

Evaluating Environmental Impacts From Forest Harvesting Operations . . . A Simulation Approach

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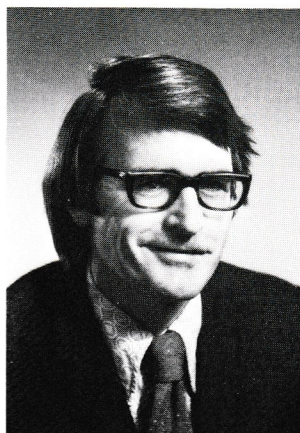
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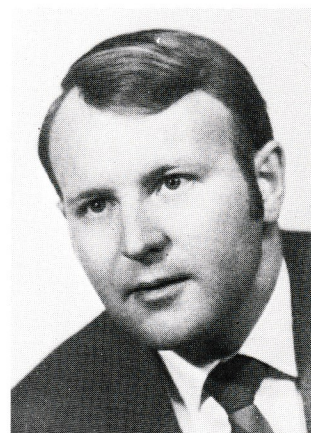
The College of Forest Resources, University of Washington, is currently engaged in a research project which has as its central objective the development of general methodology for evaluating the physical, economic, and environmental consequences of alternative land-use decisions and resultant manipulations of the forest ecosystem. Because of the scope and complexity of this task, the methodology of systems analysis and operations research has been adopted.

Funded by a National Science Foundation grant under the auspices of the Research Applied to National Needs program, the specific objectives of the project revolve around the development of a multi-resource system model that interfaces with an automated information storage and retrieval system. The system model is composed of a series of subsystem models which include forest production, recreation, fish and wildlife, and atmospheric and hydrologic subsystem models. Manipulations of the ecosystem are assessed in relation to their impacts on land, water, and air resources, as well as on the production of utilizable goods and services. Since many of the manipulations generate non-point sources of pollution, a large portion of the program is directed at modeling these processes.

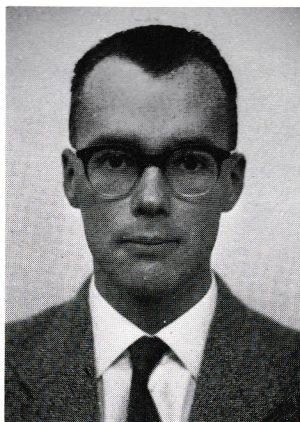
A series of simulation models were developed within the systems approach framework to attain the above-stated objective. These models are used either individually as "stand alone models" or they are interfaced into a single multi-resource system model. Two general types of decisions serve as inputs into these models: (a) land use decisions (e.g., should a particular tract be used for timber production or for recreation?), and (b) management decisions (e.g., should a tract of land be clearcut, should a buffer strip be left and should tractor logging or highlead logging be used?). As a result of these input decisions the models produce two kinds of outputs: (a) goods and services (e.g., board feet of wood produced, recreation user days generated, etc.), and (b) resulting environmental impacts and refine the existing subsystem models. A brief over-



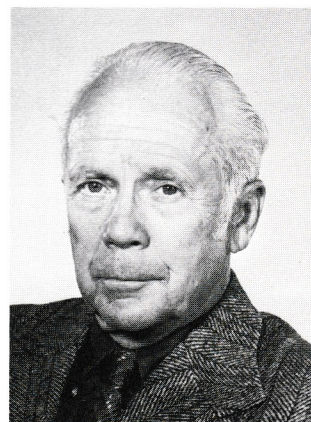
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facts (e.g., sediment load in streams, particulate matter in the air, etc.). Costs and benefits are also generated whenever practicable.

The area selected for calibration and testing of the models developed by the project is the Snohomish River Basin, located on the west slope of the Cascade Mountains in Western Washington. This basin of approximately 1.2 million acres drains into Puget Sound at Everett, Washington. An information storage and retrieval system consisting of a resource data base and a variety of computer programs for producing maps, listings and summaries was developed for this area. This information system also provides the ability to update the resource data base over time as the simulation models are run. While the models and information system were developed with special reference to this basin, a subsidiary objective throughout the study was to utilize the models elsewhere. The feasibility of applying the subsystem models to other areas is being investigated. Another ongoing activity is to validate view and description of the resource data base and the subsystem models follow.

Resource Data Base

The Snohomish River Basin has been subdivided into twenty major watersheds. Within these watersheds the basic area and data unit is a forty-acre cell. Each cell is located by its legal description (i.e., watershed, township, range, section, and cell number) or its Cartesian coordinates.

In addition to locational information, three types of computer data files have been created for the Snohomish Basin. These are: (a) cell file containing attributes describing the contents of each cell, (b) a stream file containing information on the streams, and (c) a group of auxiliary files containing specific types of data needed by subsystem models. Each of these files is briefly described below.

Cell File

A variable size cell system was developed to describe the resources of the Snohomish River Basin. As stated above, a basic cell size of 40 acres was selected. A set of 47 attributes is associated with each of these cells. Table I contains a list of the information currently contained in the cell file. As shown, these attributes relate to either cell identification, physical description, soils data, or timber inventory.

