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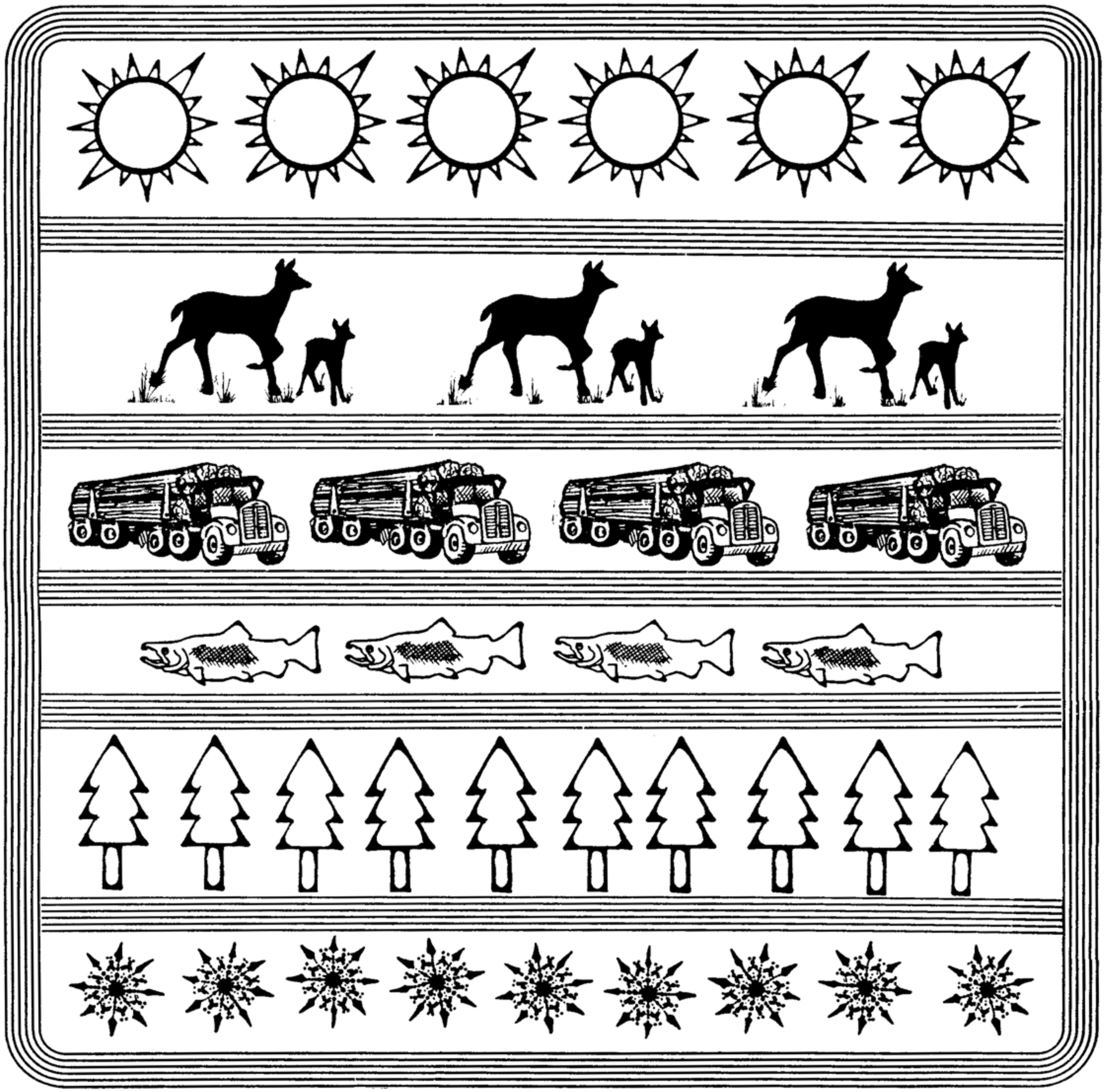
SAMM: A Prototype Southeast Alaska Multiresource Model



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SAMM: A Prototype Southeast Alaska Multiresource Model

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Abstract

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The adaptive environmental assessment method was used by an interdisciplinary team of forest specialists to gain an understanding of resource interactions and tradeoffs resulting from forest management activities in southeast Alaska. A forest multiresource projection model was developed in the process. The multiresource model, “SAMM,” is capable of characterizing and displaying interactions of four major resources over a 150-year rotation: timber, wildlife (Sitka black-tailed deer), hydrology (streams), and fisheries (anadromous). SAMM is in a prototype stage of development; final testing is required before it can be used by managers for quantitative analysis. Sufficient development and evaluation has been done by the team of specialists to permit its use in qualitative assessments for planning.

Keywords: Multiresource, forest management, systems, models, southeast Alaska, simulation.

Summary

Interdisciplinary forest specialists from southeast Alaska were brought together to develop an integrated multiresource forest management model. The mission of the group was to increase understanding of multiresource interactions resulting from forest management actions in the Tongass National Forest. They used the adaptive environmental assessment method.

A simulation modeling effort that used a procedure developed by the board-of-experts was meant to accomplish several objectives: to improve multiagency understanding of forest resource interactions; to enhance cooperative relations among agency specialists; to develop analytic relations to represent the best knowledge of individual-resource dynamics; to specify critical linkages, variables, and interactions among multiresources and to identify high-priority research needs.

Simulation modeling is an appropriate analytic approach for describing multiresource interaction in a forest environment. Analytic relations can also be appropriately defined by boards-of-experts with simulation models, which generically are not data dependent and offer flexibility in defining first approximations.

We developed four major process models and their interdependent linkages: timber, hydrology, fisheries, and deer. Each model has descriptors of the important natural processes to drive each resource and to link that resource to other resources represented. Even with the rather complex integrated algorithms developed for each resource, the models still present only abstractions of the real-world processes involved.

The overall linkage design in the model is cascade; that is, all information flow is in one direction with no negative or positive feedback loops. The timber submodel is the first component in the overall model because of the impact management actions related to timber have on the other resource models; for example, information flows from the timber model through the hydrology and soils algorithms to the fisheries submodel, and information moves directly from the timber model to the deer submodel.

The complete Southeast Alaska Multiresource Model, or SAMM, was developed for application on watershed areas of 5,000 to 20,000 acres. Three general types of input files are needed to operate the model: data to describe physical and biological resources in the

watershed area where the model will be applied, data to characterize management actions applied to the watershed and its resources, and data describing economic and social characteristics of the area.

The timber submodel uses a stand algorithm based on site index class and age to simulate growth in the relatively even-aged Sitka spruce-western hemlock forests of southeast Alaska. The algorithm regenerates and grows stands through 150 one-year increments. Stands older than 250 years are considered old growth.

Timber removals occur through precommercial and commercial thinning, final harvest, or mortality. The normal management practices simulated for a stand begin with a clearcutting and subsequent regeneration of the stand, a precommercial thinning, and then a series of one or more commercial thinnings input by the user.

The hydrology and soils submodel provides the primary link between road building, overstory management activities, and fish and deer habitat. The submodel is driven by inputs for precipitation, sediment, and air and water temperature. Precipitation regimes are developed for a watershed area, whereas sediment and temperature regimes are developed for spatial units within a watershed. The interaction of snow precipitation with timber overstory manipulation has a significant impact on deer population, and sediment production from road construction and use can have a critical impact on anadromous fish populations.

The fisheries submodel computes production and harvest of anadromous fish species and currently has algorithms for pink, chum, and coho salmon. The submodel traces critical natural processes in the life history of each species, including spawning and rearing. Water temperatures, flow levels, and siltation are taken from the timber and hydrology submodels and are critical in determining fisheries dynamics.

The deer submodel simulates changes in Sitka black-tailed deer populations in response to vegetative manipulation, snowfall and hunting mortality. The submodel has three major components: deer energy intake, energy cost, and population dynamics. Timber overstory density and snowfall are critical variables in the submodel and are derived as outputs from the timber and hydrology submodels.

Economic evaluations are developed for various timber management activities. Social inputs are represented in user days of recreational hunting and fishing and in jobs produced by harvesting timber and building roads.

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Development of SAMM,a Southeast Alaska Multiresource Model

Lawrence D. Garrett, Roger D. Fight, and Peter T. McNamee[1]

Introduction

The Southeast Alaska Multiresource Model, SAMM, is a prototype model used to project multiresource interactions in the spruce (*Picea* spp.) and hemlock (*Tsuga* spp.) forests of southeast Alaska. The model has passed through two general stages of development: conceptual and prototype. One additional stage, testing, is necessary before it can be sanctioned for quantitative assessments in management. The following descriptions relate, in general, the developmental stages needed to produce an operational model for management use.

1. Conceptual stage. Deriving a general notion or idea.
2. Prototype stage. Analysis, formulation, or framework for conceptual relation or idea.
3. Test stage. Fully documented algorithms having operational capability but without being formally verified, tested, or validated.
4. Operational stage. Techniques, equipment, and algorithms used in accomplishing normal tasks.

The developmental process for SAMM is in the testing stage. Several complete models have been drafted, each an improved design. In its current stage, the model can assess relative qualitative changes in resources in response to defined management actions.

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The model is at a suitable level of development to begin evaluations of its predictive capability and use in management. Characteristics of the model that should be evaluated include model stability, predictive effectiveness, and management usefulness and efficiency.

In general, most equations included in SAMM are first approximations of the biological relations defined. For some of the relations, these approximations are suited to the outputs desired. In general, variables or parameters changing little, or causing little to change, do not require explicit specification. Variables needing explicit specification and testing are those significantly altering model outputs.

The following brief overview of the SAMM developmental process is an assessment of the original objectives of the project and reflects how the objectives have changed over time and the effects the changes have had on model development.

Objectives of Model Development

Objectives for developing a model can range from very specific to general and can be singular or multiple. The development of SAMM was predicated at the outset on general objectives that became more specific over time. The modeling process originally was selected to improve general interagency communication and provide a common focus for multiresource tradeoffs in southeast Alaska. During development, the model has been given more technical capability, objectives have become more focused, and specific use of the model for information synthesis, research planning, and describing resource impacts have been identified. Currently, the prototype model is viewed as an analytic system to conduct qualitative impact assessments.

Initial objectives reflected the needs of the Alaska Region of the USDA Forest Service to assess the general benefits of modeling for forest planning and management. The Tongass National Forest area guide (USDA 1977) and the Tongass forest plan (USDA 1979) identified resource conflicts requiring assessment; these included conflicts of timber harvest and road building with habitat for deer and anadromous fisheries.

A method was needed to increase communication and working relations among the several agencies in Alaska involved with these resources. As the modeling process evolved objectives and the people involved changed. Interagency communication was greatly improved by the modeling process, and resource and management issues were identified and agreed on. As analysts became active in the process, a focus on specific elements of the original problems began to occur. Management, in general, became enthusiastic about the potential information and policy benefits obtainable by focusing on specific objectives.

As the developmental process progressed, original objectives were maintained but received less emphasis; instead, greater focus was on information synthesis, research planning, and policy analysis. Increased attention was devoted to model refinement, including evaluation of individual algorithms and sensitivity analysis.

The modeling effort eventually became a cooperative process to address questions on specific management actions and their impact on multiresource outcomes. Because algorithm strength for quantitative predictions was lacking, the modeling objective focused on predicting relative qualitative resource changes. Whereas the original emphasis was to enhance communication, the emphasis now became analysis.

Continuing development of SAMM might result in yet another change in the primary emphasis. With refinement and effective testing, the model might eventually be used for quantitative analysis and prediction rather than qualitative analysis. Accomplishment of this final objective will require an intense effort to define accuracies in both algorithm projections and linkages among algorithms. Additional model development, policy recommendations, and clarifying of the official status of SAMM are the responsibility of the interagency Model Management Committee.2

One difficulty in the modeling effort occurred in the evolution of the objectives. Whereas the general communication objectives specified in the beginning were agreed on and understood, the group moved toward analysis objectives without identifying or clarifying the shift in emphasis. As a result, confusion and misunderstanding existed among some cooperators before the changed direction was both understood and accepted. These issues were resolved through the close working relations that had evolved.

Evaluating the Developmental Process

The process used in developing SAMM required, by design, extensive interpersonal communication, which was repeated to define resource interactions and eventually to specify and refine quantified relations.

The approach used was adapted from Holling (1978) and is defined as the “adaptive environmental assessment and management technique.” This technique involves scientists, managers, and policy specialists in designing qualitative assessment procedures for resolving resource conflicts. The extent to which the analytic procedure is made specific depends on the interest of the parties involved. The development group pursued SAMM to a detailed analytic stage for assessing relative qualitative resource changes resulting from management action.

The SAMM project addressed the objectives that evolved during the modeling process. The process identified issues, problems, and concerns; improved interagency communication; synthesized a large volume of multiresource information; and identified important resource impacts. The current model has applicability for research planning and policy analysis. It is capable of qualitative assessments of resource interactions resulting from management actions. It is not yet appropriate for *quantifying* resource impacts resulting from management action; further testing and validation are required to assure its appropriateness in this use.

The model evaluates multiresource impacts of management action on tree growth and mortality, understory dynamics, snow regimes, deer habitat, deer energy cycles and mortality, streamflow volumes, sediment loading by silt and debris, gravel overturn, spawning rates and survival of pink salmon (*Oncorhynchus gorbuscha* (Walbaum)), chum salmon (*O. keta* (Walbaum)), and coho salmon (*O. kisutch* (Walbaum)), smolt survival, commercial salmon harvest, and sport fishing and hunting success. Economic algorithms predict costs for implementing various management activities such as harvesting and road building. We

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[2] Material taken from: Interagency Agreement, Memorandum of Understanding No. PNW-85-413, 1985, among USDA Forest Service, Pacific Northwest Research Station; USDA Forest Service, Alaska Region; U.S. Department of Commerce, National Marine Fisheries Service. Northwest and Alaska Fisheries Center; U.S. Department of Commerce, National Marine Fisheries Service Regional Office; and Alaska Department of Fish and Game.

emphasize that the intended use of SAMM is to increase understanding of the interrelations between resources and thus assist in resource planning, policy analysis, and qualitative assessments of resource interactions. As such, the model has promise as a valuable tool for managers and decisionmakers in projecting relative changes among resources after various methods of land management have been applied. The SAMM model is not appropriate, however, either for quantifying resource impacts of management actions or as a basis for economic tradeoffs. Although fish and wildlife values; are considerable, the model does not have the capability to assign dollars to either of these values. Also, economic projections for timber can be made based on the model as outlined in this paper, but we emphasize that no projections of costs and benefits for other resources are included.

General Model Assumptions

To permit efficient operation. S/\MM has many assumptions programmed into algorithms. These assumptions represent the best judgments of professional managers and resource analysts in southeast Alaska. The assumptions are based on a more holistic accounting of observed relations as opposed to accurate but often narrow perspectives permitted in individual research studies and sample data sets.

Many assumptions in the model are not based on existing data. Because of the way they were developed and the structure of the model, testing and validation will be difficult. Selected assumptions can be isolated and tested, however, as data become available.

Three assumptions about the general model structure were made. These assumptions partially define the model and how it functions, and they also control the amount and type of information available to the manager. The three assumptions are as follows:

1. The watershed area is a useful geographic scale in southeast Alaska for evaluating resource interactions.

2. Division of a watershed into subareas by stream-reach boundaries, elevation and slope establish criteria that remain basically stable over time.

3. About 250 years or more are needed to regrow forests to old-growth condition as specified by timber specialists in Alaska. During this time, the dynamics of resources differ and require different time intervals for changes in resources to occur; for example, 1 year for tree growth, fisheries, and sediment transport; 6 months for deer; and 3 days for weather.

The general model assumptions may somewhat limit the usefulness of the model in selected planning applications. Natural boundaries, such as a watershed, although useful for modeling, are not always representative of the actual boundaries for resource interacions. Use of the watershed level as the area constraint and of stream reaches as subarea delineations can cause difficulties during analyses of stand tradeoffs in traditional timber types. Current timber land management planning approaches require resource evaluations delineated by analysis area, or similar ecotypes, which are not fully compatible with the chosen spatial design. Wildlife populations, such as deer, are not always confined to a watershed. Their natural range may extend beyond the watershed, particularly in summer when deer migrate to alpine ranges.

The above concerns aside, we believe the model structure is appropriate for southeast Alaska. Because of the particular topography of the area, much forest area planning and management does occur on or within watersheds. Simplistic summation procedures also can be programmed into the model to relate interaction at the stand or analysis-area level.

The units of measure used in this paper are a mix of English and metric. They are used in most cases in the same form as they are in the computer code to make comparing the documentation and the code easier. The units used in the code are generally the ones that the model developers are most comfortable with. A table of conversion factors begins on page 90.

Submodel Assumptions

Timber

The submodels in SAMM are arranged as separate components, each feeding into the next in succession. The timber submodel is the first component, and its assumptions impact all other components because of the cascade design. Assumptions for timber therefore relate directly to timber model outputs and indirectly to outputs of other submodels. Within the timber component, these assumptions are made:

1. Tree diameter growth occurs annually, although in the model it is computed from 10-year stocking tables.

2. All tree diameters are equal in any given age class and site index class.

3. Crown cover in unthinned stands less than 30 feet in height is a function of stand height; whereas cover in all thinned stands and unthinned stands > 30 feet in height is a function of stand basal area.

4. Slash deposited after precommercial thinning is 36 inches deep and 18 inches deep after a clearcut harvest commercial thinning. Each have a half-life of 10 to 15 years.

5. Old-growth is 250 or more years old and will remain static with no growth increment or mortality until harvested.

Hydrology

The hydrology submodel is the primary link between the timber and fisheries submodels. These assumptions are made in the hydrology submodel:

1. Water yield is based on the entire watershed area, whereas sediment yield is primarily confined to a spatial unit and stream reach.

2. Two classes of inorganic sediment are recognized: < 3 mm and 3-9.5 mm. One class of organic debris is recognized: 10 cm and larger.

3. The major sources of sediment are from constructing and using roads and from logging operations in the form of mass wasting.

4. All sediment sources are 60 percent fine and 40 percent coarse material.

5. A background probability of debris torrents occurs only in first-order streams.

6. Undercut banks along the harvested part of the streambank are instantaneously reduced by 60 percent at the time of logging. Undercut banks return to predisturbance levels within 10 years.

7. Precipitation is entered as a yearly average of southeast Alaska data modified by a long-term cycle.

8. Whether precipitation is rain or snow is controlled by the temperature being above or below 32 °F.

9. Total surface water is determined by infiltration, surface runoff, and evapotranspiration.

10. Groundwater temperature is 40 °F.

11. Eight inches of snow is equivalent to 1 inch of water.

12. Eight-tenths of a percent of the inventory of large organic debris in streams is decomposed each year.

Fisheries

The fisheries submodel characterizes the various biological cycles of pink, chum, and coho salmon. These assumptions are made in the fisheries submodel:

1. The sex ratio of retuning spawners is 1:1.

2. Spawners distribute themselves among stream reaches according to available gravel areas.

3. Summer stream temperatures above 20.8 °C kill all eggs of pink and chum salmon.

4. Average stream temperatures below 2 °C in October and November reduce egg survival by 50 percent.

5. The proportion of eggs lost as a result of fall gravel bed overturn is directly proportional to the gravel overturn.

6. Pink and chum salmon remain in stream reaches one season, whereas coho salmon remain 1 or 2 years depending on growth rate.

