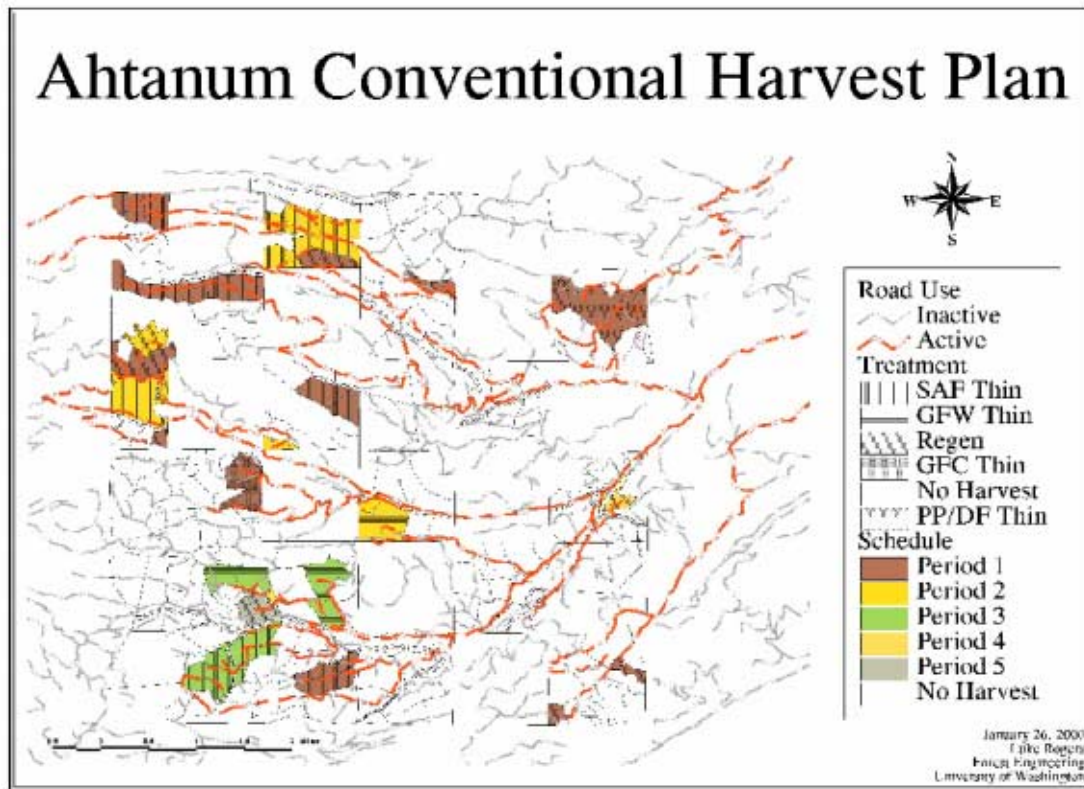


Figure 1. Harvest schedules and road use pattern for the conventional plan over five periods (as developed by DNR). Shown are the harvest areas (by period and silvicultural harvest method) and resulting road use pattern. Non-DNR ownership is usually characterized by an absence of setting boundaries. A total of 19.6 km (12.2 miles) of new roads were constructed with 18.5 km (11.5 miles) on DNR land. A total of 1032 ha (2551 acres) are scheduled for harvest of which 823 ha (2031 acres) are as partial cut and 210 ha (520 acres) as regeneration cut over a 25-year time span (5 planning periods).

The HCP dispersal and NRF habitat requirements as well as the late seral stage requirements agreed upon with local tribes were adhered to for the area-adjusted base plan (DNR's conventional plan) and the long-span plan. Target volumes for both plans were set at 56,600 m<sup>3</sup> (10 MMBF) for the first three periods and then 5660 m<sup>3</sup> (1 MMBF) for periods 4 and 5 as stated in DNR's original base plan. The software used for scheduling and network analysis was SNAP 3.19 (Sessions and Sessions, 1997).

The results for the two management plans are shown in Table 1. Neither plan is able to meet the stated harvest volumes without violating any of the adopted HCP or adjacency requirements. Harvest volumes achieved were about 56,600 m<sup>3</sup> (10 MMBF) over the five periods for both plans. The helicopter use and related harvest patterns reveal some interesting aspects. The conventional plan never used a helicopter despite its potential availability. Targeted volumes could be achieved

within the other constraints without resorting to the more expensive yarding method. It was more cost-effective to build additional roads and utilize a larger road system. The conventional plan used a total of 137.6 km (85.5 miles) versus the 83.2 km (51.7 miles) of existing road length in the long-span version. In the long-span plan, helicopters had to be used in order to meet stated harvest goals from areas that were not constrained by other requirements such as adjacency, seral stage and HCP requirements. As a result the long-span plan tried to meet stated harvest goals by harvesting more areas in closer proximity to existing roads resorting to smaller tree sizes and lower standing volumes. More mature stands further removed from the existing road network proved economically not viable because of the high yarding costs brought about by long cycle times resulting overall in lower values for the timber harvested.