Stream File

Operating in conjunction with the cell file is a stream file. This file contains locational and identifying information for each stream in the basin. Operating in conjunction with the cell file, the stream file provides the capability for routing water flow throughout each major watershed. Streams are located within each 40-acre cell by using an interior set of 12 grid points. Thus, streams are located to the nearest 300 feet. For those cells not containing a stream, a pointer to the cell into which the water will flow is stored. Using the

Table I
Cell File Attributes

<u>Cell Identification</u>	<u>Soils Data</u>
Watershed	Soil type
Township	Site class
Range	Sedimentation yield potential
Section	Capacity to retain chemicals
Cell	Potential for regeneration
Cartesian coordinates of cell (Accounts for two attributes)	
<u>Physical Description</u>	<u>Timber Inventory</u>
Cell size	Type
Land use	Size
Ownership	Crown closure
Cell description	Acres recent harvest
Elevation	Acres re-growth
Slope	Age
Aspect	Site Index
Surface area of lakes	Height
Feet of paved roads	Basal area
Feet of mainline roads	Normal (100%) stocking
Feet of secondary roads	Number of trees
Feet of temporary spur roads	Av. diameter
Feet of streams	Regeneration method
Feet of hiking trails	Fertilization method
Trail classification	Gross volume residue
Feet of railroads	Salvageable residue volume
	Residue reduction method
	Buffer strip protection
	Cubic foot volume

stream file, we are able to reconstruct the watershed which surrounds any selected cell. This provides the capability for assessing the impact of non-point sources of pollution on stream quality at any chosen point. The stream file also permits the assignment of attributes to each stream segment contained in the file. Currently, only locational and identification information is contained in this file. Other attributes such as streamflow histories, fisheries potential, stream gradient, and streambed gravel condition will be added as the information becomes available. Presently, most of these data are not available for the majority of the streams in the basin.

Soils File

The soils found in the basin have been aggregated into 42 classes according to depth, texture, structure, gravel content, and permeability. This static file is referenced by using the average soil type contained in the cell file for any particular cell. This information has been useful during model development as well as during the running of the multi-resource system simulation model. Additional soils data reflecting a subjective assessment of sedimentation yield potential, capacity to retain chemicals, and potential for regeneration are also stored in the cell file.

Miscellaneous Files

In addition to the above files, several additional files of information have been constructed. Briefly, these are: a) watershed summary file which contains summaries of selected attributes on a watershed basis (for example, deer populations), b) a recreation facilities file which contains information on the location and characteristics associated with developed recreation facilities, and c) a history of manipulations occurring during the simulation.

File Manipulation and Mapping

A series of approximately 200 computer programs has been written to create, update, edit, retrieve, summarize, list and map information from the resource data base. Most of these are best viewed as service programs which provide a much needed capability for efficient manipulation during model development and running the simulation model.

Computer-generated maps are produced which show the status of 40-acre cells in any one of the twenty watersheds. A clear plastic overlay with watershed boundaries, roads, streams, lakes, topographic features, and locational grids is superimposed over the computer-produced watershed map to facilitate interpretation. While the resolution of these maps is not equal to that produced by traditional cartographic means, the maps are produced quickly and cheaply, and interface effectively with the resource data base.

Subsystem Models

Forest Production Subsystem Model

The Forest Production Subsystem is composed of four separate models. These are: a) Timber Production Model, b) Timber Harvesting Model, c) Forest Residue Reduction Model, and d) Forest Production

(Continued on Page 136)

Evaluating Environmental Impacts

(Continued from Page 27)

Model. These models complement each other in simulating the effects of alternative forest management practices. The Timber Production Model consists of a set of growth and yield functions which are used to simulate the growth of forest stands over time if managed according to a prescribed set of management practices. Included in the model are site preparation, regeneration, fertilization and thinning alternatives. Environmental impacts, as well as timber volume statistics, are generated under each alternative. The Timber Harvesting Model reflects the harvesting of stands using several options such as tractor, highlead, skyline and mobile crane yarding systems. The harvesting model also includes amount and cost of road construction assuming different standards, the use of buffer strips along streams, etc. Costs and environmental impacts are generated under each option. The Forest Residue Reduction Model generates the volume of logging residues resulting from a harvesting operation as well as the costs and environmental impacts which arise as a result of residue reduction practices. The model currently contains several options for disposing of residue including broadcast burning, hand piling and burning, and mechanically chipping or crushing. The Forest Protection Model is currently being formulated. This model will include the economic and environmental effects introduced by the occurrence of an insect or disease outbreak or a fire.

Recreation Subsystem Model

This model generates the number of user days for 13 recreational activities generated by the population of several counties. Using a two-step procedure, user days are determined as a function of a large number of recreation supply and demand variables. Since these estimates are not site specific the model subsequently develops means of allocating the percentage of total recreation expanded by the population units in the counties to the Snohomish River Basin. Both the total number of user days estimated, as well as the percentage allocated to the basin, are subject to manipulation through land use decisions. Environmental impacts are generated in terms of total amount of effluents generated.

The recreation activities considered include skiing, swimming, hunting, fishing, developed camping, remote camping, etc. For each activity the number of user days is generated as a function of such demand variables as income, race, sex, education, etc., and as a function of such supply variables as total number of swimming pools, number of camp grounds, total land area utilizable for hiking, etc. Data for the independent variables were collected from a wide variety of sources, collated, reconciled and projected over time to the year 2000.

Fish and Wildlife Subsystem Model

The objective of this subsystem is to model the wildlife and fishery resources as they interact with forestry and recreation practices. Presently, only one

big game species—black tail deer—is included in the wildlife model.