7. Coho fry distribute themselves among stream reaches based on rearing potential of habitat.

8. Stream temperatures exceeding 25 °C result in 100 percent fry mortality.

9. Mortality occurs year round, but the model calculates it only once a year.

10. Streams with 30 percent or more protected habitat (pools) yield 25 percent first-year survival of coho.

11. Without fish harvesting, annual survival rates in the ocean are 0.02 (pinks), 0.20 (chums), and 0.10 (coho).

12. Coho and pink salmon spawn after 1 year at sea; chum spawn at 2, 3, and 4 years.

13. In the mixed-stock fishery, a user-specified percentage of commercial harvest occurs in each species.

14. Freshwater and subsistence fisheries do not operate if escapement is not sufficient to fully seed the watershed.

15. Effects of canopy closure on fish production assume bank cutting occurs equally on both sides of the stream.

Deer

The deer submodel characterizes changes in deer populations resulting from changes in the timber submodel. The impacts of management actions on timber and understory and their relative occurrence with snow cycles are the major driving relations in the deer submodel. These assumptions are made in the deer submodel:

1. Deer receive all their energy from shrubs, forbs, and lichens.

2. Canopy cover is the primary control parameter on understory production in summer.

3. Snow and slash are the primary control parameters on forage in the winter.

4. No shrub growth takes place in winter, and summer shrub biomass is reduced by 40 percent in winter to reflect leaf drop.

5. Forbs do not carry over from year to year. Only 50 percent of summer forbs are carried into winter.

6. Slash reduces forage availability.

7. Potential forage consumed is constrained by potential forage available.

8. Forage consumed per deer is directly proportional to the forage requirements for the deer relative to total herd requirements.

9. Fawns and adults forage 11 hours per day and search about 1.00 hectare per day.

10. Deer are allocated to a stand based on the net energy available in each stand.

11. Thirty percent of adult deer weight and 15 percent of fawn deer weight can be expended before starvation occurs.

12. Hunter populations include local residents, loggers and road builders, and hunters from outside the area.

13. Only nonlocal hunters exhibit a success response; that is, hunt more days after a previous successful season.

14. Killed deer are removed from herds in direct proportion to the population in each age class within each herd.

2

Specification of the Model

Peter J. McNamee, Lawrence D, Garrett, Roger D. Fight, and
Joseph R. Mehrkens[1]

Introduction

There were two primary objectives in specification of the model. The first was to provide analytic definition to interrelations among timber, hydrology, fisheries, and wildlife in southeast Alaska and provide insight to the relative changes occurring in these resources as a result of management action. The second objective was to specify the complete analytic structure of a model capable of displaying multiresource interactions and tradeoffs.

Satisfying the first objective was accomplished through interaction among specialists and scientists from disciplines representing the four resource areas under study. Available science and data permitted some definition of general interaction in each resource area.

Accomplishing the second objective required development of resource data and collaborative science. It also required repeated interaction among managers, scientists, and specialists to evaluate individual model components most suited for displaying resource interactions.

The research procedure used in specifying the model is defined by Holling (1978) as the adaptive environmental assessment and management technique. The technique brings together interdisciplinary scientists, analysts, and managers in a workshop environment to define parameters and processes best representing biologic and economic relations in a particular resource area, such as timber or anadromous fisheries. For SAMM, the same group was asked to define the most appropriate linkages among the various resource areas and the processes and relations represented in these linkages.

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Quantitative, rather than qualitative, relations were defined, which required use of concepts of statistics, probability, and math to define both intraresource and interresource relations. The resulting design represents an integrated multiresource model. Although some feedback mechanisms are employed among resource models, most linkages are in one direction, making the design cascade in both definition and function.

Bounding the Model

The primary objective was to develop a model that could project relative changes in resources as a result of management action. To do this, certain constraints were necessary to describe feasible management actions as were measures to evaluate the impact of actions on outputs of the model. The model was further defined by identifying actions and indicators or outputs in a manageable spatial and temporal framework.

Actions

In the context of this model, actions are the feasible human interventions that can alter the characteristics of the forest, fish, and wildlife. It is important to define the actions as a single intervention (high-lead logging) rather than as multiple interventions or a class of interventions (even-age management). Particular components of an environment may respond differently to specific actions that are often grouped into one generic category. Most of the actions included in the model are related to forest management practices, although some are related to fisheries, wildlife, and stream management (table 1).

Driving variables are, in a sense, special actions in that they affect the system dynamics and are a kind of intervention. The key difference is that driving variables are exogenous to the system and represent the links between the internal aspects of the model and the external world the model is not considering in any great detail.

Indicators

Outputs or indicators, as defined here, are those measurements used to evaluate the state or health of the system. They are the links between the simulation model and the manager’s mental model of the system being defined. Because managers have different measures of system performance, it is important to include in the model a comprehensive set of outputs representing the system being described. The outputs projected by the model reflect the areas of major interest to managers with defined interactions and yields represented. The following list gives examples of outputs produced by the model:

- Miles of road constructed
- Employment in forest industry
- Number of deer
- Number of deer harvested
- Percentage of fines in sediment
- Monthly streamflows
- Minimum summer and winter streamflows
- Volume of large debris in streams
- Total sediment volume by reach
- Volume of timber harvested
- Catch of pink, chum, and coho salmon
- Production of pink, chum, and coho smolt

Table 1—Actions included in the 4 submodels

Submodel	Type of management activity	Action
Timber	Harvesting practices	High-lead logging Skyline logging (short, medium, long) Tractor logging Helicopter logging A-frame logging
	Old-growth management	Buffer strips on streams Patch size Number of entries
	Second-growth management	Thinning—precommercial and commercial
	Road construction	Mainline Temporary
	Reforestation	Natural reforestation
Hydrology and soils	Riparian habitat management	Removal or addition of large organic debris during logging
Fisheries	Regulation	Harvest rates, escapement Recreational, commercial, and subsistence users
Deer	Regulation	Road access Number of hunters

Spatial Structure

The spatial structure of the model determines whether the model will be used to examine highly specific hypotheses or more general classes of hypotheses. In establishing the spatial structure, two questions are important: (1) What spatial area will be considered internal to the model? and (2) What is the spatial resolution within the areas modeled?

The spatial area chosen for modeling is a watershed, which can range from about 5,000 to 20,000 acres. A watershed-level model can represent a wide range of silvicultural practices and harvest patterns as well as the population dynamics of the fish and wildlife species being modeled. Three main advantages of a watershed-level model are:

1. It allows representation of biophysical processes for which data and conceptual understanding exist.

2. Much forest- and area-level planning by interdisciplinary terms occurs on similar-size areas.

3. Many management-area delineation in southeast Alaska use natural watershed boundaries.

The spatial resolution desired is obtained by dividing a watershed into subareas of irregular boundaries with topography, stream-reach boundaries, and elevation as criteria. This representation allows the user to adapt the model to other watersheds by altering the subarea characteristics in the initial conditions; for example, area, site index class, and tree age per volume. Each spatial unit within the watershed of interest is associated with the above collection of characteristics that do not change with time. These characteristics are detailed in the submodel descriptions in later chapters.

Time

Development of a dynamic simulation model requires specifying a time horizon over which model projections are of interest. A time step must also be specified over which the change in value of the state variables will be calculated and displayed. Because the model does not allow for harvesting young-growth stands, the model time horizon is limited to 150 years. The basic time step for the model is 1 year. Selected processes in each submodel are simulated on short or long time frames, as in the following tabulation:

Process	Time step
Timber growth	1 year
Timber management activities	1 year
Sediment dynamics	1 year
Streamflow, temperature, and snowfall	3 days
Fisheries	1 year
Wildlife	6 months

Looking-Outward Matrix

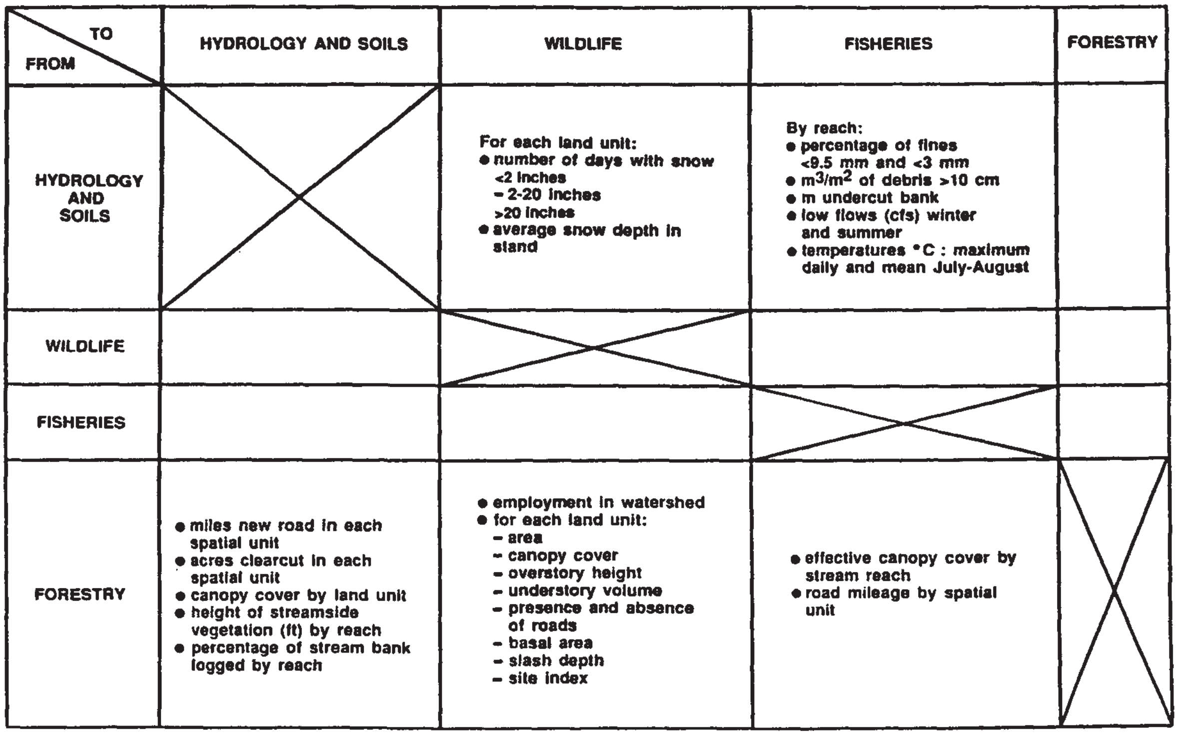
The looking-outward matrix in figure 1 defines the set of information a particular submodel requires from all other submodels. Each set of information listed in the matrix implies a specific hypothesis; for example, the fisheries submodel requiring summer low flows for each stream reach means that fisheries scientists hypothesize that fish survival is influenced by water flows. Similar arguments can be made for each information transfer.

The interaction matrix encourages workshop participants from different resource disciplines to concentrate on identifying common variables, units of measure, and time frames and to focus on important functional relations. The result is mutual understanding of issues and system dynamics and the creation of a positive atmosphere for mutual problem solving.

Submodel Definitions

The major criteria for proper division of the model into submodels was minimizing the transfer of information between submodels. Each submodel simulates a distinct self-contained component of the whole system.

The four submodels of the simulation model are timber, hydrology and soils, fisheries, and deer. The cascade design of SAMM results in an integrated rather than interactive structure. And, because overstory manipulation is the primary cause of change in outputs to all submodels, documentation of the timber submodel is presented first.



FROM \ TO	HYDROLOGY AND SOILS	WILDLIFE	FISHERIES	FORESTRY
HYDROLOGY AND SOILS		For each land unit: ● number of days with snow <2 inches – 2-20 inches >20 inches ● average snow depth in stand	By reach: ● percentage of fines <9.5 mm and <3 mm ● m^3/m^2 of debris >10 cm ● m undercut bank ● low flows (cfs) winter and summer ● temperatures °C : maximum daily and mean July-August	
WILDLIFE				
FISHERIES				
FORESTRY	● miles new road in each spatial unit ● acres clearcut in each spatial unit ● canopy cover by land unit ● height of streamside vegetation (ft) by reach ● percentage of stream bank logged by reach	● employment in watershed ● for each land unit: – area – canopy cover – overstory height – understory volume – presence and absence of roads – basal area – slash depth – site index	● effective canopy cover by stream reach ● road mileage by spatial unit	

Figure 1—A looking-outward matrix illustrating submodel linkages in SAMM.

3

The Timber Submodel

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Introduction

The timber submodel is a dynamic representation of timber growth in southeast Alaska. It includes a growth and yield model for the hemlock and spruce forests predominating there. The model also simulates management actions applied to these forests and the associated economic costs and revenues. Stand dynamics in the model are responsive to timber management strategies other than just those attempting to maximize timber yields or economic returns.

A relatively simple whole-stand model based on site index (SO class and age is used to depict the development of even-aged stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.). Stands are grown in 10-year age classes from age zero to age 250 years. Stands more than 250 years old are classified as old growth.

Removal of trees from the stand occurs during precommercial thinning, commercial thinning, or final harvest and as regularly occurring natural mortality. Timber actions and indicators and the outputs fed to other submodels are listed in figure 2.

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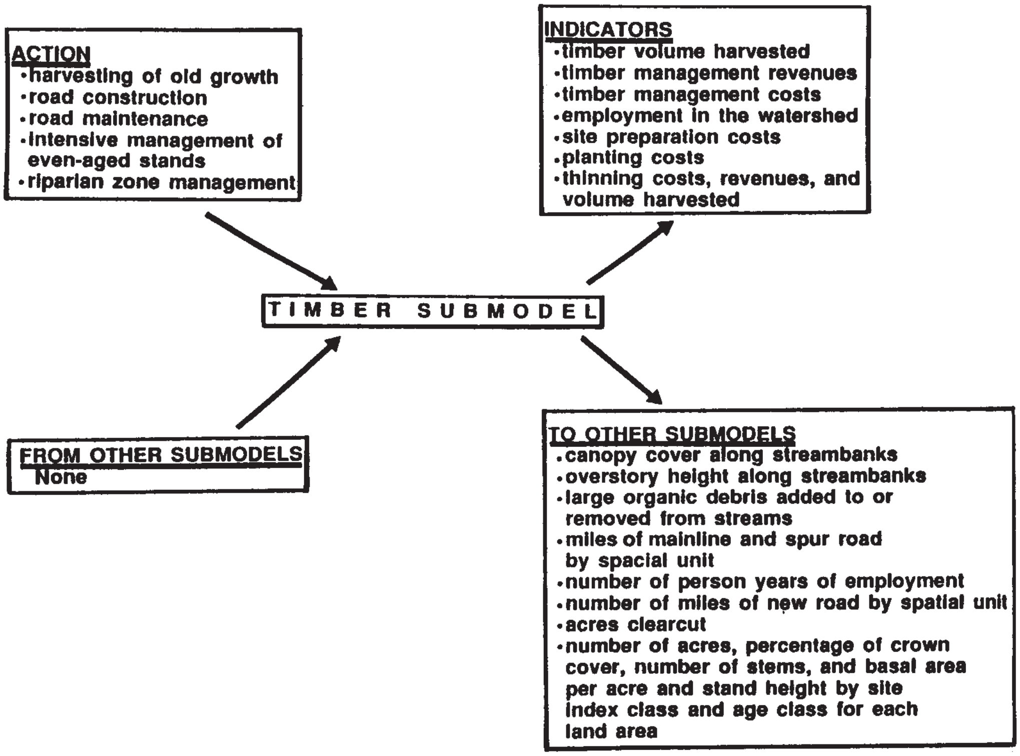

Figure 2—Information flow and system linkages for the timber submodel.

Basal area, mean stand height of dominants and codominants, and number of stems per acre are the most important variables influencing growth and yield of the well-stocked stands (fig. 3). Stand age is equal to the number of years since an area was clearcut. Basal area increment is a function of existing basal area, potential growth of well-stocked stands of similar site and age, and growth adjustments if stands are less than well-stocked. Mean stand diameter is calculated from basal area and number of trees per acre Mean stand height of sawtimber trees ($\geq$ 9.0 inches diameter at breast height [DBH]) is a function of mean height of dominant and codominant trees. Mortality, in number of trees per acre, is calculated as a function of site, age, and density.

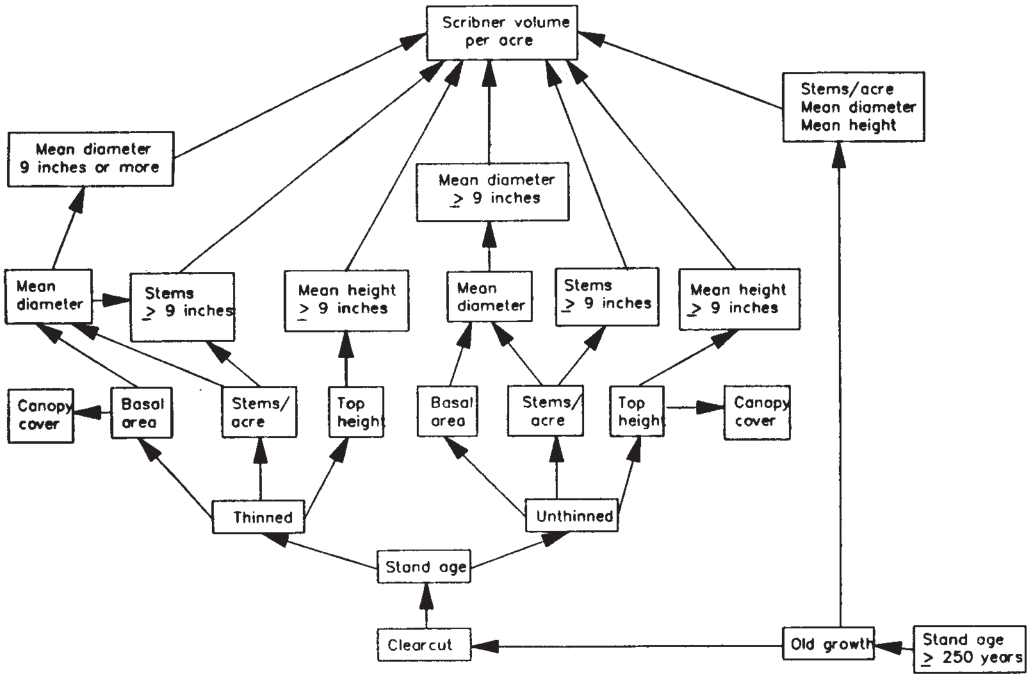

Figure 3—Basic structure and driving parameters of the timber submodel.

Scope

Management actions in the timber submodel are scheduled annually, and stand growth is computed yearly. Actions and indicators in the submodel are presented in figure 2. Linkages in the model are represented as information received from and directed to the various submodels. the acreage in each spatial unit may be subdivided into as many as five SI classes (70, 90, 100, 110 and 130). Site index is based on the mean total height of dominant and codominant hemlock and spruce at a total age of 100 years.