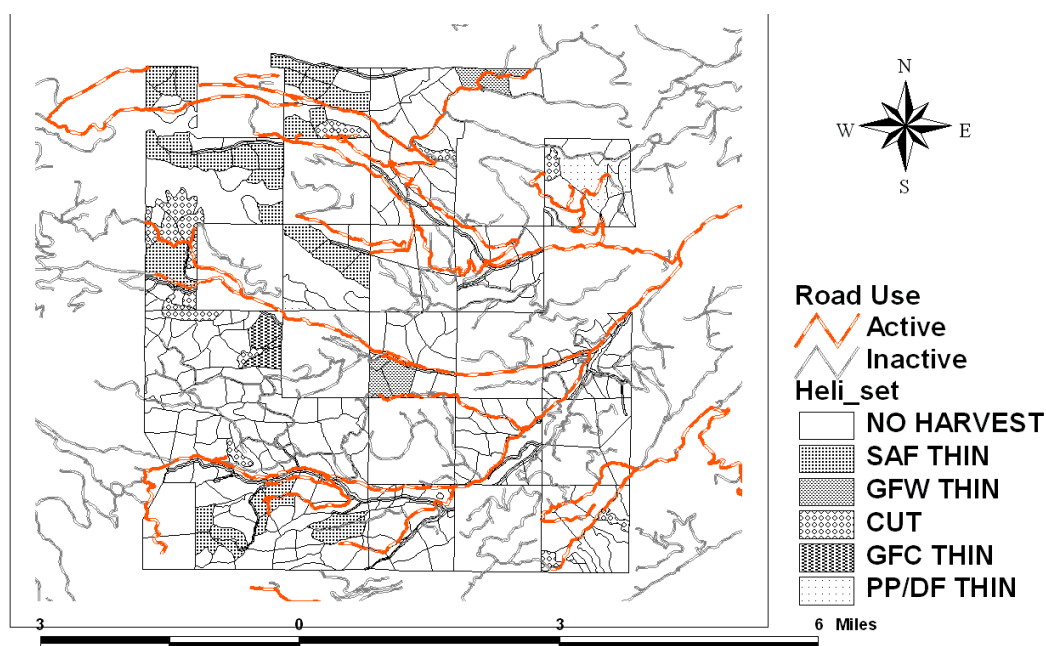


Figure 2. SNAP analysis for the long-span. Shown are the harvest areas (by period and silvicultural harvest method) and resulting road use pattern. Non-DNR ownership is usually characterized by the absence of setting boundaries. Note the absence of any new road construction. A total of 1035 ha (2557 acres) are scheduled for harvest of which 873 ha (2158 acres) as partial cut and 161 ha (399 acres) as regeneration cut over a 25-year time span (5 planning periods).

### Delivered Sediment

The study area was divided into a grid, and information relevant to sediment production and delivery (e.g. local slope, distance to stream, road surfacing) were recorded for each cell. The Washington Forest Practices watershed analysis manual (WFPB, 1997) was used as the basis of a GIS program to estimate sediment production and delivery from each grid cell. Road usage was estimated from the scheduled timber haul estimates ( $\text{m}^3/\text{period}$  (MBF/period)). Vegetation on cut and fill slopes was assumed to increase by 1% per year, while all existing cut and fill slopes were assumed to be 30% vegetated at the start of the simulation. Harvest related soil

disturbance was assumed to produce 1819 t/ha (810 tons/acre) during the period of harvest. Overland filtering/delivery to streams was estimated by assuming that half the sediment was filtered every 27 m (90 feet).

The results of this analysis are summarized in Table 2. Contrary to expectations, the long-span (no new roads) option produced more total sediments than the conventional harvest/transportation plan. The no-new-roads option produced less sediment from cut and fill slopes (which is expected because due to fewer , that is, no-new roads), but this reduction was dwarfed by haul related erosion from the tread surface. In the long-span case the scheduling program routed more of the long-span haul along roads in proximity to the stream network. The resulting increase in total sediment delivery does not represent a failure of the long-span system, but rather that usage of specific roads is far more significant than road density.

Table 1. Results from the scheduling and networking analysis for the two management plans. Shown are the harvest systems utilized, road uses and road construction requirements together with costs and revenues. Note that the long-span plan requires no new road construction.