Forestry practices affect black-tail deer herds by manipulating the habitat and thus altering forest succession patterns. By harvesting forests and placing areas into earlier successional conditions, the carrying capacity for deer is improved. As the cut areas age, their effective carrying capacity is reduced. These changes in carrying capacity in turn change environmental resistance, a measure of the per capita resources available to the population. In addition, the new carrying capacity defines the theoretical density that an area can support. Density and environmental resistance together then influence the mortality and fecundity rates such that the population attempts to reach equilibrium with the changing carrying capacity.

Forest management practices also have an influence on the anadromous fishery resource in that they affect fish spawning and fish rearing. A fish population dynamics model is presently being developed. Ultimately, this model will simulate the impact of changes in streamflow sedimentation, water temperature dissolved oxygen, and nitrate concentrations introduced by forest management activities on the fisheries resource. Several anadromous fish species will be included in the model when completed.

Meteorological Subsystem Model

The meteorological model generates air temperature and precipitation on a monthly basis. These values are used to represent future conditions which are likely to occur. Historical data from all weather stations in the Snohomish River Basin were used to estimate means and variances. These parameters were then modeled by the normal distribution to generate mean monthly temperature and precipitation for each weather station. A weather station or group of weather stations are associated with each of the twenty watersheds in the basin to define the meteorological conditions in that watershed.

Atmospheric Subsystem Model

Work is now underway to develop a model which will distribute pollutants emitted into the air by forest practices such as slash burning and by such recreational activities as driving for pleasure. A finite set of atmospheric conditions will be considered along with their respective probabilities of occurrence. The atmospheric conditions of particular concern are wind direction and velocity, and the occurrence of inversion layers.

Hydrologic Subsystem Model

The basic objective of this model is to simulate the response of the hydrologic system to the various manipulations of the forest ecosystem and the various recreational activities. The responses being considered are generally categorized as surface flow quantity and timing as well as several water quality parameters. A monthly time resolution was adopted for this model. The hydrologic system is driven by the meteorological subsystem outputs. Water quality parameters currently being handled are suspended sediment, water temperature, dissolved nitrate, and dissolved oxygen.

Timber Production and Timber Harvesting Models

As outlined earlier, the Forest Production Subsystem Model includes the Timber Production Model, the Timber Harvesting Model, the Forest Residue Reduction Model, and the Forest Protection Model. Because of their importance both the Timber Production and Timber Harvesting Models will be discussed in more detail below. Also, the interrelationship of the resource data base and the models will be illustrated.

Timber Production Model

The Timber Production Model is a computer simulator which updates stand parameters over any desired length of time. Besides updating as a result of growth, the model also executes management decisions relating to each stand. Management decisions include final harvest, thinning, fertilization, site preparation, and regeneration. Stand growth is handled using statistically developed relationships by updating age, basal area per acre, number of trees per acre and dominant height of the stand. Stand cubic foot volume is computed directly from basal area per acre and the dominant height using volume equations. The model assumes final harvest by clear-cutting and thinnings from below. Spatial and temporal ordering of final harvest and thinning is an input to the model and not determined by it.

Fertilization of stands is handled as an independent activity and may be prescribed by the decision maker in any manner. Currently, the model handles only one level of application and assumes that as a result of fertilization the basal area and height growth will increase by twenty and ten percent, respectively, over the next five years.

Neither regeneration nor site preparation are handled automatically by the model. For both activities the decision of when and how to regenerate or site prepare a stand are open to the decision maker. The model will regenerate a stand with any desired species at any specified stocking level.

Output from the model includes a listing of parameters of the stands harvested and thinned during the planning period, and a summary of total growing stock, interim growth and removals. At the present time the model does not compute costs and returns of different management activities. However, these will be incorporated into the model during the coming year. Also to be added are alternative harvesting methods other than clear-cutting.

Timber Harvesting Model

The Timber Harvesting Model is a computer program which provides a means whereby timber harvesting operations are simulated so that various timber management options may be examined and tested. Timber harvesting decisions revolve around answers to such questions as: Where on the property should logging take place? What type of cut (i.e., partial or clear-cut) is best? How large should cutting units be? Where should roads be located? What logging meth-

ods should be used? Since all of these decisions are interrelated, none can be answered without also considering the others. For example, choice of logging method is influenced by topography, type of cut and unit size. Prospective road locations can also be of overriding importance. Given this close dependence between decisions, it is useful to deal with timber harvesting questions in the context of a system, so that relationships and trade-offs between elements of the system can be highlighted. The Timber Harvest Model was constructed with the foregoing thought in mind. It is an attempt to simulate the interaction of harvest decisions dealing with road location, road standards, logging methods, type of cut and size of unit. Location of harvest units with their concomitant topography, soils, streams and timber resources is at the discretion of the model user. Once harvest sites and road locations are chosen, the Timber Harvest Model simulates various logging options. Results consist of road construction costs, logging costs, timber volumes and values removed, environmental impacts, and acreage removed from the timber growing base because of roads, landings and buffer strips.

How the Model Works

Given the legal description of a 40-acre cell to be logged, the harvest model creates the physical environment of that cell by retrieving from the resource data base information on topography, timber type, stream location and soil type. A logging system is then chosen and, using characteristics of that system, the model "logs" the cell.