Within each SI class are 26 age classes of forest. The first 25 represent 10-year age classes between 0 and 250 years. The 26th class is for stands older than 250 years of age.

Developing a detailed distance-independent, individual-tree forest growth model like PROGNOSIS (Stage 1973) would be one way to examine the effects of alternative timber management strategies, such as precommercial and commercial thinning for timber production, or to assess the probable effects of repeated heavy thinnings on understory forage production for wildlife. Another approach would be to develop a detailed whole-stand model similar to DFSIM (Curtis and others 1981). Such models unfortunately are not yet available for the hemlock-spruce forest type of southeast Alaska.

A PROGNOSIS variant known as SEAPROG, for southeast Alaska prognosis, is under development for western hemlock and Sitka spruce in southeast Alaska.[2] Field work underway for the past 10 years is contributing to this effort and will also contribute to development of a whole-stand growth and yield model for the area.

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[2] Development plan on file: Forestry Sciences Laboratory, P.O. Box 909, Juneau, AK 99802.

The relatively simple whole-stand model developed for SAMM uses Taylor’s (1934) normal-yield tables to project yields for western hemlock and Sitka spruce. The tables are based on SI at a total stand age of 100 years. Adjustments have been made to the statistics for well-stocked stands to allow for the probable effects of intensive timber management such as precommercial and commercial thinning.

Farr’s (1984) total height function for Sitka spruce was used to estimate height and height growth of dominant trees. Equations were also developed to convert these estimates of height and height growth based on SI at breast height age 50 years to Taylor’s (1934) estimates based on a total age of 100 years.

Total basal area and basal area growth, and total number of trees and tree mortality for well-stocked stands by SI and age were estimated from Taylor’s (1934) tables 7 and 4, respectively. Estimates of the effects of precommercial and commercial thinning on basal area and diameter growth were derived from British yield models (Edwards and Christie 1981).

Model Parameters

Basal Area

Basal area at 10-year intervals for normally stocked stands (adapted from Taylor 1934, table 7), is given in table 2. Annual basal area increment (ΔBA) for natural stands is calculated by:

$$\Delta BA_{SI,j} = (NBAG_{SI,j} \ast PBAG_{j}) \ast [1 + IBAG_{SI} \ast (1 - BA_{SI,j}/NBA_{SI,j})],$$

where
j = age in years,
SI = site index class,
$\Delta BA_{SI,j}$ = annual basal area increment for site index class SI between ages j and j+1,
$NBAG_{SI,j}$ = net annual basal area growth for normal stands,
$PBAG_{j}$ = percentage of net annual basal area growth,
$IBAG_{SI}$ = increase in basal area growth for stands with less than normal stocking,
$BA_{SI,j}$ = stand basal area per acre, and
$NBA_{SI,j}$ = normal stand basal area per acre.

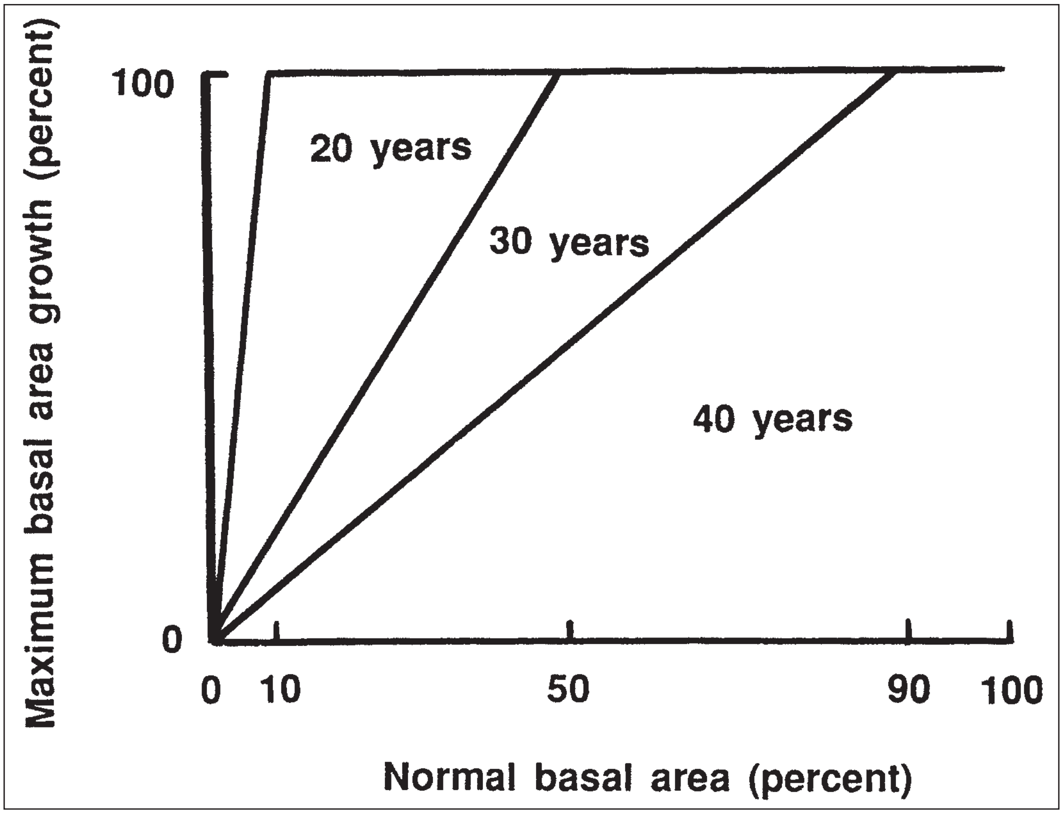

Figure 4—Percentage of maximum rate of basal area growth as a function of stand age and percentage of normal basal area.

Percentage of maximum rate of basal area growth (PBAG) is a function of stand age and percentage of normal basal area (fig. 4) and reflects the fact that stands become less capable of responding to thinning as they get older.

A potential increase in basal area growth (PBAG) takes place in less-than-well-stocked stands and is a function of SI:

$$IBAG_{SI} = 0.4 + 0.01 \ast SI.$$

Annual basal area increment (ΔBA) for thinned stands is calculated by:

$$\Delta BA_{SI,j} = (NBAG_{SI,j} \ast PBAG_{j} \ast{:}1.1) \ast (1 + IBAG_{SI,j} \ast [1 - (BA_{SI,j/}NBA_{SI,j}) \ast 1.1]).$$

This equation differs from the previous equation for basal area growth of natural stands in that thinned stands are allowed to grow at a relatively faster rate and eventually accumulate up to 10 percent more basal area than a natural stand. This is because thinning reduces stand composition to more vigorous, well-spaced trees.

Table 2—Basal area for second-growth western hemlock-Sitka spruce stands in southeast Alaska by age at breast height and site index

Total age	Site index				
	70	90	100	110	130
Years			*Square feet/acre*		
10	10	15	25	35	45
20	68	81	96	112	118
30	123	150	160	170	178
40	170	192	205	212	220
50	217	228	233	240	259
60	230	243	248	255	275
70	242	254	259	267	287
80	250	264	270	277	298
90	258	272	278	285	306
100	263	277	284	291	313
110	268	283	289	297	320
120	272	287	293	301	324
130	276	291	297	305	328
140	277	292	299	307	331
150	279	294	301	309	333
160	280	296	303	311	335
170	281	297	304	313	337
180	283	298	305	314	339
190	284	299	306	315	340
200	284	300	307	316	341
210	284	301	308	317	342
220	284	301	309	318	343
230	284	301	309	319	344
240	284	301	309	320	345
250	284	301	309	321	346

Source: Adapted from Taylor (1934, table 7).

Mortality

A stand with 100 percent of normal basal area is modeled to have a given number of trees per acre based on SI and age (table 3). Mortality rates are derived from these values, and model outputs follow these expected values.

Tree mortality in thinned stands and in natural stands that are less than well-stocked is typically low until stand basal area approaches that of a normal stand. The tree mortality rate for these stands is a function of normal number of trees based on SI, age, normal mortality rates, and percentage of normal basal area (fig. 5). It is calculated from:

$$MORT_{SI,j} = ST_{SI,j} \ast (ST_{SI,j}/NST_{SI,j}) \ast (1 - NST_{SI,j+1}/NST_{SI,j}) \ast MULT,$$

where

$MORT_{SI,j}$ = annual stem mortality for site index class SI between ages j and j+ 1 if $MORT_{SI,j}$ is greater than 0, otherwise $MORT_{SI,j} = 0$;

$ST_{SI,j}$ = number of stems per acre;

$NST_{SI,j}$ = number of stems in a normal stand of the same site index class and age; and

MULT = multiplier between) and 1 to reduce mortality in stands having less than normal basal area (obtained from fig. 5).

Table 3—Number of trees per acre in normal stocked stands of western hemlock and Sitka spruce in southeast Alaska by age at breast height and site index

Total age	Site index				
	70	90	100	110	130
Years			*Trees per acre*		
0-10	3300	3300	3300	3300	3300
10-20	3300	3300	3300	3370	3300
20-30	3300	3300	2900	2930	1950
30-40	3300	2770	2140	1610	1100
40-50	3300	1860	1470	1140	780
50-60	2440	1360	1050	830	550
60-70	1840	1030	800	625	415
70-80	1470	815	625	495	335
80-90	1210	680	520	410	285
90-100	1040	580	450	350	240
100-110	900	510	400	310	210
110-120	800	450	350	270	180
120-130	690	400	310	245	160
130-140	620	350	275	220	150
140-150	570	330	250	200	140
150-160	538	310	236	188	135
160-170	505	290	222	175	130
170-180	480	275	212	167	125
180-190	455	260	203	160	120
190-200	440	250	195	155	115
200-210	425	240	189	150	112
210-220	410	235	183	145	110
220-230	400	230	177	140	108
230-240	385	225	171	135	105
240-250	375	220	165	130	102

Source: Adapted from Taylor (1934, table 7).

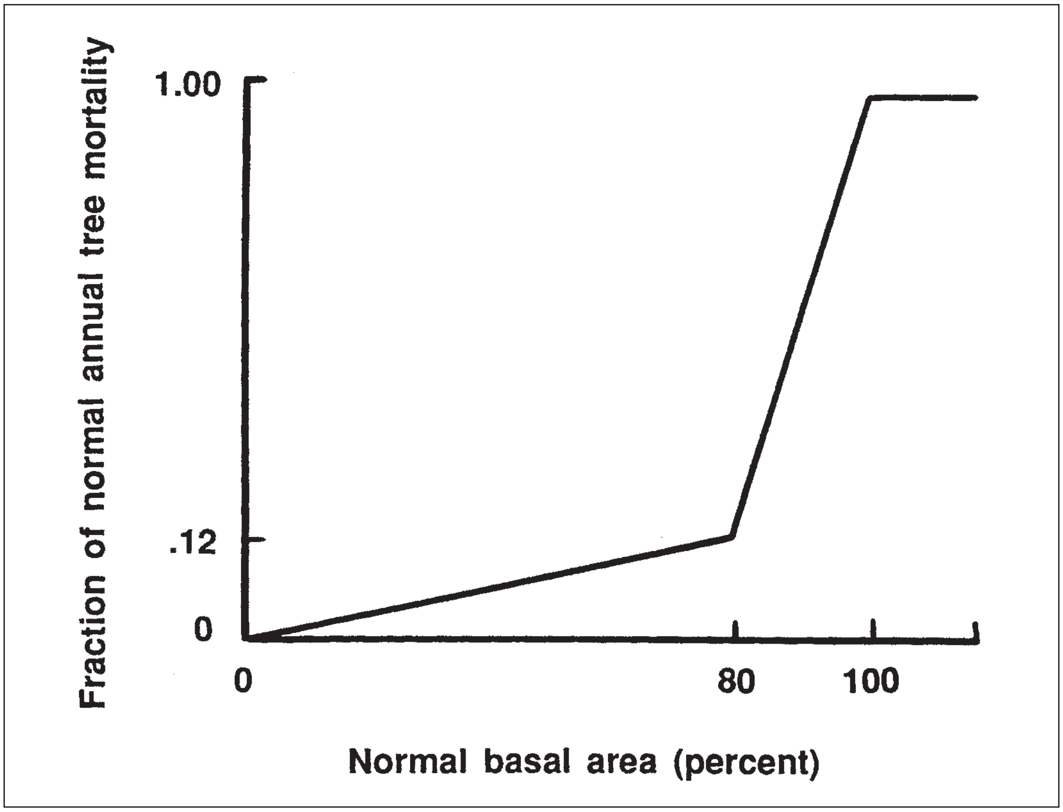

Figure 5— Fraction of normal annual tree mortality related to percentage of normal basal area, to adjust mortality in understocked stands.

Tree Height

Overstory height in the model is the mean height of dominant and codominant hemlock and spruce in a stand. Overstory height is computed indirectly by using Farr's (1984) height equation for Sitka spruce based on SI at a breast height age of 50 years. Heights are converted to a 100-year base, and this equation is solved to give patterns of height growth such that at total age 100 years mean height of dominant and codominant trees is 70, 90, 100, 110, or 130 feet, thereby satisfying conditions required to enter Taylor's (1934) normal yield tables.

Timber volume, Scribner rule, is calculated for trees 9.0 inches and larger DBH between a 1-foot stump and a 6-inch top. The relation between mean stand height and mean height of dominant and codominant trees in the stand is calculated with the equation:

$$MH_{SI,j} = -4.0 + 0.9833 \ast OH_{SI,j},$$

where

$MH_{SI,j}$ = mean height of trees 9.0 inches DBH and larger; and

$OH_{SI,j}$ = overstory height; that is, mean height of dominant and codominant spruce and hemlock.

Volume

Volume per acre, Scribner rule for 32-fool logs to a 8inch top, is calculated for sawtimber trees (9.0 inches DBH and larger) in the stand. Number of trees per acre that are 9.0 inches DBH and larger is a function of the total number of stems and mean diameter of the stand and is given by:

$$ST9_{SI,j} = ST_{SI,j} \ast [-78.29 + 18.041 \ast D_{SI,j} - 0.5229 \ast D^2_{SI,j} + 0.00335 \ast D3_{SI,j}],$$

where
$ST9_{SI,j}$ = number of stems per acre 9.0 inches DBH and larger for site index class SI at age j if $D_{SI,j}$ is greater than 5.1 inches; otherwise $ST9_{SI,j} = 0$;
$ST_{SI,j}$ = total number of stems per acre; and
$D_{SI,j}$ mean stand diameter.

Mean stand diameter of trees 9.0 inches DBH and larger ($D9_{SI,j}$) a function of mean stand diameter, is calculated from:

$$D9_{SI,j} = 6.4 + 0.6506 \ast D_{SI,j}.$$

Total volume per acre is a product of total number of stems 9.0 inches DBH and larger and mean volume per tree. Mean volume per tree for diameter $D9_{SI,j}$ and mean height $MH_{SI,j}$ is calculated from the Scribner volume equation given in Chambers and Foltz (1979).

Canopy Cover

Canopy cover (a fraction between 0 and 1) in young, unthinned even-aged stands with an overstory height less than 5 feet is calculated as a function of overstory stand height:

$$CC_j = 0.015 \ast OH,$$

where
CC_j = fraction of canopy cover at age j if overstory height $\leq$5 feet, and
OH = overstory height.

Canopy cover for stands with an overstory height greater than 5 feet is computed by using two equations. The first equation estimates mean crown width for trees of mean stand diameter; the second uses estimated mean crown width and total number of trees taller than 4.5 feet per acre to estimate canopy cover.

Mean crown width is a function of mean stand diameter:

$$CW_j = 4.04 + 1.98 \ast DBH_j^{\,0.87},$$

where
CW_j = mean crown width for trees of mean diameter at age j, and
DBH_j = mean stand diameter at breast height for trees taller than 4.5 feet.

Slash

Slash dynamics are modeled by using a time-dependent decay function to reduce slash height from three types of harvesting: clearcutting, commercial thinning, and precommercial thinning. Each action results in a given height of slash being left in a stand. Initial depths of slash are 18 inches for areas clearcut or commercially thinned and 36 inches for areas precommercially thinned. Any remaining slash is reduced by 5 percent per year.

Dynamics of Old Growth

In this model, any stand more than 250 years old is classified as old growth. A key assumption is that stands initially classified as old growth will remain in a steady-state condition until they are harvested. Younger even-aged stands will move toward the steady-state condition of old growth. When an even-aged stand is 250 years old, it will be classified as old growth and will then, over time, decay to the steady-state condition.

Dynamics of Streamside Overstory

The timber submodel keeps track of overstory stand height and canopy cover along streambanks so that stream temperatures can be calculated for the hydrology submodel and food availability for the fisheries submodel. Overstory height and canopy cover for each stream reach in a spatial unit are calculated as follows:

$$ATS_{i,m} = (\sum_{j=1}^{26} AT_{i,SI,j} * TA_{i,SI,j}) / TAS_{i,SI} ,$$

where
$ATS_{i,m}$ = either overstory height or canopy cover for stream reach m in spatial unit i, $AT_{i,SI,j}$ = either overstory height or canopy cover for the spatial unit i through which the stream reach flows,
$TA_{i,SI,j}$ - area in spatial unit i of site index class SI and age class j, and
$TAS_{i,SI}$ = total area in acres in spatial unit i and site index class SI.

Implementing Actions

Four types of forest management actions are allowed in the model:

1. Clearcutting.
2. Road construction.
3. Stand establishment and precommercial thinning.
4. Commercial thinning.

Overstory Harvest Actions and Methods

Forest management actions may be implemented through a designed timber management plan providing the details considered in most timber sales and giving projections of revenues and costs. The specific design of the procedure also makes it adaptable to geographic information systems.

Timber Management Plan

When the timber management plan begins is time dependent; that is, the user must specity the year or years when each specific activity is to occur. To accomplish this, a separate matrix must be set up for each type of action (table 4). All actions scheduled for a particular year are carried out when the appropriate simulated year is reached. Each entry in the matrix includes information on how that action will be implemented.

Table 4—Example of a partial matrix of management actions that must be entered in the timber submodel to implement the timber management procedure

Year	Spatial unit	Area clearcut	Stream bank harvested	Harvest type
		Acres	*Percent*	
3	12	40	0	2
4	11	120	9	1
35	11	40	0	1
64	13	60	0	4

Clearcutting—The following information is required for each area to be clearcut:

1. Acres cut.
2. Spatial unit.
3. Year to cut.
4. Percentage of streambank vegetation to be removed.
5. Harvest method.

The acreage that is clearcut in the model can be allocated to each SI class by two methods. In the first method, it is allocated in proportion to the relative area of the SI class in the spatial unit. For example, a 70 percent of the land in a spatial unit has an SI of 110, then 70 percent of the cut will come from SI class 110. In the second method, acreage cut in each SI class is allocated by the user. All acreage that is cut is put into a pool, which is moved into the youngest age class.