			5-period Total
Conventional Plan			
Volume harvested			10,688 MBF
Roads used <b>Existing</b>			<b>119 km(74 miles)</b>
Roads used <b>New roads</b>			<b>18.5 km(11.5 miles)</b>
Yarding costs	20 \$/m <sup>3</sup>	112 \$/MBF	\$ 1,200,000
Haul costs	8 \$/m <sup>3</sup>	47 \$/MBF	\$ 507,00
Construction costs	7 \$/m <sup>3</sup>	37 \$/MBF	\$ 396,000
Total Costs	35 \$/m <sup>3</sup>	197 \$/MBF	\$ 2,104,000
Revenues	47 \$/m <sup>3</sup>	269 \$/MBF	\$ 2.880,000
Long-span alternative (no new roads)			
Volume harvested			9218 MBF
Roads used <b>Existing</b>			<b>83.2 km (51.7 miles)</b>
Yarding costs	36 \$/m <sup>3</sup>	202 \$/MBF	\$ 1,861,000
Haul costs	8 \$/m <sup>3</sup>	47 \$/MBF	\$ 431,000
<b>Construction costs</b>	<b>0 \$/m<sup>3</sup></b>	<b>0</b>	<b>0</b>
Total Cost	44 \$/m <sup>3</sup>	249 \$/MBF	\$ 2,294,000
Revenues	44 \$/m <sup>3</sup>	251 \$/MBF	\$ 2.310,000

Minimizing road density did not reduce road sediment because the existing road network (Figure 3, left) routes most of the haul traffic (Figure 3, right) onto roads that closely parallel the stream network (Figure 4). The problem with using road density to describe road impacts is that the vast majority of the road network gets little or no haul, and the vast majority of the haul traffic goes over relatively few road segments. This concentration of haul volume over roads located very close to streams produces the large tread derived sediment load, which in turn dwarfs the sediment produced on all other roads and all other sediment sources in Table 2.

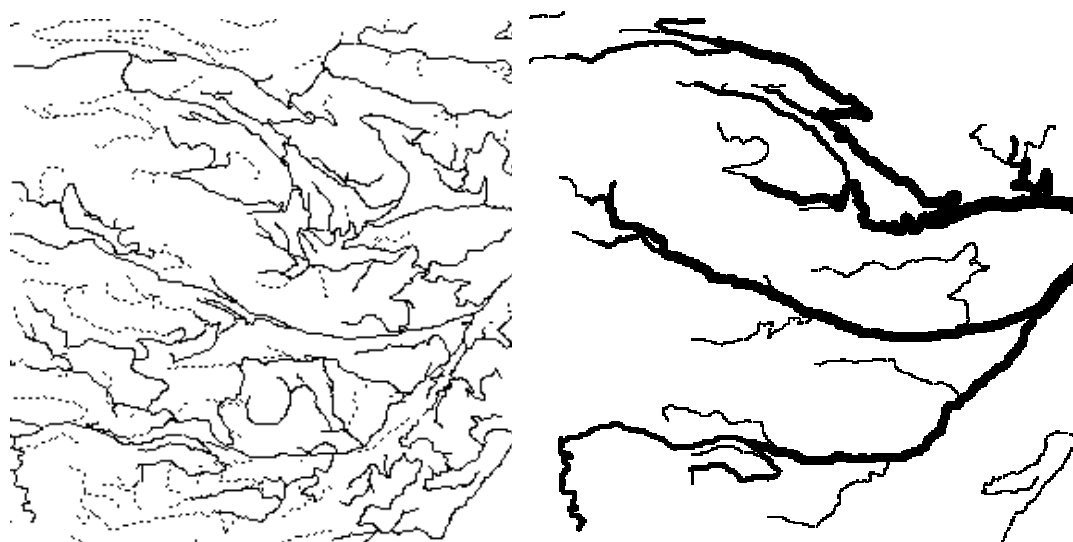


Figure 3. The road network covers most of the planning area (left: existing roads are solid, proposed roads are dashed). Most of these roads remain unused in a 25-year harvest plan and most of the haul is carried over a few roads (right: thicker lines represent more haul traffic).

Table 2. Sediment Delivered to the Stream Network (t/year (tons/year)) is estimated for each management plan, study period, and source area. Concentrating haul onto native surface roads in close proximity to the stream network results in a sediment delivery rate from the road tread that dwarfs all other sources.