Figure 1 shows the relationship of the Timber Harvesting Model to the resource data base, inputs and outputs.

Presently there are five logging methods available in the model. These are: highlead, skyline, tractor, running skyline-grapple, and running skyline-chokers. Differences among the available harvesting methods are taken into account by the model. It is possible to log many cells at one time using any desired combination of logging systems. It is also possible to directly compare results from the various systems by simulating each system over the same physical environment. Areas where differences tend to be significant are: optimum yarding distance, haul road pattern, amount and pattern of soil disturbance, ability to function on steep slopes, and cost.

The broad output areas identified in Figure I are the result of more specific outputs generated by the models. These outputs are:

1. Suspended sediment in streams from haul roads, skid roads and landings
2. Stream temperature
3. Acres harvested by logging method
4. Cubic foot volume harvested by logging method
5. Board foot volume harvested by logging method and breakdown into log grade (peeler, special mill, sawlog)
6. Log value by grade
7. Acreage removed from timber growth base because of roads, landings and buffer strips

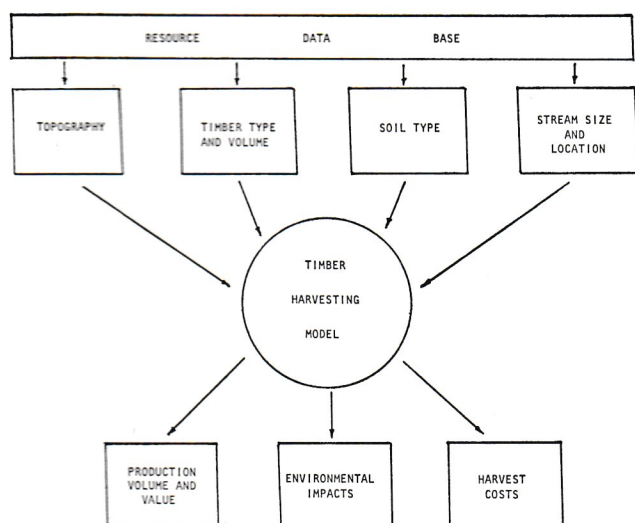


Figure 1. Timber Harvesting Model: Data Base, Inputs and Outputs

8. Road mileage by road class (mainline, secondary, spur)
9. Logging cost by logging method
10. Road construction cost.

Figure 2 shows the accepted haul road and yarding road patterns for the logging systems as incorporated within the model. Each square in Figure 2 represents a 40-acre cell which is the basic land subdivision of the resource data base.

The relationship and interrelationship of both inputs and outputs may best be brought into focus by applying the models to what is considered to be a real-life situation. The application of the models is presented in the next portion of this paper.

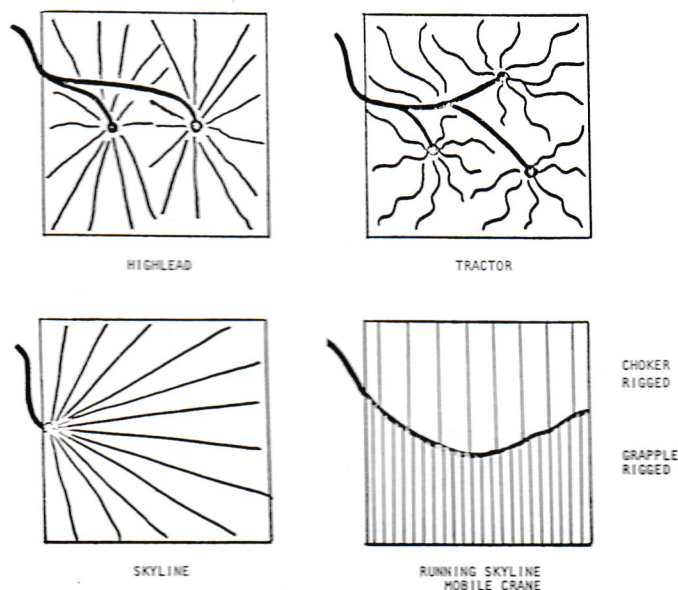


Figure 2. Haul Road and Yarding Road Patterns For Timber Harvesting Systems Included In The Timber Harvesting Model.

Illustrative Example

Background

The following example is included to illustrate the magnitude of selected impacts resulting from a set of timber harvesting decisions within a managed forest ecosystem. These impacts were obtained using modified versions of the simulation models described above. Specifically, elements of the timber production, timber harvesting and hydrology models were utilized in this endeavor.

In this illustrative example a yearly time resolution was adopted. However, the streamflow component of the hydrology model operates at a monthly level with monthly figures aggregated to provide annual measurements. As discussed earlier, the spatial resolution of this project is tied to a 40-acre cell system. However, in the illustrative example shown below, the individual identity of the cells in the study area was not retained. Instead, summary information describing the status of the area was used.

The area selected for illustrative purposes is the Taylor River watershed (see Figure 3). This 14,227 acre watershed located on the west slope of the Cascade Mountains in Western Washington constitutes part of the Middle Fork of the Snoqualmie River watershed—one of the twenty major watersheds identified within the Snohomish River Basin. Approximately 75 percent of the Taylor River watershed is managed by the U.S. Forest Service with the remaining acreage under private control. Table 2 contains selected items retrieved from the resource data base which describe the current status of the watershed¹. Before presenting the results of the study of alternative management strategies within the Taylor River watershed, a brief overview of the three model components included in the study is presented.