The percentages of streambank vegetation removed from each spatial unit are summed over all cuts each year to give a total percentage cut in each spatial unit.

Road construction—The following information is required for each occurrence of road construction:

1. Year road is constructed.
2. Spatial unit where the road is located.
3. Miles of mainline road to be built.
4. Miles of temporary road to be built.

Retirement of roads is not considered in the model.

Site preparation, planting, and precommercial thinning—The following information is required if intensive timber management actions are to occur after clearcutting:

1. Year action is to be implemented.
2. Spatial unit affected.
3. Acres of site preparation.
4. Acres to plant.
5. Acres to be precommercially thinned.

Consequences of implementing site preparation or planting are reflected only in the economic costs of carrying out the actions. The economic costs of these actions are discussed in the section on economics of forest management.

Commercial thinning of even-aged stands—The following information is needed to implement commercial thinning of even-aged stands:

1. Year action is to be implemented.
2. Spatial unit affected.
3. Age class of stand at time of cutting.
4. Residual basal area left after cutting.
5. Harvesting method.

Repeated commercial thinnings are implemented by specifying a series of thinnings in a particular stand. All acreage in a given age class in a spatial unit is thinned, irrespective of site class. It is assumed that any old-growth acreage harvested early in a run of the model will be managed as a unit and not be broken down into acreages by SI class.

Timber Management Economics and Employment

Revenues, costs, and employment associated with management activities are derived in the model by using several equations (given below) and tabular data on revenue, cost, and employment, which are given in appendix 1. Economic evaluations are currently restricted to capabilities related in these functions and data. Much of the procedure is taken from the Alaska Region timber sale appraisal procedure (Mifflin and Lysons 1979, USDA 1979). All the unit costs and revenues given in appendix 1 are in data files in the model and should be changed by the user to correspond to the situation being simulated. Employment, an area significantly impacted by timber operations, is developed in the timber submodel for use in the fisheries and deer submodel. Employment is also used as a social measure of community impacts.

Timber Revenues

Timber could be valued at various points in the production process; that is, on the stump, at the terminal transport facility, delivered at a mill, or as finished product, FOB mill. In this discussion and in the data shown in appendix 1, timber is valued as delivered at a mill. The timber prices used are therefore mill pond values, and the costs include all the costs of harvesting, including delivering the logs to a mill. Pond values are approximations generated by applying time- and site-specific assumptions to the Alaska Region timber sale appraisal procedures (USDA 1979). The model could be used with values at some other point, as long as the prices and costs that are put in the model are for the same point in the process.

The annual revenue, REV, from wood harvest in an entire watershed in year k is calculated by:

$$REV_k = \sum_{i=1}^{ns} \sum_{n=1}^{nc}$$

$$A_n \sum_{SI=1}^{5} \{(AR_{i,SI,26}/TA_i) \ast [V_{i,SI,26} \ast (PC_{i,SI} \ast RC) + (1-PC_{i,SI}) \ast R_{VSI}]\}$$

$$+ \{\sum_{SI=1}^{5} \sum_{j=1}^{25} AR_{i,SI,j} \ast VT_{SI,j} \ast [1-(BAT_{i,SI,j}/BA_{i,SI,j})] \ast V_{i,SI,j} \ast R_{VSI}\} ,$$

where
n = cut number;
nc = number of cuts made in spatial unit i in year k;
ns = number of spatial units in the watershed;
A_n, = acreage harvested in cut n;
TA_i, = total area of spatial unit i;
$V_{i,SI,j}$ = volume per acre (thousand board feet) in age class j, site index class SI, and spatial unit i;

$AR_{i,SI,j}$ = area of age j in site index class SI in spatial unit i;
$PC_{i,SI}$ = proportion of volume in cedar, site index class SI, spatial unit i;
RC = revenue from cedar (per mbf);
R_{VSI} = revenue for the particular volume of noncedar wood in site index class SI;
$BA_{i,SI,j}$ = basal area per acre before treatment;
$BAT_{i,SI,j}$ = basal area to which the stand is thinned; and
$VT_{SI,j}$ = second-growth revenue multiplier.

The first part of the right side of the equation calculates revenue from old growth harvest; the second part calculates revenue from second-growth commercial thinning.

The value of Vt varies with the type of young-growth entry being made. It equals 0.46 for second-growth thinnings, 0.40 for second-growth final harvest on unthinned stands, and 0.64 for final harvest on previously thinned stands.

Unit revenue varies with timber quality. In the model, timber quality is assumed to be related to stand volume, and unit revenues are used for both old-growth and second-growth timber (table 12).

Timber Costs

The following list presents the cost items that should be included in the model. Included are all costs for harvesting and transporting timber to a mill. Each item should include overhead costs customarily charged to these activities.

Administration—Costs include planning and management of sales, roads, and facilities. In general, these represent the costs of resident forest managers and specialists and specific costs for designated activities, such as particular sale layout or an environmental impact statement.

Road construction—Costs include general overhead plus specific costs associated with road segments. Treatment of both mainline and temporary road systems is included.

Harvesting, stump to truck—Harvest system costs cover harvesting logs and moving them from the stump to the loading site. Eleven different harvest systems are specified. These systems and the associated costs for logging different volume classes are given in appendix 1.

Hauling to a terminal transportation facility (TTF)—Hauling costs include two elements, unit hauling cost and unit maintenance costs for roads. Hauling cost is expressed in dollars per thousand board feet (mbf) per mile hauled from landing to TTF. The road maintenance cost is a dollar cost per mbf per mile from landing to the TTF.

Hauling from TTF to manufacturing point—The transfer cost from the TTF to the mill is expressed as dollars per mbf per mile from TTF to mill site.

Timber management—Costs relate primarily to regrowth of stands. Costs for site preparation, planting, and precommercial thinning are required in many stands and are listed in appendix 1.

Support facilities—Costs include construction of facilities such as logging camps or TTF. These costs are allocated over an expected total sale volume serviced and are expressed in dollars per mbf.

Environmental protection—Costs directly relate to preventing or controlling environmental damage. Stream cleaning, grass seeding, undercut bank protection, directional felling, and differential road alignment costs are examples of costs incurred in timber management. To account for these costs, the manager inputs incremental costs of management activities such as road construction and harvesting.

Some of the costs described above are combined to enter them in the model. The following sections show what cost categories are used in the model and how the costs are summed for the watershed.

Old-Growth Logging Costs

The total annual costs associated with old growth logging (CL) are given by:

$$CL = \sum_{i=1}^{ns} \sum_{n=1}^{nc} \left\{ [CPMBF_{CT_{i,n}} + (DFLD_i) \ast (CHAUL) + OCOST] \ast \sum_{SI=1}^{5} VC_{i,SI,n} \right\},$$

where
$CT_{i,n}$ = harvest method used for cut n in spatial unit i;
$CPMBF_{CT}$ = cost per mbf of using harvest method CT;
CHAUL = hauling costs per mbf per mile;
$VC_{i,SI,n}$ = volume of wood cut in spatial unit i, site index class SI, and cut n (mbf);
$DFLD_i$ = mean distance of each spatial unit from the mouth of the watershed, the assumed log storage site; and
OCOST = other costs per mbf.

Eleven different logging methods can be specified (table 14).

Road Costs

The total costs for roads in a given year (CR) are given by:

$$CR = \sum_{i=1}^{ns} [(CBMR \ast MMR_i) + (CBSR \ast MSR_i) + (CMR \ast TV_i \ast DFLD_i)] ,$$

where
MMR_i = miles of mainline road built in spatial unit i,
MSR_i = miles of temporary road built in spatial unit i,
CBMR = unit cost for constructing mainline road,
CBSR = unit cost for constructing temporary road,
CMR = unit cost for road maintenance,
TV_i = total volume harvested in spatial unit i (mbf),
$DFLD_i$ = mean distance of each spatial unit from the mouth of the watershed, the assumed log storage site.

This equation considers new road construction (both mainlines and spurlines), and maintenance on roads constructed up to the current year.

Stand Establishment and Thinning

The total cost of stand establishment and precommercial thinning in a particular year (TM) is given by:

$$TM = \sum_{i=1}^{ns} \sum_{m=1}^{3} CPM_m \ast AM_{m,i} ,$$

where

$AM_{m,j}$ = the acreage in spatial unit i subject to management practice m (1 = site preparation; 2 = planting; 3 = precommercial thinning), and

CPM_m = the unit cost of management practice m.

Timber Employment

Employment is determined for each watershed from volume of old growth harvest, miles of road built, and volume of commercial thinnings. It is also affected by management actions such as site preparation, planting, and precommercial thinning in young even-aged stands.

Employment (E) on a watershed is calculated by:

$$E = R_1 \ast TVC + R_2 \ast TRB + R_3 \ast TVT + \sum_{i=1}^{3} R_{3+i} \ast AS_i ,$$

where

$R_{i\text{-}6}$ = employment rate parameters (person years per unit of management),

TVC = total volume clearcut,

TRB = miles of road built,

TVT = volume of second-growth cut,

AS_i.=.acreage of each management action in young even-aged stands.

Model Documentation

A summary of the sources of documentation for the timber submodel is given in appendix 2. Most of the relations in the growth and yield model were derived from normal yield tables for western hemlock and Sitka spruce (Taylor 1934). Effects of thinning were extrapolated from the British forest management tables (Bradley and others 1966) or were based on professional judgment. Data on crown cover, slash depth and decay, and the dynamics of streamside overstory are based on the professional judgment of the participants involved in model development. Data on revenue and costs in appendix 1 are mostly from published sources.

4

The Hydrology and Soils Submodel

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Introduction

The hydrology submodel provides a primary link among road building, overstory management activities, and impacts on fish and deer habitat. This linkage is specific to measured and predicted changes in streamflow, sediment and debris transport, water temperature, and snow accumulation. The submodel is driven by precipitation, sediment, and air and water temperature inputs, with feedback from and to other submodels (fig. 6).

The submodel structure and basic ordering of the rules for change within the submodel are presented in figure 7. Precipitation information for driving the flow model is developed for an entire watershed. Information on sediment and temperature inputs is developed for and maintained within each spatial unit and within each stream reach making up a watershed. Each spatial unit drains into only one stream reach.

Sediment and Debris Input

A primary purpose of this submodel is to predict the quantities of sediment and organic debris transported through and deposited within anadromous fish habitat. Fisheries biologists in the North Pacific region have defined three classes of inorganic sediment and organic debris that have major influence on egg, alvin, and fry survival, rearing habitat, and food sources:

1. Debris less than 3.0 mm (fine sediment).
2. Debris 3.0 mm to 9.5 mm (coarse sediment).
3. Debris greater than 10.0 cm.

To provide output directly compatible with input requirements of the fisheries submodel, (levels of each of these classes are simulated in each stream reach.

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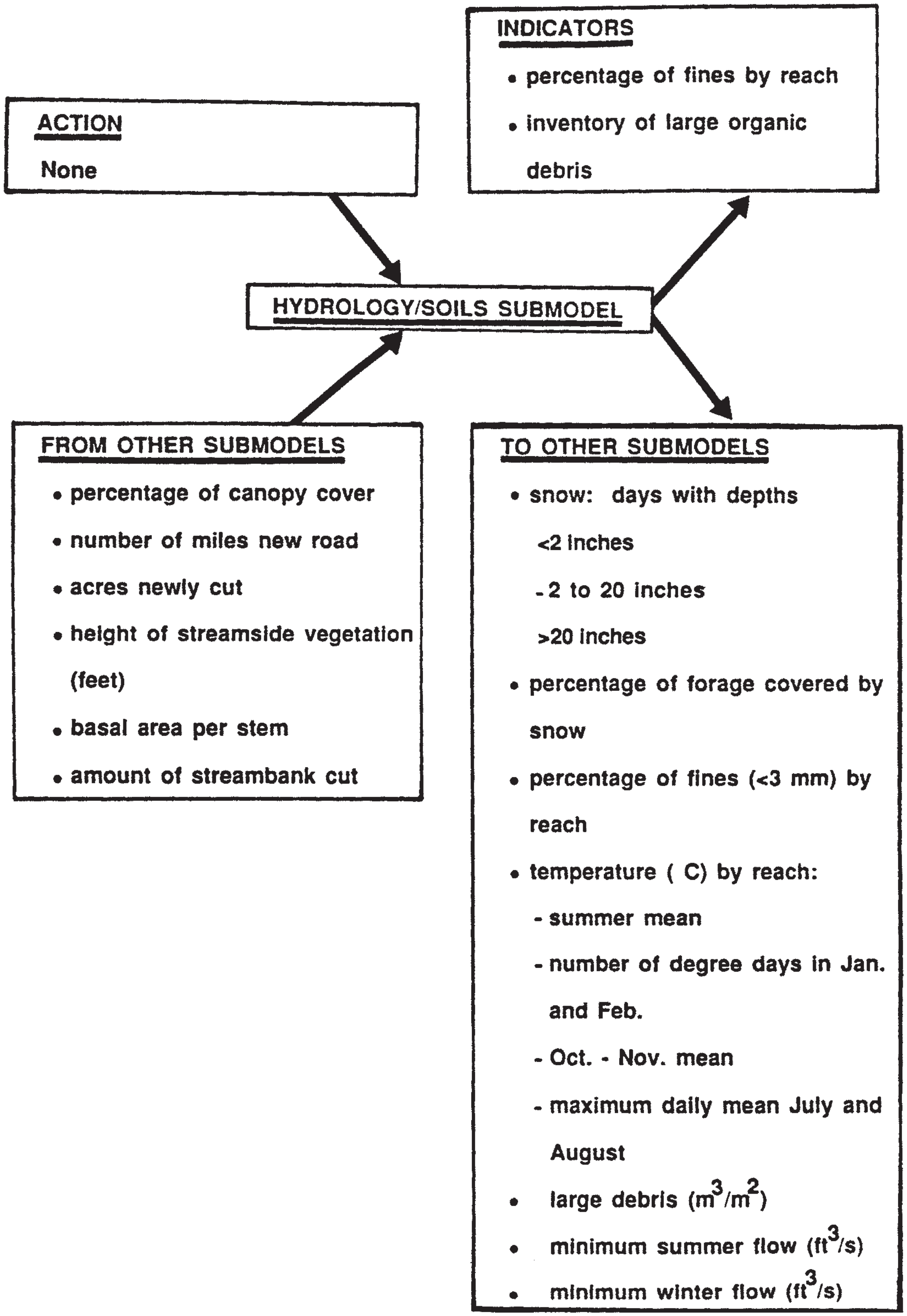

Figure 6—Information flow and system linkages for the hydrology submodel

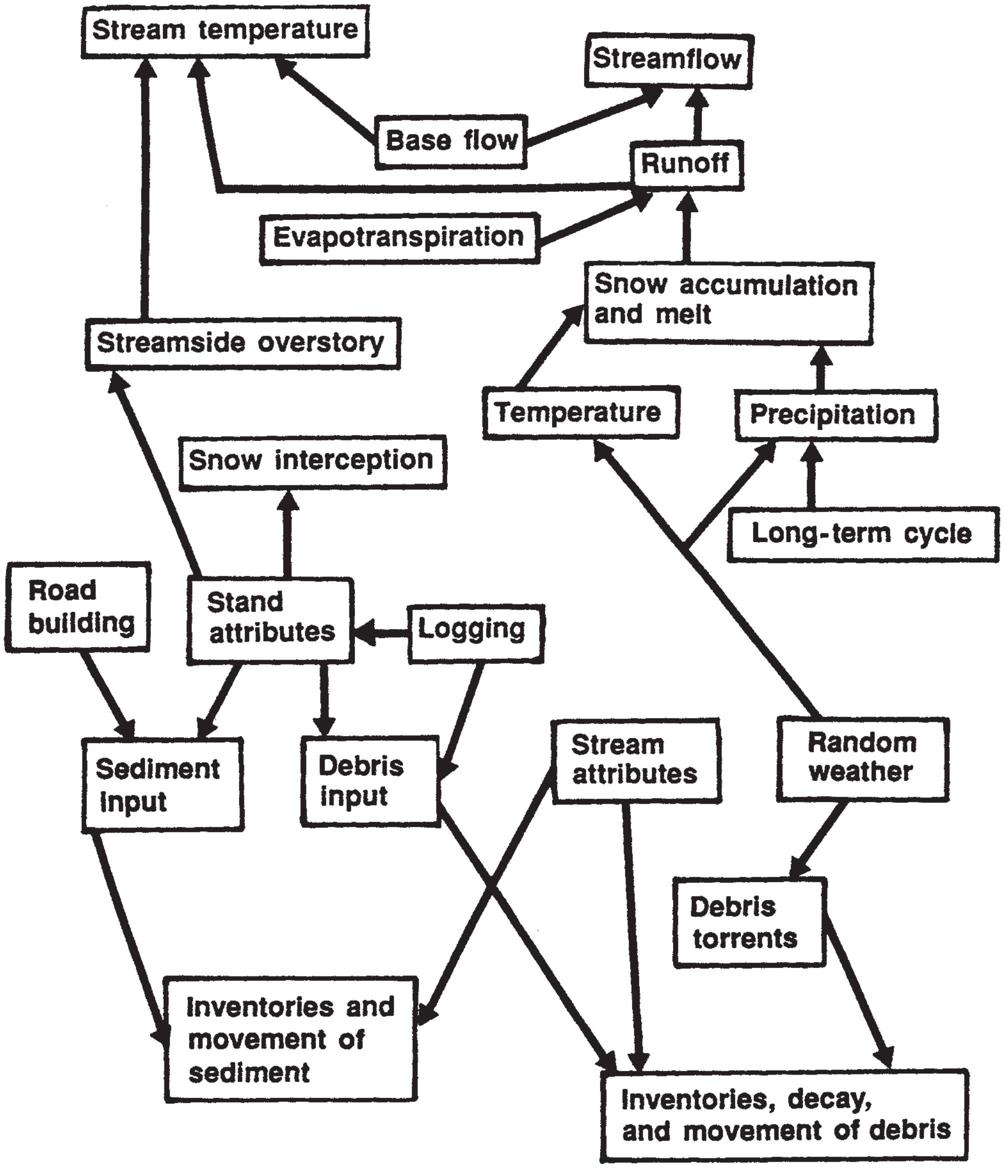

Figure 7—Basic structure and driving parameters of the hydrology submodel.

The total input of a single class of sediment into a stream reach is calculated by accumulating (1) the natural input per acre multiplied by the delivery ratio for that spatial unit, (2) estimated input from roads and logging in each spatial unit feeding the reach, and (3) input from stream reaches feeding the reach. The delivery ratio accounts for not all sediment reaching the stream. For purposes of this submodel, natural sediment loading from soil mass movements was estimated at a rate of (0.16 m^3/acre)/ year. Loading rate is based on data obtained for areas in the Pacific Northwest having similar topography and climate (Swanston and Swanson 1976).