Period	1	2	3	4	5	Average
<b>Sediment Delivery t/year (tons/year) Conventional Plan</b>						
Background	678 (747)	678 (747)	678 (747)	678 (747)	678 (747)	678 (747)
Harvest	24 (26)	19 (21)	5 (5)	2 (2)	3 (3)	10(11)
Cut Slopes	345 (380)	337 (371)	318 (350)	288 (318)	285 (314)	315 (347)
Fill slopes	167 (184)	161 (177)	152 (167)	137 (151)	136 (150)	151 (166)
Tread	6778 (7471)	5827 (6423)	3969 (4375)	3144 (3466)	3893 (4291)	4722 (5205)
<b>Sediment Delivery t/year (tons/year) Long-span Plan (no new roads)</b>						
Background	678 (747)	678 (747)	678 (747)	678 (747)	678 (747)	678 (747)
Harvest	27 (30)	21 (23)	4 (4)	4 (4)	0 (0)	11 (12)
Cut Slopes	321 (354)	299 (330)	275 (303)	250 (276)	250 (276)	279 (308)
Fill slopes	159 (175)	149 (164)	137 (151)	124 (137)	124 (137)	139 (153)
Tread	8762 (9658)	6753 (7444)	4081 (4498)	2784 (3069)	2784 (3069)	4722 (5548)

A traditional program of road density reduction would eliminate many unused spur roads, which being unused would thus not be the ones producing the sediment. According to the watershed analysis manual, applying a thick gravel to this native surface road network would eliminate 80% of the tread sediment production but the remaining 20% of the tread related sediment will still approximately double the background sediment. In fact, even if every road in the study area were paved, the cut and fill slopes alone would still provide more than 50% of background levels.

An alternative approach to reducing delivered sediment is suggested by Figure 4 in which long linear segments of the study area can be identified that deliver little or no sediment to the road network. A network of primary and secondary roads following this ridge network (and crossing the stream network only rarely) would deliver almost no sediment to the stream network, even if native surfaced. Assuming that rock accounts for half the cost of a new rocked road, then for the same cost as rocking a



length of existing road, it is possible to build the same length of ridgeline road, with much less sediment delivery.

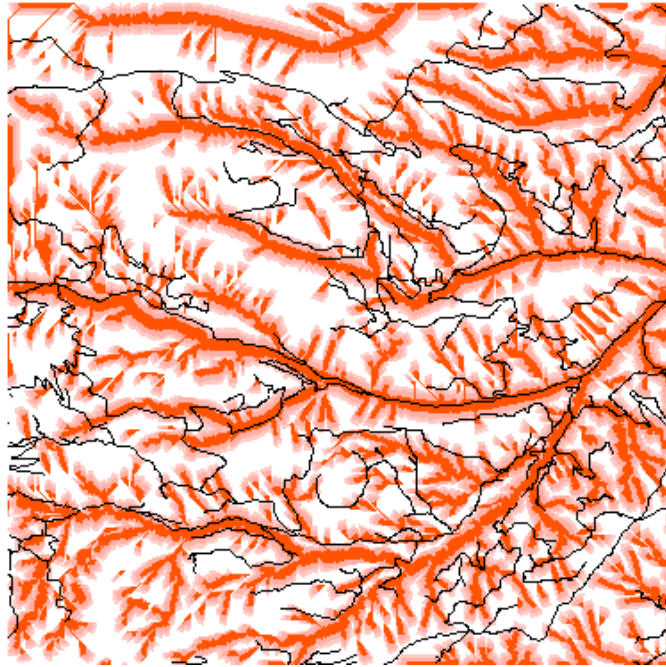


Figure 4. Sediment delivery and the existing road network. While areas near streams have near 100% delivery (darker areas), a large fraction of the landscape has  $<0.1\%$  delivery (white areas), in which road networks can be constructed that will deliver almost no sediment to the stream network. Examples of such ridge road networks exist in the Northwest and Southeast portions of the planning area.

These results show that sediment budgets and their spatial origins are most critical to effectively address salmonid habitat impacts. As shown here and in the Hoodspport analysis (Schiess, 1999), road density management in isolation is not an effective tool to management impacts. To the contrary, uninformed road de-commissioning might result in no improvement at all.

## Conclusion

Effective management to improve salmonid habitat depends on a clear understanding of the agents of sediment generation and delivery. Both processes are directly linked to transportation issues (both yarding and truck haul) which include the earlier stated six general phases of road system development. Paradoxically as it may sound, new road construction may actually improve salmonid habitat by routing traffic over less sensitive roads. However, such a solution is only possible in the context of comprehensive harvest and transportation planning at the landscape or watershed level, which includes cumulative assessment tools, among them a sediment budget. As part of a different project, we are pursuing such an approach.



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