Figure 3. Snohomish River Basin and Taylor River Watershed.

¹ The major portion of the information stored in the resource data base was estimated from maps and aerial photographs provided by management agencies. However, certain attributes, such as stand age and cubic foot volumes, were calculated from available information.

Table 2
Summary Statistics of the Taylor River Watershed

<i>Item</i>	<i>Acres</i>					
	1	2	3	4	5	6
Age Class ¹	80	1050	1530	160	5677	5730
Slope Class ²	0	330	1665	6567	5665	—
Site Class ³	0	0	4260	320	9647	—
CF Volume Class ⁴	1930	2757	2595	735	200	—
¹ Age Classes						
1	0- 19 years					
2	20- 39 years					
3	40- 59 years					
4	60-170 years					
5	170+ [Old-growth (250 average age assumed)]					
6	Non-forested					
² Slope Classes						
1	0- 5%					
2	6-15%					
3	16-30%					
4	31-60%					
5	61+%					
³ Site Classes						
1	100 year Douglas-fir Site Class I					
2	100 year Douglas-fir Site Class II					
3	100 year Douglas-fir Site Class III					
4	100 year Douglas-fir Site Class IV					
5	100 year Douglas-fir Site Class V					
⁴ Cubic Foot Volume Classes						
1	1- 5000 cubic feet					
2	5001-10000 cubic feet					
3	10001-15000 cubic feet					
4	15001-20000 cubic feet					
5	20001+ cubic feet					

Hydrology Model

Mean annual runoff from the Taylor River watershed was determined by generating precipitation and temperature inputs and transforming them by a hydrologic model into surface runoff. Flows were calculated on a monthly basis for each year and then averaged to provide mean annual runoff.

The hydrologic model used is

$$R = P - I \pm \Delta S - ET$$

where R = monthly runoff; P = precipitation ET = evapotranspiration loss; I = interception loss and ΔS = changes in monthly watershed storage. Storage processes considered important over a monthly time interval include snowpack accumulation, soil moisture storage and subsurface watershed storage. Water balance was computed monthly and then averaged to produce a mean annual discharge.

Suspended sediment in streams was predicted using Anderson's² (1954) model. The form of this model is

$$SS = f(A, MA, SC, R, S)$$

where

SS = average annual suspended sediment in thousands of tons per year;

² Anderson, H. W. 1954. Suspended Sediment Discharge as Related to Streamflow, Topography, Soil and Land Use. Trans. Amer. Geophys. Union. Res. 35(2): 268-281.

A = watershed area in square miles;

MA = mean annual runoff in cfs per square mile;

SC = mean percentage of silt and clay in top 6 inches of soil (equal to 35% for the watershed);

R = percent of watershed area in roads;

S = mean slope of streams in feet per mile (equal to 1900 feet for the watershed).

Development of a response model for the addition of nitrogen fertilizer was based primarily on the work of Cole and Gessel³ (1965) in the Cedar River watershed of Western Washington. Due to the time resolution of the model, estimating the initial urea response was deemed impractical. Therefore, the peak monthly nitrate concentration occurring during the 12-month period following fertilization was estimated as a function of area fertilized and leachate concentration.

Impacts of forest management activities on stream temperature and dissolved oxygen concentrations were not included in the illustrative example.

Timber Production Model

A timber yield function was developed for predicting the future volume of forest stands under differing levels of management intensity. Yield functions were generated to fit the data reported by the Washington State Department of Natural Resources⁴ (1971). These yield functions which assume full (100 percent) stocking determine volume as a function of site quality and stand age. Yields for stands > 100 years of age were extrapolated from the given data. Timber volumes include all trees 7 inches and larger in diameter and include the cubic foot volume of the total stem.

Timber volumes generated from the yield functions were adjusted to reflect the impact of three levels of management intensity. Tables 3 and 4 contain the definitions and assumptions utilized in the timber production model. The timber volumes shown in Table 4 that are assumed removed via a commercial thinning

Table 3
Levels of Management Intensity

Level of Management	Definition
No Management	Regeneration; protection against fire; clear-cutting at rotation age
Light Management	Regeneration; commercial thinning at ages 45, 55, 65, 75 and 85; protection against fire; clear-cutting at rotation age
Intensive Management	Regeneration; fertilization at ages 15, 25, 35; pre-commercial thinning at age 15; commercial thinning at ages 35, 45, 55, 65, 75 and 85; protection against fire; clear-cutting at rotation age

³ Cole, D. W., and S. P. Gessel. 1965. Movement of elements through a forest soil as influenced by tree removal and fertilizer additions. Proceedings of Second North American Forest-Soils Conference, Oregon State Univ. Press, Corvallis, Oregon. p. 95-104.

⁴ Chambers, C. J., and F. M. Wilson. 1971. Empirical Yield Tables for the Douglas-fir Zone. DNR Report No. 20. Department of Natural Resources, Olympia, Washington.

operation are average figures extracted from DNR Harvest Regulation Report No. 4⁵ (1971). Also shown in Table 4 are average increases in final harvest levels due to fertilization. These figures are based on preliminary results of a regional forest fertilization program and are assumed to reasonably reflect an average response to fertilization. An application rate of 250 lbs. of N/acre was assumed for all acres fertilized.