In areas disturbed by logging activities, additional sediment loading is derived from debris avalanches, slumps from clearcuts and roads, road surface erosion, and road use. Inputs

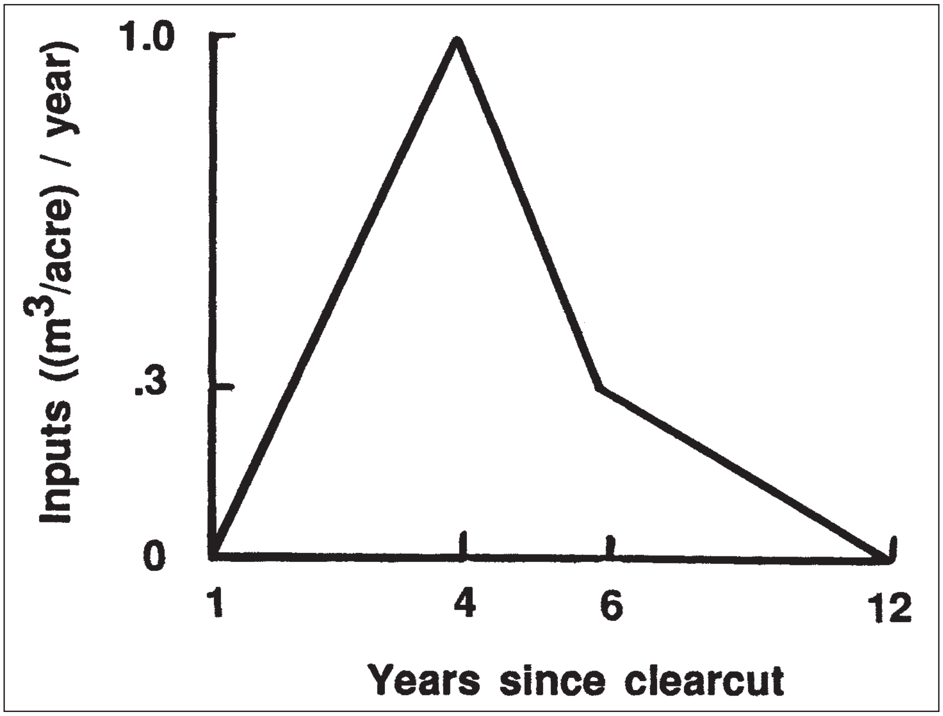

Figure 8—Sediment inputs from clearcut areas.

of sediment from logging-related loading are a function of years since clearcut (fig. 8). Inputs of sediment from road erosion are a function of time since the road was constructed (fig. 9). Construction of these functions is based on data from Swanston and Swanson (1976), Reid and others (1981), Reid and Dunne (1984), Paustian (1987), and on professional judgment and experience of field personnel in southeast Alaska.[2]

All sources of sediment are assumed to be composed of 60 percent fine and 40 percent coarse material. This ratio approximates the findings of sediment budget studies elsewhere in the Pacific Northwest and generally agrees with preliminary data from southeast Alaska.[3]

Road sediment data for southeast Alaska are limited; however, preliminary measurements of sediment delivery from forest roads in two watersheds on Chichagof Island (see footnote 2) indicate peak volumes of 160 to 170 (m3/mile)/year during and immediately after construction. This volume is believed to diminish substantially as the road ages and becomes more stable (see fig. 9).

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[2] Paustian, S.J.; Marion, D.; Maki, S.; Kelliher, D. 1987. Kadashan sediment monitoring study. Juneau, AK: U.S. Department of Agriculture, Forest Service, Tongass National Forest. 29 p. Interim report. On file with: U.S. Department of Agriculture, Forest Service, Tongass National Forest-Chatham Area Fisheries, Wildlife, and Watershed Staff Office, Sitka, AK 99835.

[3] Personal communication, S.J. Paustian, hydrologist, USDA Forest Service, Chatham Area, Tongass National Forest, Sitka, AK 99835.

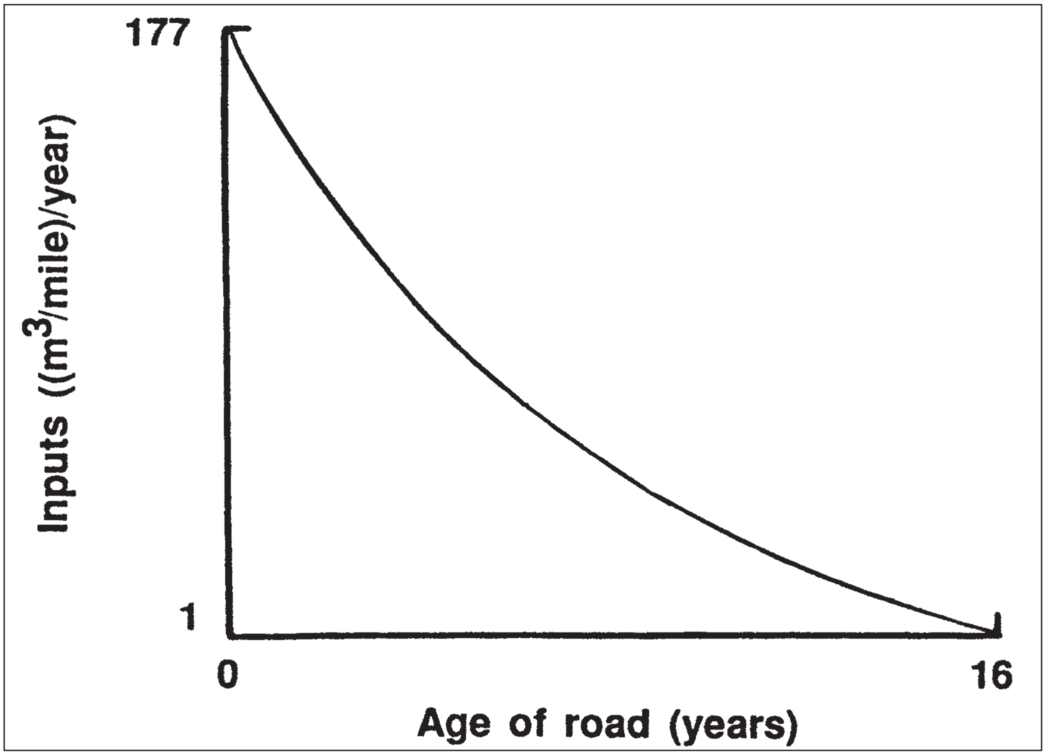

Figure 10—The decay function for sediment from constructed roads.

Sediment delivery to channels as the result of regular road use is believed to be lower in southeast Alaska than elsewhere in the Pacific Northwest and is estimated to be about 50 percent below construction levels (83.0 [m^3/mile]/year) for normal log-haul traffic (5-10 hauls per day). This is believed to be the case for several reasons. Most road construction has a fairly low level of ground disturbance because of the occurrence of a thick organic mat and muskeg and limited hillslope cuts and fills. Furthermore, there is a general lack of fine sediment in surface and subsurface materials, and log-haul traffic is moderate and Runs on less than full-year operating periods. Sediment delivery from light traffic on main haul roads (two or less hauls per day) is believed to be low and is estimated at about the same level as reported by Reid and Dunne (1984) for the Olympic Peninsula [1.30 [m^3/mile]/year]. Sediment delivery directly linked to traffic on spur roads is believed to be minimal because these roads are not generally close to viable channels; sediment delivery is estimated at about the natural rate [0.15 [m^3/mile]/year]. Estimated sediment inputs from road use are shown in the following tabulation:

Type of use	**Annual sediment input**
	m^3/mile
Light use, spur road	0.15
Light use, main road (2 or less hauls/day)	1.30
Normal use, main road (5-10 hauls/day)	83.00

The total input of debris into a stream reach is calculated by (1) the natural inputs from vegetation next to a stream reach, (2) logging, and (3) inputs from streams feeding the reach.

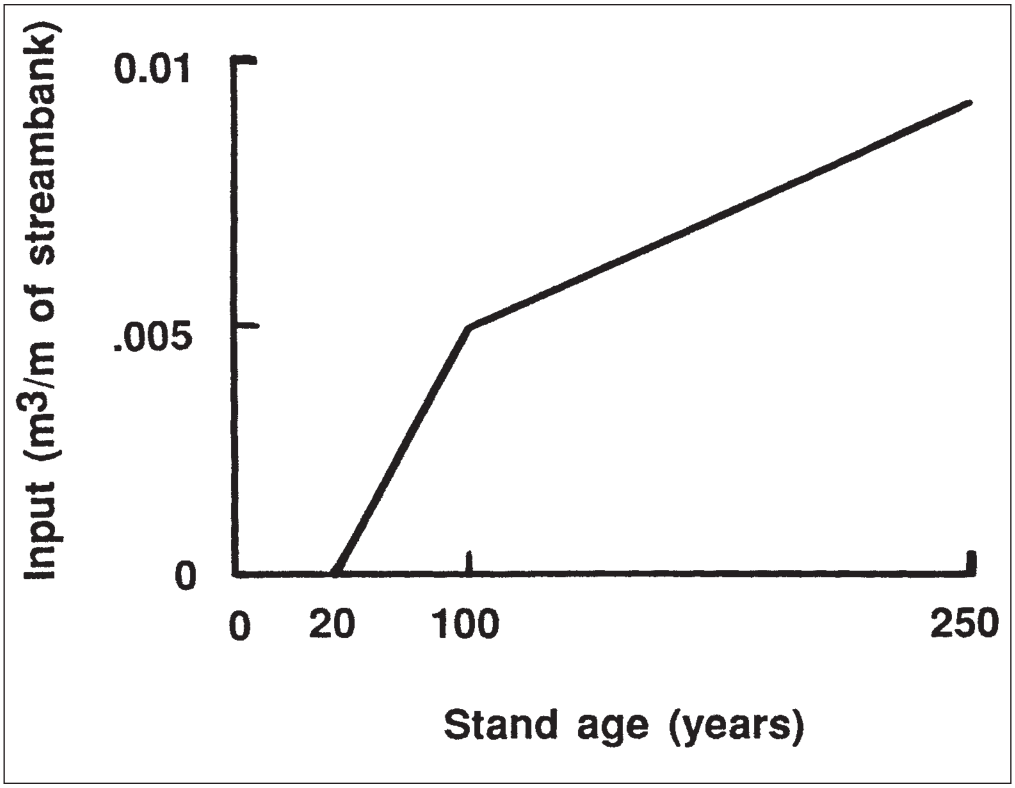

Figure 10— Debris inputs from stands.

Addition of organic debris to stream channels is a continuing natural process in the old-growth spruce and hemlock forests of southeast Alaska. This input is estimated at 0.015 m3/m of streambank/year. The inputs of organic debris after logging are a function of stand age and time since cutting. The curve in figure 10 reflects the debris input over the life of the stand. Changes in stream debris inventory resulting from logging are a user input. The input from a reach entering a spatial unit is the sum generated in the spatial units the reach passes through. This routing of debris can have a significant impact on spawning and therefore is treated below in more depth.

Routing

The sediment-routing portion of the submodel uses a simple scheme based on the assumption that a fixed proportion of the sediment and debris in the various classes is washed out of each reach each year. The basic equation for debris routing in year tn is:

$$L_{t+1} = (L_t + I_t) * (1 - P) * (1 - D) ,$$

where
L_t = total sediment (debris) level,
I_t = total sediment (debris) input,
P = proportion moving out of a reach each year, and
D = 0.008 (proportion decomposing each year).

At the beginning of the simulation, the model calculates the proportion of debris moving to the next stream reach (P). This implies:

$$P = (I_e + I_u - D)/L_e ,$$

where
I_e = annual input for equilibrium for this reach,
I_u = annual input from upper reaches at equilibrium,
D = 0.008 (proportion of debris decomposing each year), and
L_e = inventory of debris at equilibrium.

The determination of equilibrium conditions for fine and coarse sediment is slightly more complex. The model calculates an initial condition based on the equilibrium ratio for fine to coarse sediments (L_{e1}/L_{e2}):

$$L_{e1}/L_{e2} = (I_1/I_2) \ast [(1/P_1 -1)/(1/P_2 -1)] ,$$

where
L_{e1} =: equilibrium level of fine sediment,
L_{e2} - equilibrium level of coarse sediment,
I_1 = input of fine sediment,
I_2 - input of coarse sediment,
P_1 = movement rate of fine sediment, and
P_2 = movement rate of coarse sediment.

Given the ratio L_{e1}/L_{e2}, I_1, I_2, and the movement rate P_1, for each reach, the model calculates P_2 at the beginning of the simulation. Once this calculation is completed, equilibrium levels for fine and coarse sediment are determined. Table 5 shows the sediment movement rates used in the calculations for different stream orders.

Table 5—Proportions of sediment washed out of each reach In each year, and proportion of fines at equilibrium, by stream order

	Proportion washed out per year		Equilibrium proportion of fines < 3 mm
Stream order	<3 mm	> 3 mm	
3; 4	0.20	0.026	0.30
2	.50	.097	.20
1	.90	.493	.15

Debris Torrents

Debris torrents are high-velocity, high-volume flows of heavily charged sediment and organic debris in confined channels. They are usually triggered by debris avalanches into upper slope gullies and canyons during major storms. Debris torrents create a major source of short-term sediment and debris loading.

Data from the Pacific Northwest (Swanston and Swanson 1976) and professional judgment of hydrologist in southeast Alaska indicate an increase in the frequency of occurrence of debris torrents as a result of logging. For purposes of this submodel, the probability of debris torrents was assumed to occur in first-order streams only. Logging increases this probability (fig. 11). The delayed rise seen in figure 11 is due to a hypothesized gradual reduction in strength of upper slope soils as the binding and reinforcing effect of tree roots diminish through decay after logging.

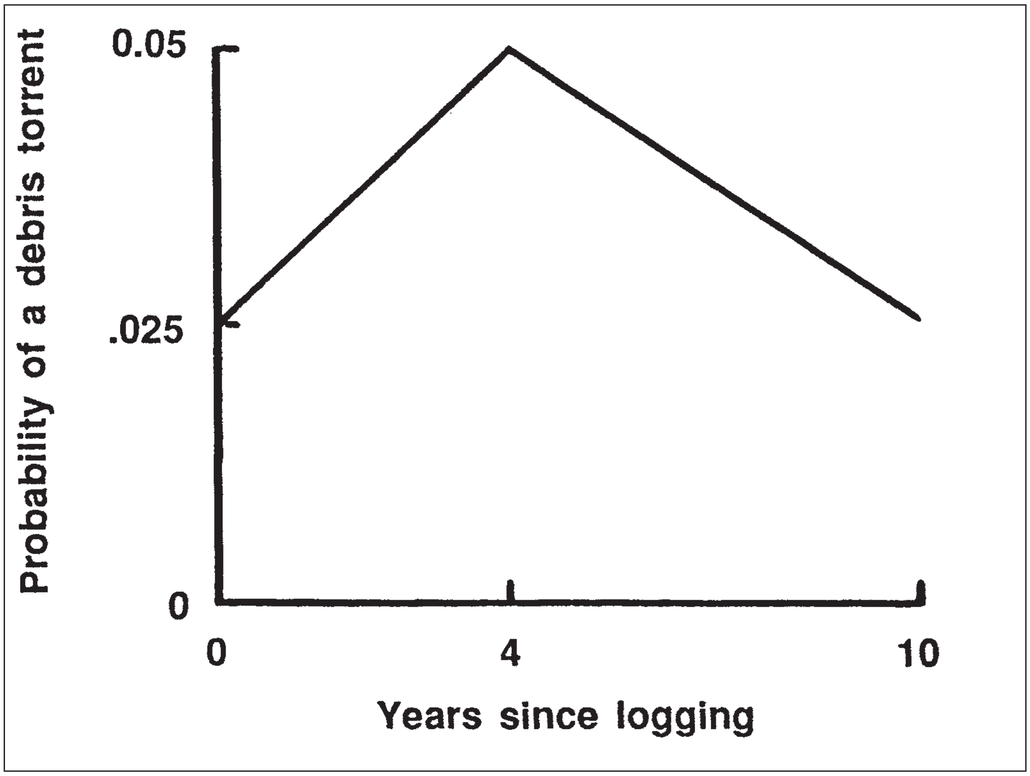

Figure 11—Effect of logging on the probability of debris tonents in first-order streams.

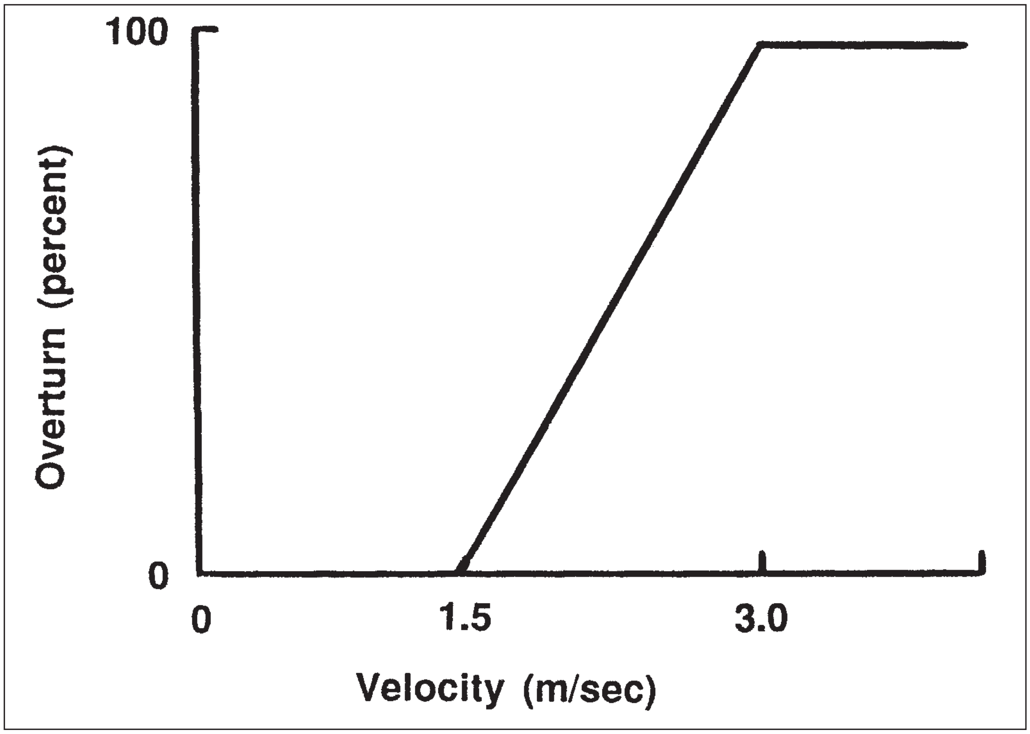

Figure 12—Bedload overturn as a function of peak velocity in the largest fall storm (value set by user).

Bedload Stability

Information on bedload overturn is required by the fisheries submodel to predict potential destruction of eggs and alvin during fall stormflow periods. Overturn is tied to calculated peak velocities by using the relation shown in figure 12. The maximum possible bedload overturn in each reach is assumed to be less than 100 percent because of various local effects within the stream.

Undercut Banks

To predict habitat changes, the fisheries submodel also requires information on the quantity of undercut banks along each reach. According to Murphy and others (1984, 1986) as much as 200 ma of undercut bank per kilometer of main stream channel may occur In old-growth stands. In the model, area of undercut bank is calculated for each reach based on estimated length and mean depth of undercut (user input). Logging along stream banks reduces available area of undercut banks of affected portions by 60 percent (Murphy and others 1986). Reestablishment of these bank undercuts begins almost immediately after initial destruction as a result of frequent lateral cutting during annual fall and winter high flows in the channel (storm periods). The time needed to develop fully stabilized undercut banks is unknown. Experience of hydrologists and fisheries biologists in southeast Alaska suggests that, although the available area of undercut banks is ephemeral and subject to local collapse during storm flows, it generally returns to prelogging levels within 5 to 25 years after disturbance. In the model, 10 years is used as an average return time.

Streamflow

To adequately model streamflows, temperatures, and the interaction between them, a smaller time-step flow model is included within the main submodel. This model is structured to run with a 3-day time step. Each year, the flow model runs according to the appropriate time step, starting on November 1.

Water Balance

Factors considered in water balance are rain, snow, snowpack, evapotranspiration, snow melt, infiltration, runoff, base flow, and water table (fig. 13).

In the model, the precipitation rate is driven by average monthly precipitation similar to that shown in figure 14. The average monthly precipitation is modified in two ways: a long-term adjustment of the form shown in figure 15, and a random annual pattern drawn from a random normal distribution with a standard deviation selected by the user.

Air temperature is calculated by using average monthly temperature similar to that shown in figure 16 and a standard altitude effect of 3.6 °F per thousand feet. This temperature distribution is then modified by using the following procedure:

1. Mean winter air temperature is modified by a normal distribution variant with mean of zero and a user-input standard deviation.

2. Mean 3-day temperature is modified by a normal distribution variant with a mean of zero and an input standard deviation of 4 °F for summer and 6 °F for winter.

3. Mean day and night temperatures are on 12-hour intervals. Mean daily temperature Is modified by a value reflecting the difference between day and night temperatures (7 °F for summer and 6 °F for winter).

When the air temperature in a particular area is below 32 °F, precipitation falls as snow and is added to the snowpack. When the temperature is above 32 °F, all precipitation is assumed to fall as rain.

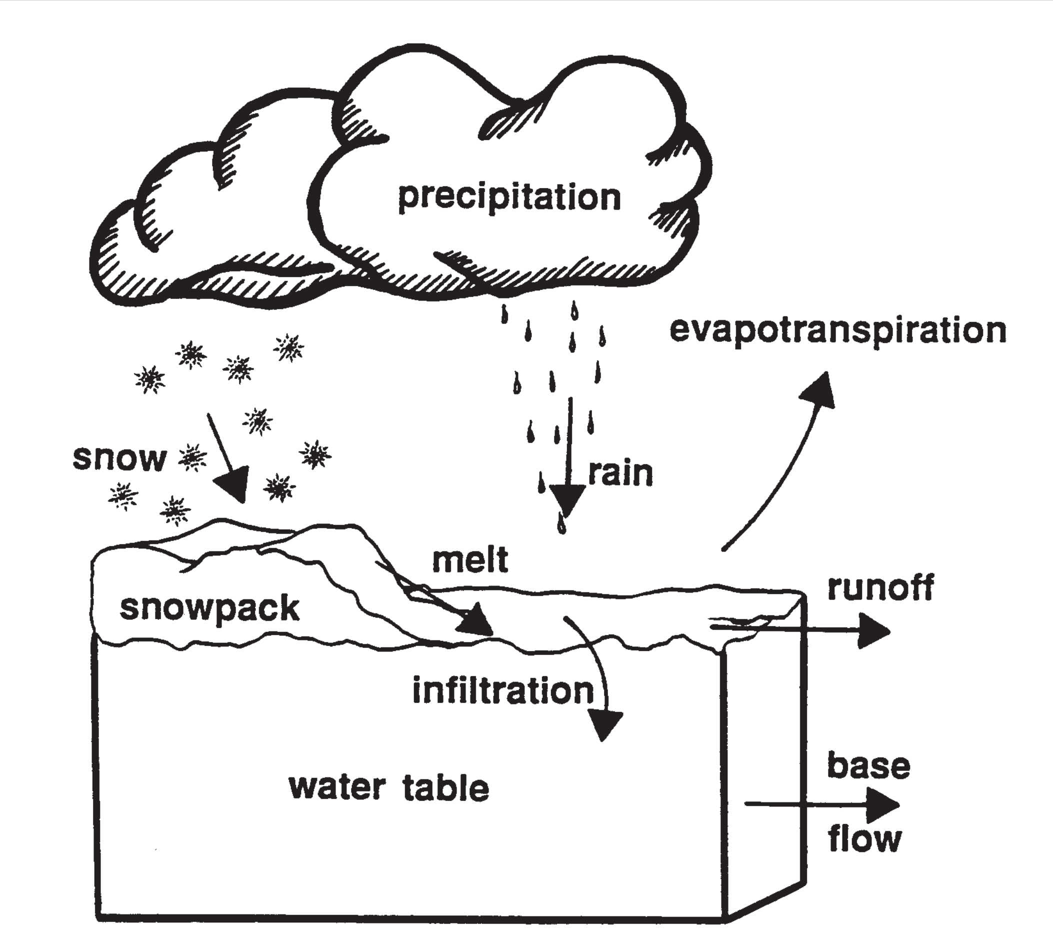

Figure 13—Generalized model of water movement through a watershed system.

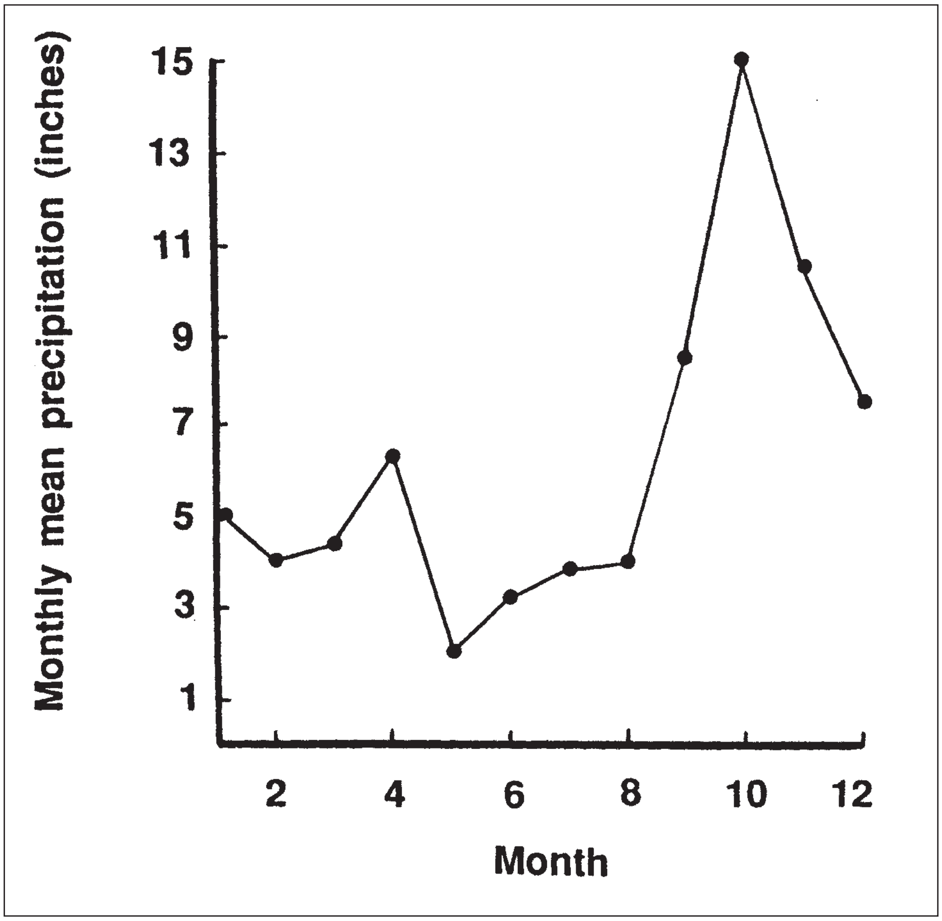

Figure 14—Typical mean precipitation pattern used in the hydrology submodel.

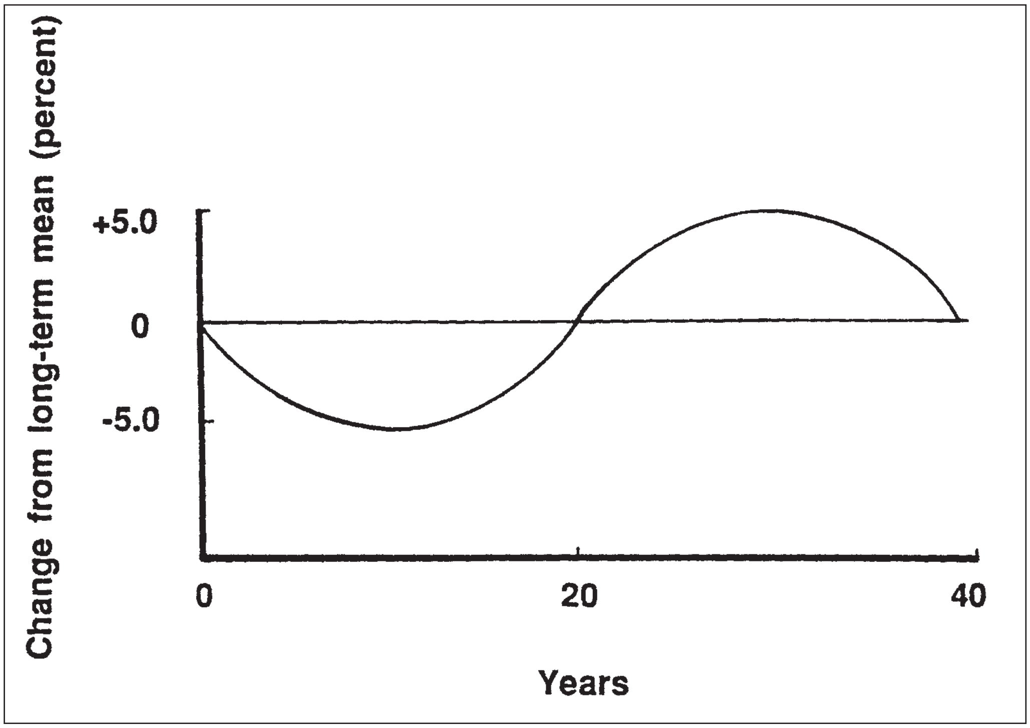

Figure 15—Forty-year mean adjustment for yearly precipitation.

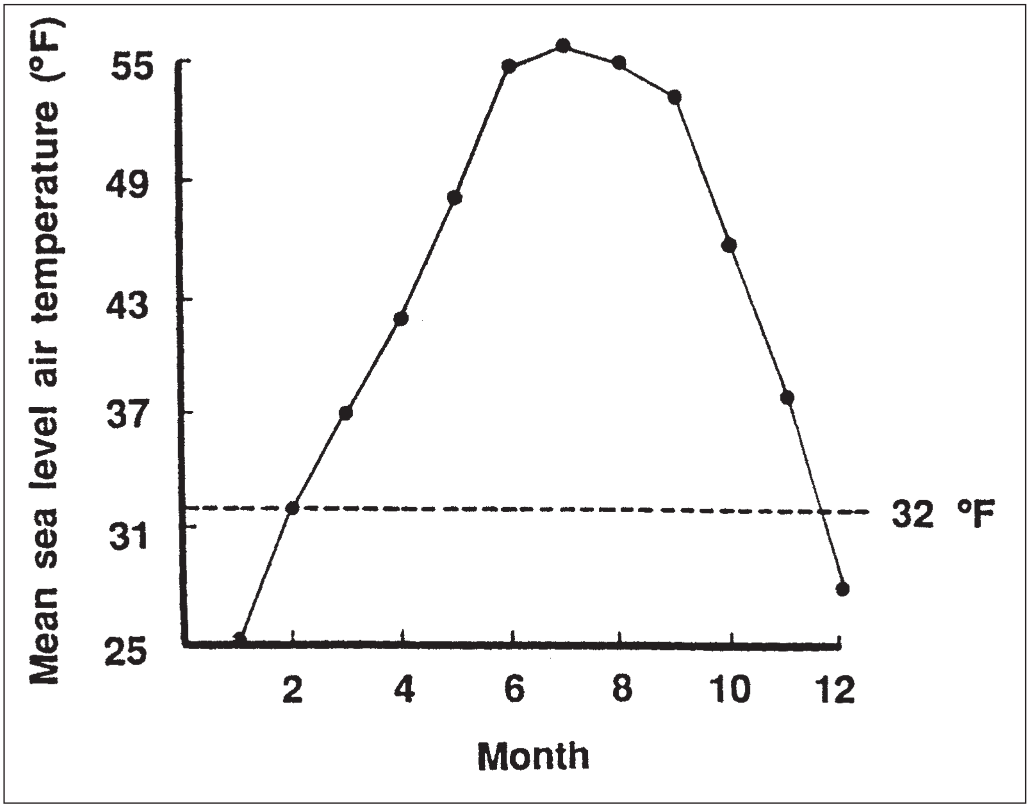

Figure 16—Typical annual distribution of mean sea level air temperature.

Snow melt is driven by both temperature and rainfall. When the temperature is below freezing there is no melt. When temperature is above freezing, there are two sources of snowmelt. Air temperature causes melt of 0.06 inch of snow (water equivalent) per degree-day. Rain causes melt of 0.007 inch of snow (water equivalent) per degree per inch of rain.

Three things happen to the total surface water (precipitation plus melt): evapotranspiration, surface runoff, and infiltration. The percentage of evapotranspiration in an old-growth stand is a function of time of year (fig. 17), which has two elements: a constant background evaporation of 10 percent, and an evapotranspiration effect that is active during summer and rises to a peak adding up to an additional 15 percent. Figure 18 illustrates the way this summer evapotranspiration effect is assumed to vary after clearcutting. It returns to a maximum at a stand age of 10 years.

The proportion of the water remaining to infiltrate the soil after evapotranspiration depends on two things: a background rate hypothesized to be 20 percent and the remaining water capacity of the soil. All watershed areas are assumed to have an available water capacity of 5 inches; when this capacity is reached, no further water is allowed to infiltrate.

Water in the soil is assumed to enter streams as base flow in direct proportion to the amount of water in the water table, or 0.5 percent per day. Flows into each reach consist of surface runoff from surrounding areas and base flow from those same areas. Flows from one reach to another move downstream as instream flows.

Water Temperatures

Water temperatures are hypothesized to depend on air temperature and solar radiation on the stream surface. The initial water temperature in a stream reach (T_I is the flow-weighted average of groundwater (40 °F), surface runoff, and the final temperature from the previous time step:

$$T_I = [(T_F \ast Q_s) + (T_R \ast Q_R)] + [(T_B \ast Q_B) \ast (Q_S + Q_R + Q_B)] \ ,$$

where
T_I = initial water temperature (°F),
T_F = final water temperature from the previous time step (°F),
T_B = groundwater temperature (40 °F),
T_R = surface runoff temperature (°F),
Q_S = streamflow (cfs),
Q_B = groundwater inflow (cfs), and
Q_R = Surface runoff (cfs).

The effect of solar heating follows Brown’s (1970) model, which states that the heating effect is described by:

$$\begin{aligned} T\ (°\mathrm{F}) = {} & (\text{area of exposed stream surface } (\mathrm{ft}^2) \\ & \ast \text{ rate of heat absorption } [(\mathrm{BTU}/\mathrm{ft}^2)/\mathrm{min}] \\ & \ast\ 0.000267\ \}/\text{discharge } (\mathrm{ft}^3/\mathrm{sec}) \ , \end{aligned}$$

where
T(°F) = the incremental increase in stream temperature, and
0.000267 = a constant for converting discharge (ft^3/sec) to pounds of water per minute.

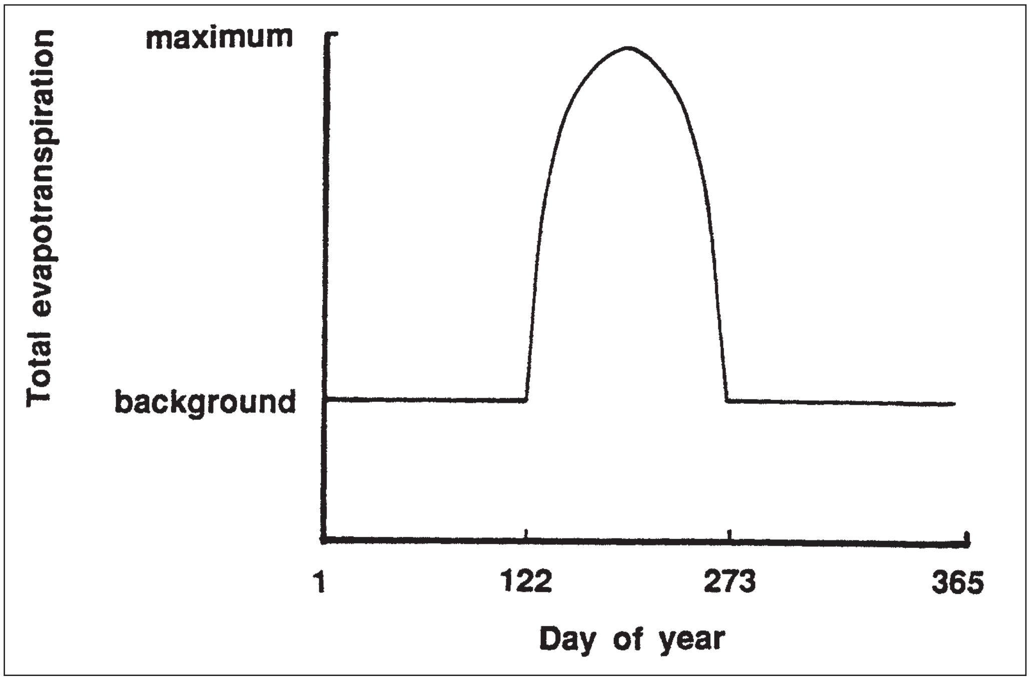

Figure 17—Evapotranspiration over the year in oldgrowth stands.