Costs of the intensive management activities included in the study are shown in Table 5. These figures represent region-wide averages as of 1974. In the simulation results reported below, all costs are increased at a rate of 1 percent per annum. The regeneration expenditure was assumed to be needed on each acre harvested.

A simplified harvest regulation system was built into the model by using area regulation, with the watershed being regulated as an independent unit. Based on the age class structure of the watershed (see Table 2), the specified rotation age and an arbitrary harvest schedule priority of harvesting the oldest timber first, the acreage and cubic foot volume harvested annually were computed. Using area regulation an equal number of acres are harvested annually with potentially wide variations in harvested volume resulting. The previously discussed timber yield functions were used

⁵ Washington Department of Natural Resources. 1971. Sustainable Harvest Analysis, Harvest Regulation Report No. 4, Olympia, Washington.

Table 4

Timber Yields Resulting From Intensive Management

<u>Level of Management</u>	<u>Assumption and Procedures</u>		
No Management	Final harvest volume equals 75 percent of volume produced by the timber yield function. The assumption is that the average stand in the watershed is 75 percent stocked		
Light Management	Final harvest volume equals 75 percent of volume produced by the timber yield function. Additional thinning volumes shown below		
Intensive Management	Final harvest volume equals 75 percent of the sum of volume produced by the timber yield function plus increase due to fertilization. Additional thinning volumes shown below		
<u>Average Volume Removed By Commercial Thinning</u>		<u>Increase in Final Harvest Volume Due to Fertilization</u>	
<u>Thinned at Age</u>	<u>Cubic foot volume/acre</u>	<u>Site Quality</u>	<u>Cubic Foot Volume Increment If Fertilized at Ages 15, 25 and 35*</u>
35	726	1	525
45	1419	2	495
55	1415	3	450
65	1214	4	405
75	1365	5	375
85	818		

* Stands fertilized only once or twice receive only 1/3 and 2/3 respectively, of above increment.

to generate the volumes harvested each year as a function of site quality and the average age of the age class being harvested. As shown in Table 2, the major portion of the forested acres in the Taylor River watershed are occupied by old-growth timber stands.

As shown in Table 4 timber yields were increased to reflect the level of management intensity specified for each age class within the watershed. Annual commercial thinning volumes, acres thinned, acres fertilized and acres pre-commercially thinned were computed by averaging the total volumes and acres, respectively, over the entire rotation established for the watershed. This was a simple and convenient procedure for handling the timing of these activities.

In the simulation results discussed below, timber stands aged 0-30 years were given the most intensive level of management, stands between 50 and 70 years of age were subjected to light management and stands 90+ years were given no management (see Table 3 for a definition of these levels of management intensity).

Timber Harvesting Model

Three of the previously discussed five optional methods for harvesting timber stands were included in the illustrative example. These are: a) highlead, b) skyline, and c) running skyline-choker. The road requirements as well as the cost of logging, varied as a function of each logging method.

Table 5

Summary of Timber Management and Harvesting Costs

<u>Item</u>	<u>Initial Values</u>	<u>Annual Increase</u>
Fertilization (250 lbs. N/Acre)	\$30.00/Acre	1.0%
Precommercial Thinning	\$45.00/Acre	1.0%
Regeneration	\$50.00/Acre	1.0%
Road Construction		
a) Mainline—		
\$1,500/sta or	\$79,200/Mile	1.0%
b) Secondary—		
\$1,200/sta or	\$63,360/Mile	1.0%
c) Spur—		
\$750/sta or	\$39,600/Mile	1.0%
Logging Costs (Felling, Bucking, Yarding, Loading)		
a) Highlead	\$162/MCF or \$27/MBF	1.0%
b) Skyline	\$210/MCF or \$35/MBF	1.0%
c) Running Skyline-chokers	\$186/MCB or \$31/MBF	1.0%
d) Thinning	\$225/MCF or \$50/MBF	1.0%
Hauling Costs (To Snoqualmie Falls)	\$8.25/MBF	1.0%
Average Log Prices		
a) Final Harvest (Old-growth)	\$1,212/MCF or \$202/MBF	2.0%
b) Thinning	\$700/MCF or \$140/MBF	2.0%

As previously discussed, three classes of roads are recognized in this project. Mainline roads are defined as those log haul roads connecting a secondary road to either a paved road, a log dump, or a log yard. All mainline roads are 24 feet in width and are unpaved. There are currently zero miles of mainline roads within the Taylor River watershed. However, six miles of mainline roads will eventually be required if logging commences. In the results discussed below all mainline roads were retained as permanent additions to the road network.

Secondary roads are defined as those log haul roads connecting a spur road to a mainline road. All secondary roads are 14 feet in width and are unpaved. Currently there are nine miles of secondary roads in the watershed. It was assumed that all secondary roads constructed were maintained as permanent additions to the road network. The rate of new secondary road construction was determined as a function of the selected logging method. Table 6 contains the miles of secondary roads required per acre harvested for each of three logging methods. Secondary roads were constructed until the entire watershed was cut over. The product of the number of acres harvested and the miles of road required per acre harvested generated the mileage of secondary roads constructed each year.

Spur roads are defined as those log haul roads connecting a landing to a secondary road. All spur roads are 10 feet in width and are unpaved. Initially, no spur road exist in the watershed. It was assumed that the average spur road was utilized for approximately one year after which it was put to bed. The rate of new spur road construction was determined in the same manner as for secondary roads. The mileage of spur roads required per acre harvesting is contained in Table 6.