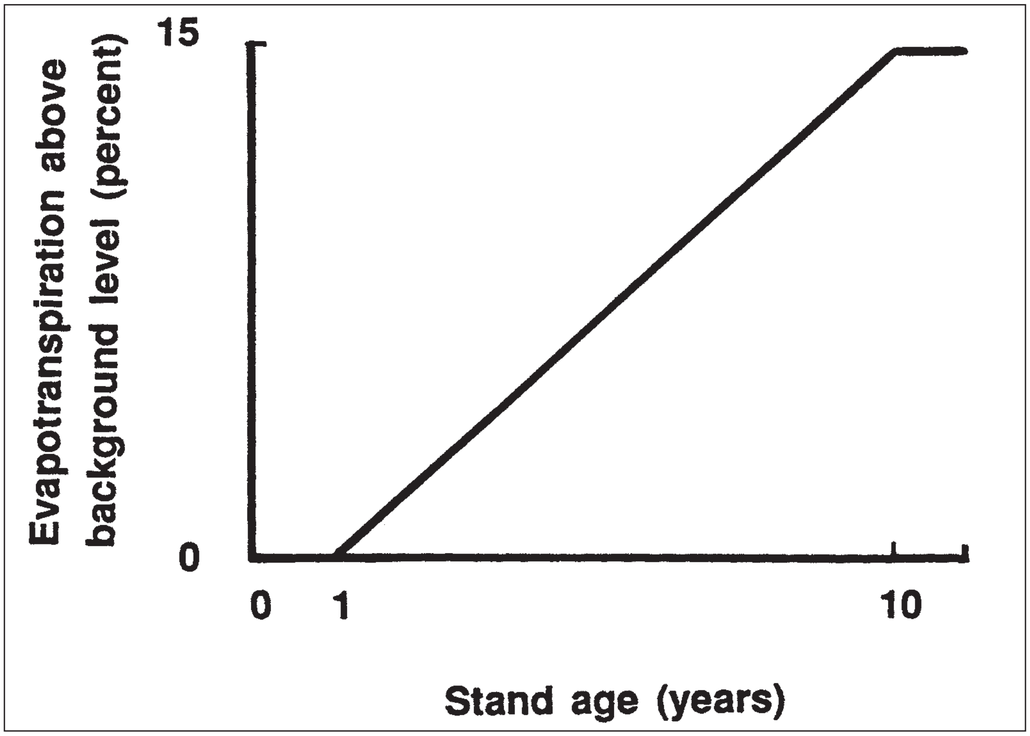

Figure 18—Maximum increase in summer evapotranspiration above background level as a function of stand age.

This relation is applied to the water in each reach as it flows through the system. Final temperatures are a flow-weighted average of final temperatures for water in a reach and incoming water from upper reaches.

The area of exposed stream surface is the surface area of the reach not shaded by streamside vegetation. The amount of shading depends on the stream width, the height of streamside vegetation, and the time of year.

Each reach has a user input of maximum possible shading,which is less than 100 percent, that results from open areas of various sorts, such as rocky ground and muskegs. The height of streamside vegetation required for maximum shade is calculated as shown in figure 19. Given the maximum solar angle for each month (fig. 20), the height of streamside vegetation for maximum shade is calculated with the equation:

$$\text{Height} = \text{stream width} \ast \tan\ (\text{solar angle}).$$

This height is used in the relation shown in figure 21, along with the height needed for maximum shade, to calculate the proportion of the shaded stream surface. this calculation neglects the orientation of the stream.

The rate of heat absorption is hypothesized to depend on two factors: the maximum solar angle and the residence time of water within a reach. The maximum solar angle, given in figure 20 for each month, is used to generate a factor indicating the reduction in heat absorption to compare with that for the maximum solar angle of the year (fig. 22).

The residence time of water within a reach is calculated as:

$$\text{Residence time (hr)} = \text{reach volume } (\text{ft}^3)/\text{discharge } (\text{ft}^3/\text{hr}).$$

This is used to calculate the rate of heat absorption by using the relation shown in figure 23.

Snow

The wildlife submodel requires estimates of the number of days in winter when snow accumulation in each spatial unit is between 2 and 20 inches and when it is greater than 20 inches. Eight inches of snow is assumed to equal 1 inch of water.

The flow model keeps track of the mean depth of snow in each spatial unit as equivalent inches of precipitation. Snow depth on the forest floor includes snow that accumulates in openings between the trees and snow that accumulates under the trees. The proportion of the stand that is between crowns, or at 0 percent crown closure, accumulates the same amount of snow as does a measured opening. Under the remainder of the stand, snow depth is modified as a function of the average basal area per stem in the stand:

$$\begin{aligned}\text{Modified snow depth} = {} & 1 - (0.166 \ast \text{basal area/stem}) \\ & \text{x (unmodified snow depth).}\end{aligned}$$

Average snow depth in the stand is equal to:

$$\begin{aligned}\text{Average snow depth} = {} & (\text{modified snow depth} \ast \text{percent crown closure}) \\ & + [(\text{unmodified snow depth}) \\ & \ast (1 - \text{percent crown closure})].\end{aligned}$$

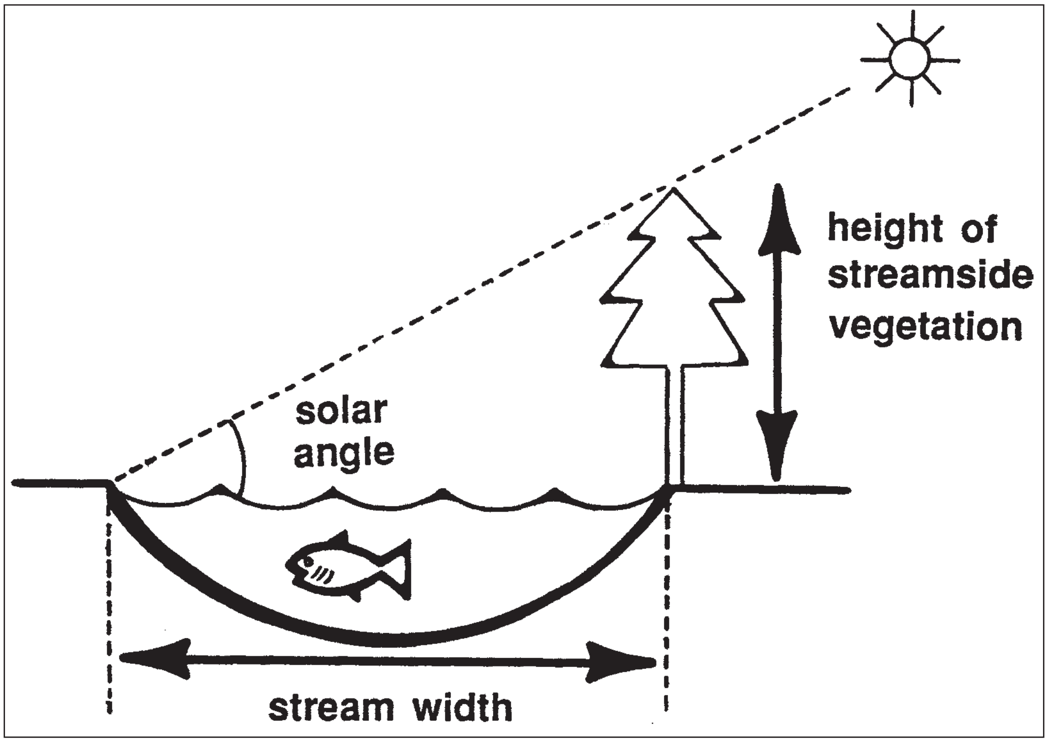

Figure I9—Method of calculating height of streamside vegetation required for maximum shade.

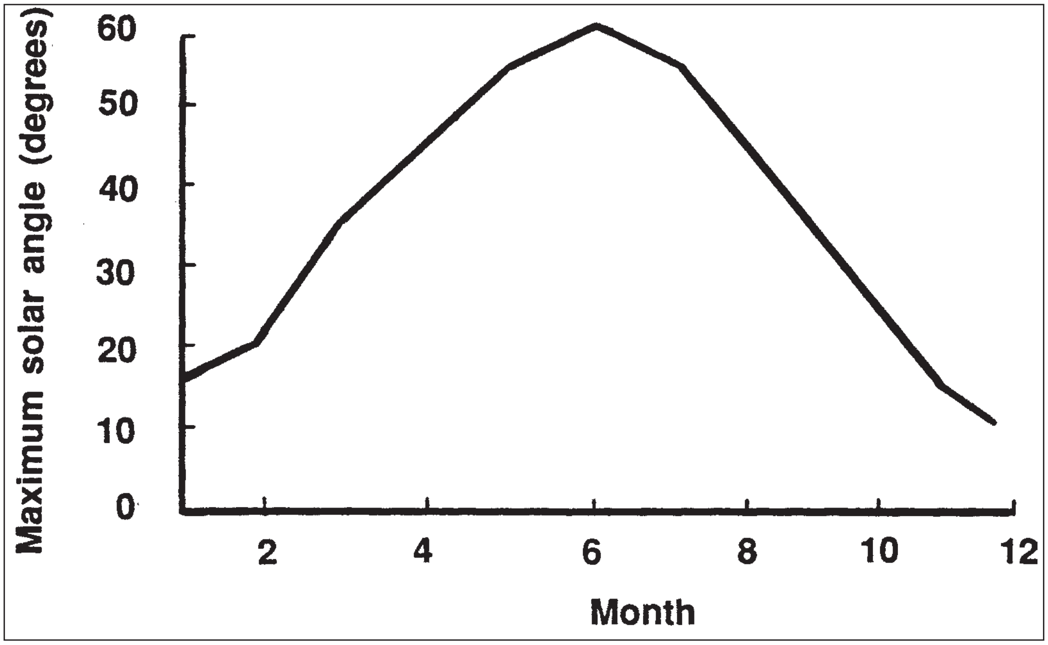

Figure 20—Maximum solar angle by month in southeast Alaska.

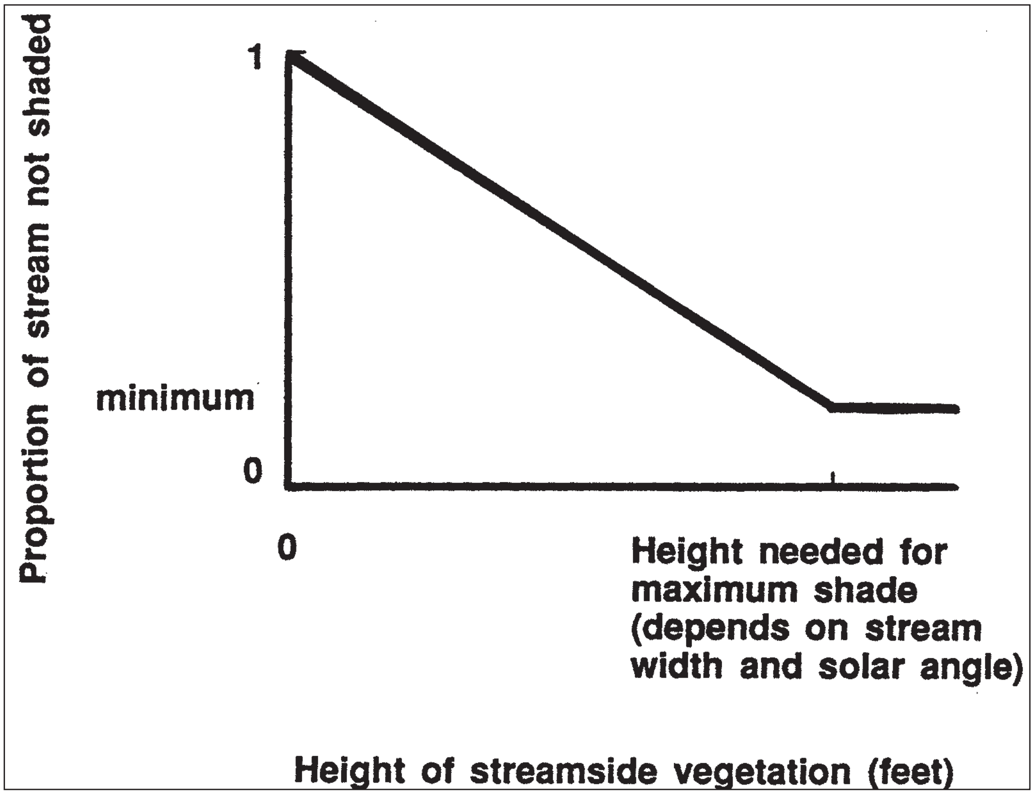

Figure 21—Effect or vegetation on shading of streams. The minimum is determined by the percentage of bank having vegetation.

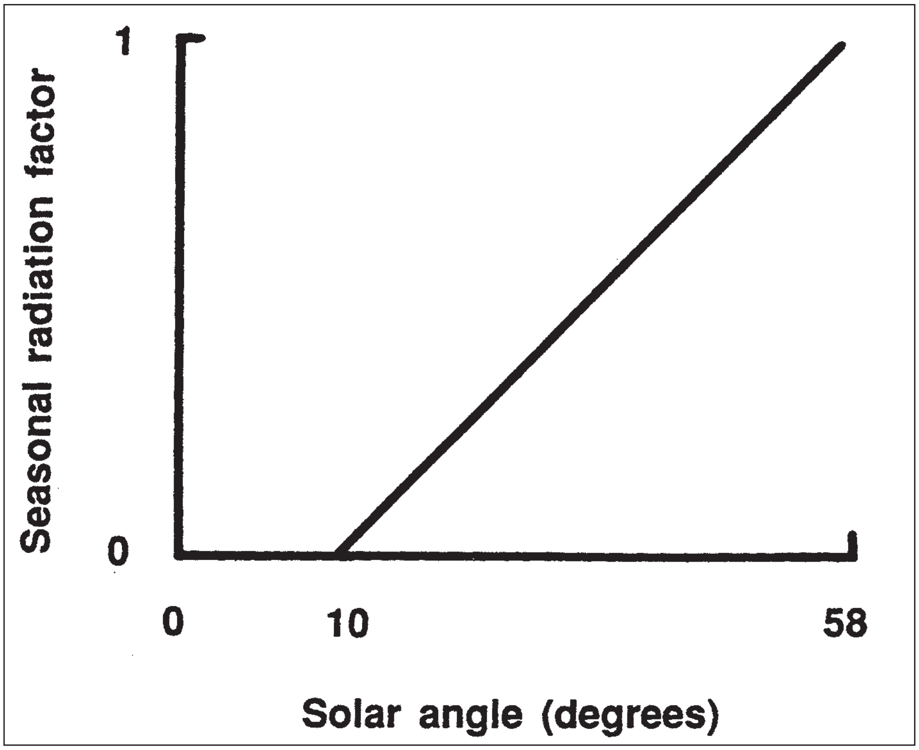

Figure 22—Effect of solar angle on heat absorbed by water.

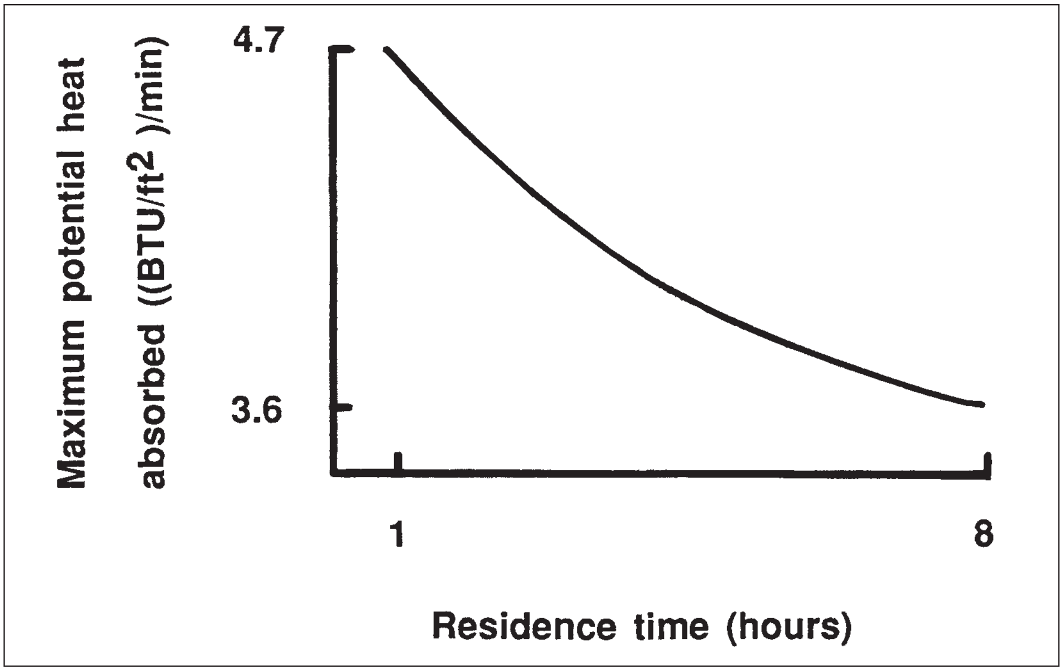

Figure 23—Effect of residence time on heat absorbed by water.

Model Documentation

A summary of documentation for the hydrology submodel is given in appendix 3. Most of the model reactions and parameters pertaining to streamflow and temperatures are documented either from scientific research in Alaska or the Pacific Northwest or from estimates made by using extrapolations from related work. Many of the relations describing sediment and debris routing and snow interception have not been documented by scientific study.

5

The Fisheries Submodel

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Introduction

The fisheries submodel calculates production and harvest of some anadromous fish species having recreational, personal use, or commercial importance in southeast Alaska. The submodel is designed to do calculations for pink, chum, and coho salmon.

This chapter describes the calculations made to simulate the life history of these species, beginning with spawning and ending with escapement of harvest. The responsibilities and order of calculations of the fisheries submodel are summarized in figures 24, 25, and 26.

The submodel is driven by precipitation patterns, snowmelt conditions, morphological characteristics of the stream, vegetative manipulation and road building at the stream site or in the watershed. It models several key processes, including escapement to a particular stream reach, egg deposition, egg survival, smolting success, rearing success, and harvest.