Table 6
Road Requirements For Different Logging Methods

Logging Method	Miles of Road Required Per Acre Harvested		Acres in Landings and Skid Trails Per Acre Harvested
	Secondary	Spur	
Highlead	.00750	.00375	.163
Skyline	.00375	.00094	.062
Running			
Skyline-choker	.00750	.00094	.046

The area of the watershed devoted to landings and skid trails was also generated as a function of the selected logging method. Table 6 contains the coefficients used for this purpose. The sum of the acreage covered by roads, landings and skid trails was summed and expressed as percent of the total area of the watershed. As illustrated below, this figure significantly affected the suspended sediment concentration reported during the simulation.

The costs of felling, bucking, yarding, loading and hauling for each of the three logging methods, as well as the costs of road construction, are shown in Table 5. These figures represent averages for both public and

private organizations in the Pacific Northwest as of 1974. Also shown in Table 5 are average log prices for final harvest and commercial thinning operations. These log values represent average prices for logs delivered at Snoqualmie Falls, Washington. Stumpage values were derived using the conversion surplus approach utilizing a profit ratio of 15 percent. Log values were increased at an annual rate of 2 percent.

Simulation Results

The above described versions of the timber production, timber harvesting and hydrology models were applied to the Taylor River watershed to determine selected economic and environmental impacts of three alternative logging systems over a 27-year (i.e., 1974-2000) planning period.

The annual rate of clearcutting—the assumed method of final harvest—was determined using area regulation and a rotation age of 70 years. This resulted in an annual harvest of 121 acres. Since there currently exists 5,677 acres of old-growth timber (see Table 2) and since the oldest timber is to be harvested first over the next 27 years, only old-growth timber stands were harvested over the 27-year planning period. The computed average volume per acre for these stands was 10,593 cubic feet, yielding an average annual harvest of 1,285,824 CF for each of the 27 years. Average stumpage returns generated by this annual harvest were computed using the log prices and logging costs tabulated in Table 5. The highlead, skyline and running skyline-choker systems were compared using suspended sediment and stumpage returns as criteria. The reader is again reminded that additional criteria are used in the more complete versions of the timber harvesting and hydrology models included in this project.

Figure 4 displays the estimated annual flow in cubic feet per second (cfs) at the outflow of the Taylor River watershed for each of the next 27 years. The predicted total suspended sediment concentrations (in thousands of tons per year) resulted from road building and timber harvesting activities for each of the three alternative logging systems are shown in Figure 5. As expected, sediment concentrations correlated closely with streamflow and logging method. Also, the logging system with the lowest logging costs (i.e., the highlead) produced the greatest amount of sediment while the more expensive skyline system generated the least amount of sediment. The range in stumpage returns for the three logging systems over the same planning period are shown in Table 7. Because a constant volume was harvested each year, the stumpage returns reported in Table 7 reflect differences in logging costs and expected increases in log prices over the next 27 years.

Table 8 contains the secondary road mileage figures constructed and maintained in the watershed over the planning period. Recall that six miles of mainline road were constructed and maintained irrespective of the logging method selected. While landings, spur roads and skid trails were constructed as a function of log-

(Continued on Page 150)

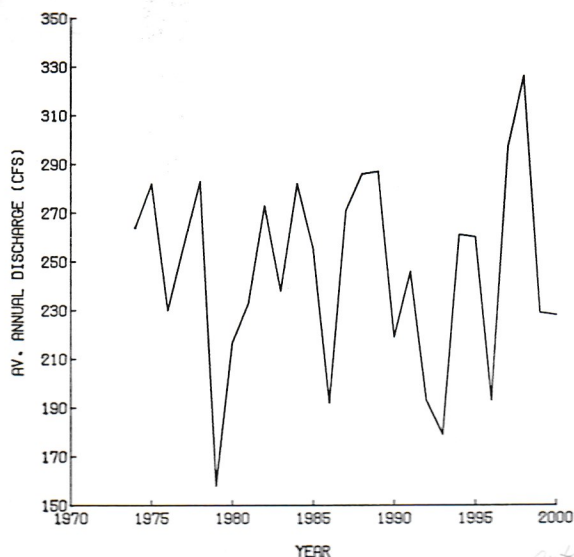


Figure 4. Average Annual Discharge (CFS) At Overflow of Taylor River Watershed.

ging method, they were not retained as part of the permanent road network. Thus, the differences in sediment concentrations shown in Figure 5 were primarily attributable to the differences in secondary road mileages.

Because only 16 acres were fertilized over each of the 27 years—at the rate of 250 lbs. of N/acre—an insignificant increase in peak nitrate concentrations as measured at the outflow of the Taylor River watershed were produced. Two additional parameters included in the hydrology model—dissolved oxygen and water temperature—were not estimated as part of this illustrative example.

Applying the previously specified levels of management intensity, 39 acres were thinned each year removing an average of 45,768 cubic feet. Using tractor logging this produced \$14,300 of stumpage in 1974. Due to anticipated increases in logging costs and log prices over the next 27 years, this annual stumpage

Table 7

Stumpage Returns Summarized by Logging Method

Logging Method	Average Annual Stumpage Returns (MM's of Dollars)	
	Final Harvest ¹	2000
Highlead	1.053	1.897
Skyline	0.984	1.808
Running Skyline-choker	1.019	1.853

¹ Assuming an average annual harvest of 1,285,824 cf covering 121 acres.

Table 8

Secondary Road Mileages by Logging Method

Logging Method	Miles of Secondary Road in the Watershed	
	1974	2000
Highlead	9.91	33.58
Skyline	9.46	21.29
Running Skyline-choker	9.91	33.58

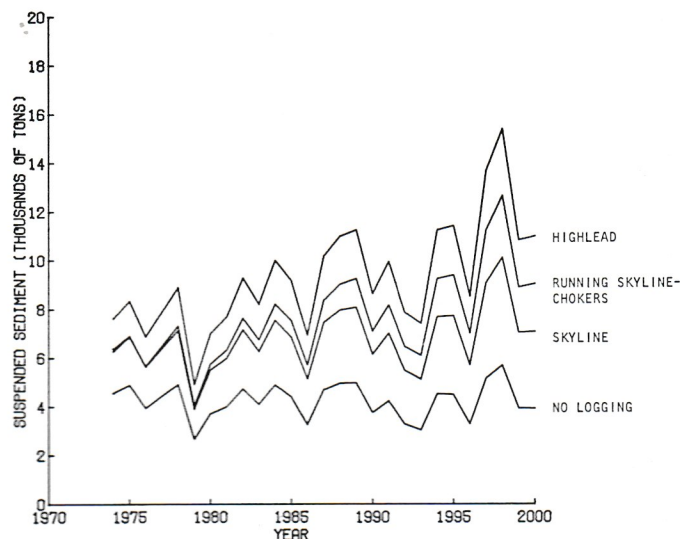


Figure 5. Total Suspended Sediment (M of Tons) At The Outflow of Taylor River Watershed.

increased to \$29,700 by the year 2000.

Results shown in Figure 5 and Table 7 illustrate a conflict situation requiring further evaluation of the trade-offs involved. For instance, would a decision maker forgo \$69,000 in stumpage in 1974 to reduce suspended sediment 1.26 M tons. If so, a skyline system might be preferred over a highlead system. A similar comparison of other logging systems using additional criteria and conducted over time would be required before any final decision could be reached. However, the above-discussed sample problem does indicate the nature of the trade-offs involved.

Summary

A multiple resource system simulation model useful for evaluating alternative management strategies in a managed forest ecosystem is currently under development at the University of Washington, College of Forest Resources. This system consisting of forest production, recreation, fish, wildlife, hydrologic, atmospheric and information subsystems is being developed and tested within the Snohomish River Basin of Western Washington.

A subset of the information currently incorporated in the simulation models being developed as part of this project are used in this paper to illustrate the magnitude of selected economic and environmental impacts resulting from alternative timber harvesting and growing operations. To demonstrate the general capabilities of the system an illustrative sample problem is presented. This example concerns the estimation of selected environmental and economic impacts associated with timber harvesting in the Taylor River watershed of Western Washington. The highlead, skyline and running skyline-choker logging systems are included in this sample analysis. Results of the simulation experiments performed on this sample watershed indicate the magnitude of predicted sediment loads and stumpage returns expected if the logging systems were actually to be used. This ability to evaluate a



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wide range of alternatives, using a variety of criteria, prior to actual field implementation, is one of the great advantages that computer simulation offers to forest resource managers.

The models described above are being changed continually as better information becomes available. Thus, in a sense, they are, or never will be finished. Also, several models are presently being extended to handle more management activities. Examples of modifications include changes in the forest production model to handle additional species, mixed forests and silviculture systems (other than clear-cutting) for simulating final harvest operations. Finally, the models will be tested for their usability and transportability to other geographic areas through a series of validation studies undertaken with interested forest industries and public forest management agencies. ■

Woods Road Robbery

(Continued from Page 134)

Service to consider the ugly appearance, but not the cost, of needlessly wide roads, the impractical planners in Washington, D.C.. are swinging in some cases from roads foolishly wide to roads foolishly narrow. Some of the latest timber sale contracts specify spur roads not more than 10 feet in width. A bulldozer with a 12-foot blade can't build such a narrow road, nor can heavy machines maneuver on it, and smaller equipment can't root out big stumps or lift 10-ton logs. But bureaucratic planners have no reason to be practical. They are not wasting their own money.

The same impractical minds that call for culverts every 500 or 600 feet regardless of rock bluffs and no water have issued a blanket directive requiring spur road culverts to be dug out after the logging is finished. This is a more expensive procedure than the installation, and the pipe is ruined.

The same impractical minds delay the return of spur roads to a natural state by ordering disposal by burning of stumps and large pieces of wood trash instead of letting it be buried under the fill where it would eventually turn to humus. Complete disposal of trash is likely to cost more than the excavation. Fire is hazardous to the surrounding timber so the trash must often be hauled elsewhere for burning. This is a slow and expensive procedure and the money has to come from timber sale proceeds. Private enterprise must be practical or go bankrupt, but public money is inexhaustible, and so is the permissiveness of taxpayers.

The condition of hundreds of miles of older roads in the Coeur d'Alene National Forest proves that the cheap construction methods of years ago are adequate in many instances. It would take great pressure, however, to force a return to economical and practical logging roads like the ones illustrated in photos I and J.

Government extravagance is never self-destructing. ■