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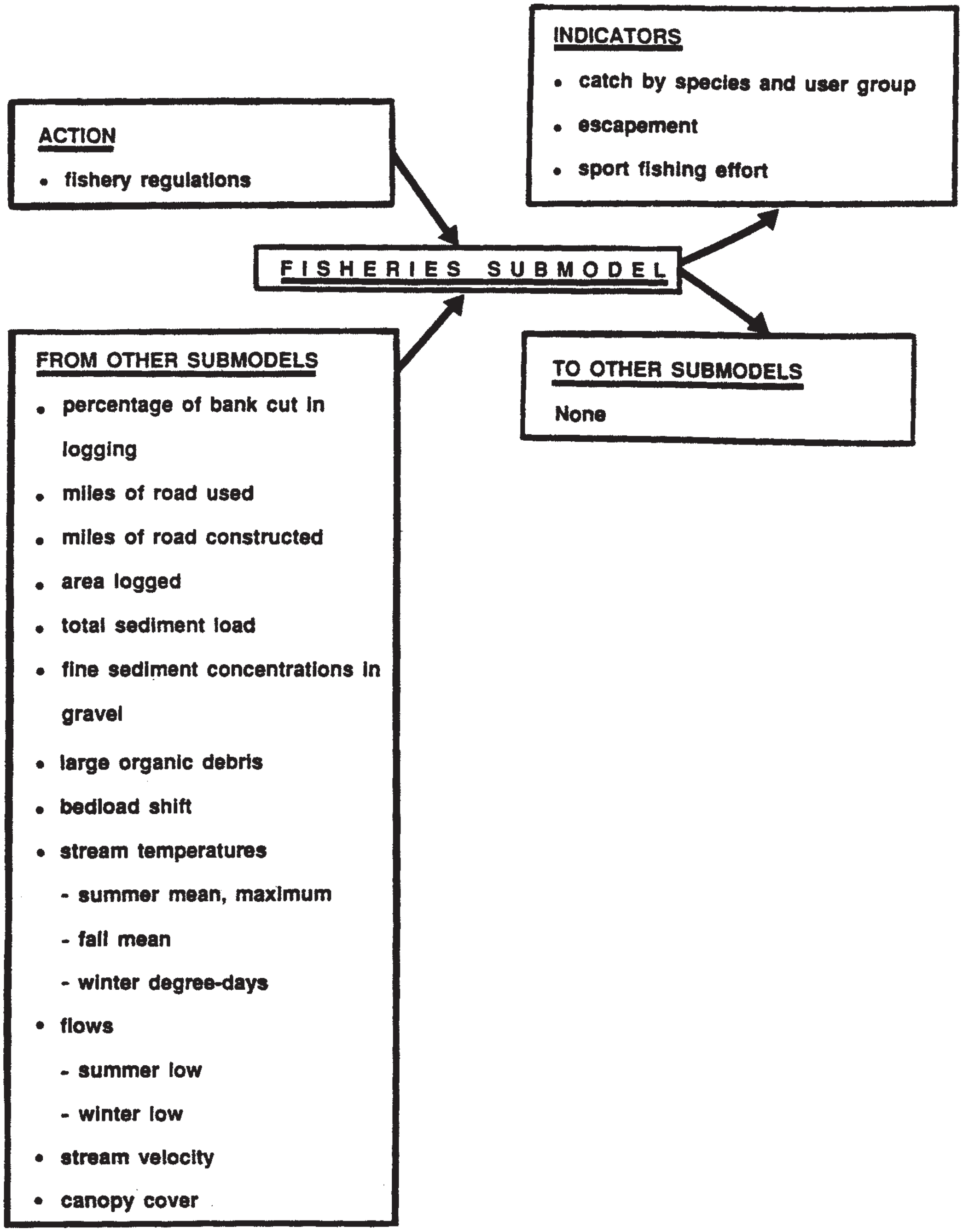

Figure 24—Information flow and system linkages for the fisheries submodel.

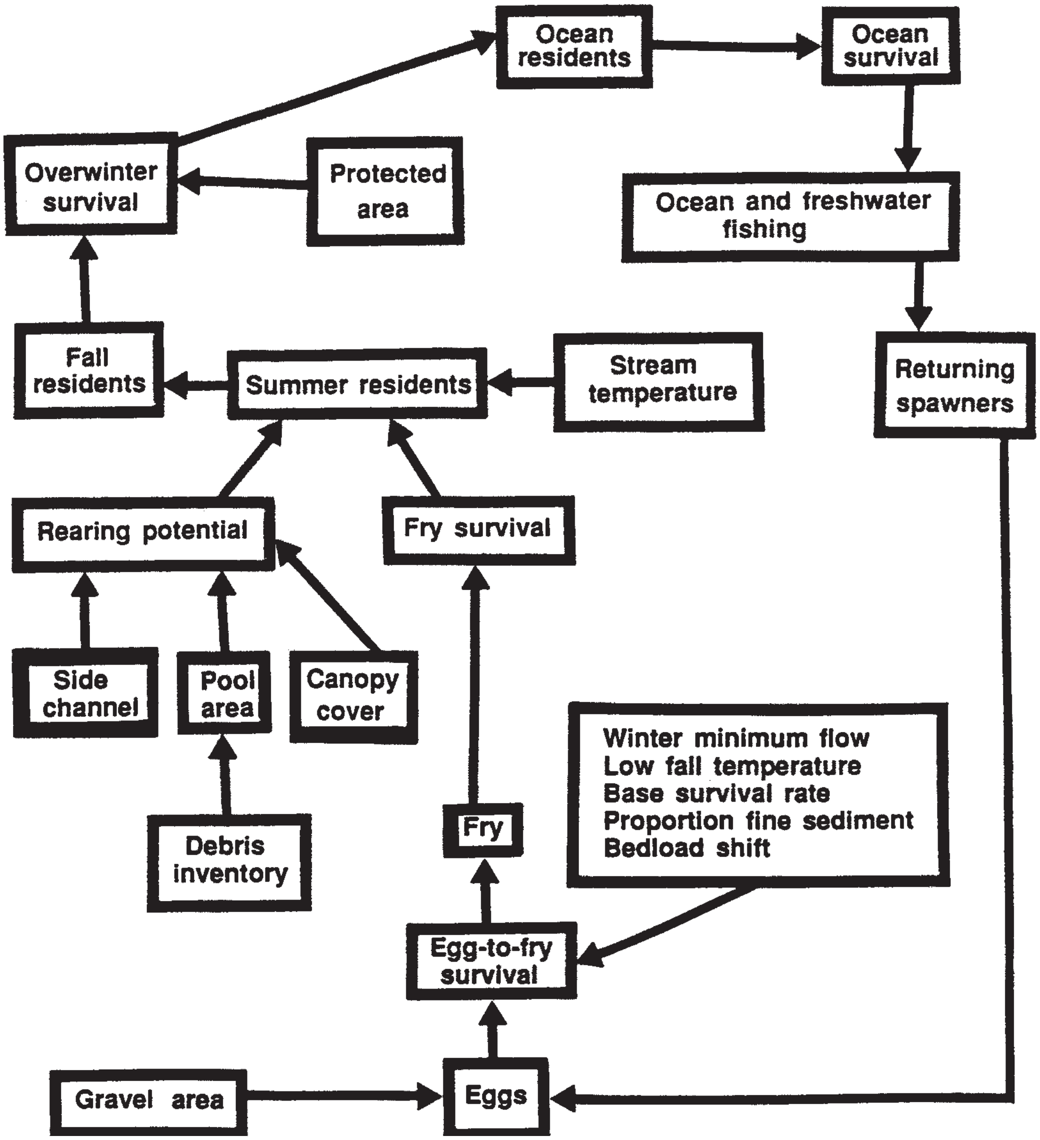

Figure 25—Basic model structure and driving parameters for coho salmon in the fisheries submodel.

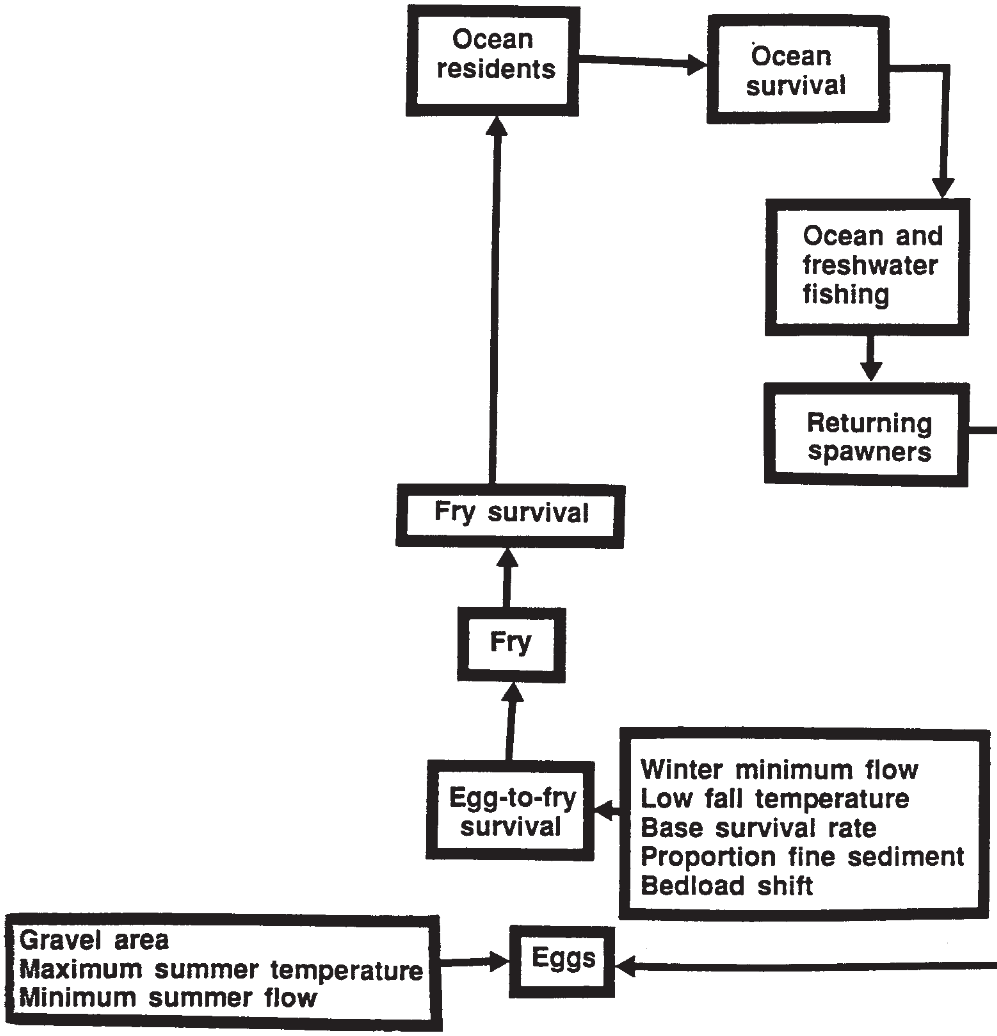

Figure 26—Basic model structure and driving parameters for pink and chum salmon in the fisheries submodel.

Egg deposition in each stream reach is driven by escapement. The number of adult spawners assigned to a selected stream reach is related to available gravel area. In addition, for pink and chum salmon only, summer flows and summer temperatures affect stream assignment. Summer flow depends on the precipitation regime in the watershed and the evapotranspiration rate of streamside vegetation. Flow variance is strongly associated with overstory removals and the impacts of this on snowmelt conditions and evaporation during the spring and early summer runoff.

Summer water temperatures can also affect egg deposition. Summer temperatures are influenced by air temperature, base water temperature, and streamside vegetation height.

The production of fry from deposited eggs and their survival are directly related to the general morphological condition of the stream and to streamwater temperature, volume flow, bedload shift, base survival rates, and changes in percentage of fine sediments. Bedload shift results in destruction of eggs. Increases in percentage of fine sediment, resulting from debris torrents, road building, road use, and clearcutting, directly impact egg-to-fry survival.

The development of the coho fry is primarily controlled by summer water temperature, which is influenced by air temperature, solar angle, streamside vegetation, and streamflows. Summer flows and streamside vegetation are directly related to the management treatment of the overstory.

Survival of rearing fish in a stream depends primarily on winter water temperature and amount of protected area. The amount of protected area is directly related to bedload shift, side channel area, main channel pool area, and rubble area in the streams. The percentage of area of a stream in pools is directly related to debris density and debris dynamics. Debris density and its dynamics are influenced primarily by clearcutting and overstory manipulation.

Model Stages

The structure of the fisheries submodel includes simulation of primary natural processes: spawning, egg-to-fry survival, freshwater rearing of coho, migration of smolt, ocean survival, and fish harvest.

Spawning

After all the fish harvest has occurred, a spawning stock of each species remains. The desired spawning stock in each reach of the stream for each species is calculated as follows:

$$S = 2(GA/GPP),$$

where

S = number of spawners required to fully utilize the available gravel under long-term average flow conditions,
GA = gravel area available under average flow conditions, and
GPP = gravel required per spawning pair (table 6).

Table 6—Gravel area required per spawning pair, by salmon species

Species	Area
	m^2
Pink	1.0
Chum	1.7
Coho	11.1

Source: (1979) Reiser and Bjornn.

This calculation assumes that the sex ratio is 1:1. The available spawners each year are allocated to each reach of the watershed in proportion to available gravel area. Reaches with more gravel area will have more spawners. If the summer flow in the current year falls below the long-ten average, the desired number of pink and chum spawners is reduced proportionately, thereby reflecting reduced available gravel area. The number of spawners required to seed available gravel for the current year is calculated:

$$K = S * LSQ/LALSQ \text{ , if } LSQ < LALSQ \text{ , and}$$
$$K = S \text{ , if } LSQ \geq LALSQ \text{ ;}$$

where
K = number of spawners required to seed available gravel in the current year,
LSQ = low summer flow, and
LALSQ = the long-term average low summer flow.

In some watersheds, pink salmon spawning stocks can differ dramatically in odd and even years; a year of great abundance may a~ternate with a year of low abundance. The model accounts for this through the addition of a density-dependent mortality rate (fig. 27): the mortality rate is low at extremely low stock size, increases rapidly to a maximum at an intermediate stock size, and decreases rapidly as stock size increases (fig. 27). The density-dependent relation acts to keep a stock of low abundance at a low level and to maintain a stock of high abundance at a high level. Escapement is always at least 1 percent of desired escapement to account for strays from other streams. This allows a decimated population to be reestablished.

The phenomenon of different run sizes for pink salmon in odd and even years is often observed, but no satisfactory explanation yet accounts for it. Perhaps high exploitation rates keep one stock trapped at a level of low abundance, or the stock in odd and even years could be genetically different. In the model, if the watershed is such that the odd-even phenomenon is present, the relation depicted in figure 27 is included as an additional mortality factor.

The number of eggs deposited (fig. 28) is determined after the spawners are allocated to each stream reach. In its simplest form, egg deposition is calculated as follows:

$$E = F * S/2 \text{ , a s} < K \text{ , and}$$
$$E = F * K/2 \text{ , if } S \geq K \text{ ;}$$

where
E = number of eggs deposited,
F = fecundity,
S = number of returning spawners, and
K = desired number of spawners required to seed available gravel in current year.

Egg deposition can be reduced by high stream temperatures in summer. Figure 29 shows the relation used to portray effects of summer temperature on egg deposition for pink and chum salmon. Below a daily mean temperature of 15.6 °C, no eggs are lost; whereas above 20.8 °C, all eggs are lost. This relation does not apply to coho salmon because coho generally spawn in fall.

Survival From Egg to Fry

Several factors influence egg-to-fry survival including concentration of fine sediment in the spawning gravel, mean fall temperature, bedload shift during fall storms, and winter low flows. Other factors influencing survival during this life stage are assumed to be unaffected by logging practices and are included as a constant background survival rate. This relation is given as:

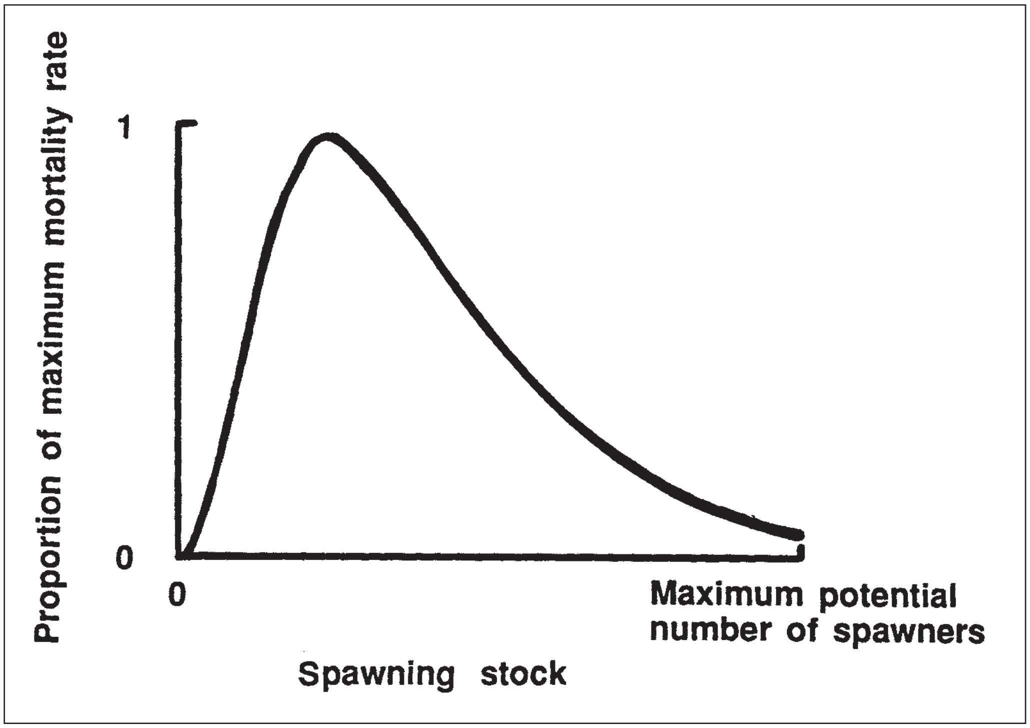

Figure 27—Density-dependent mortality rate as a proportion of spawning stock.

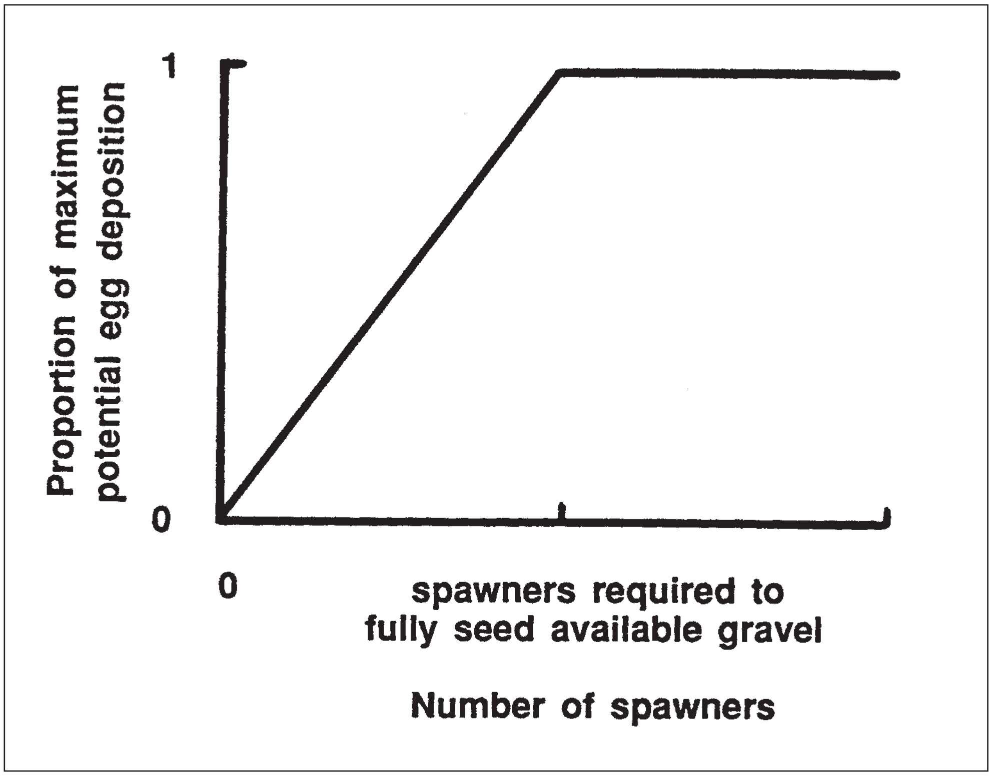

Figure 28—Egg deposition as a function of spawning stock.

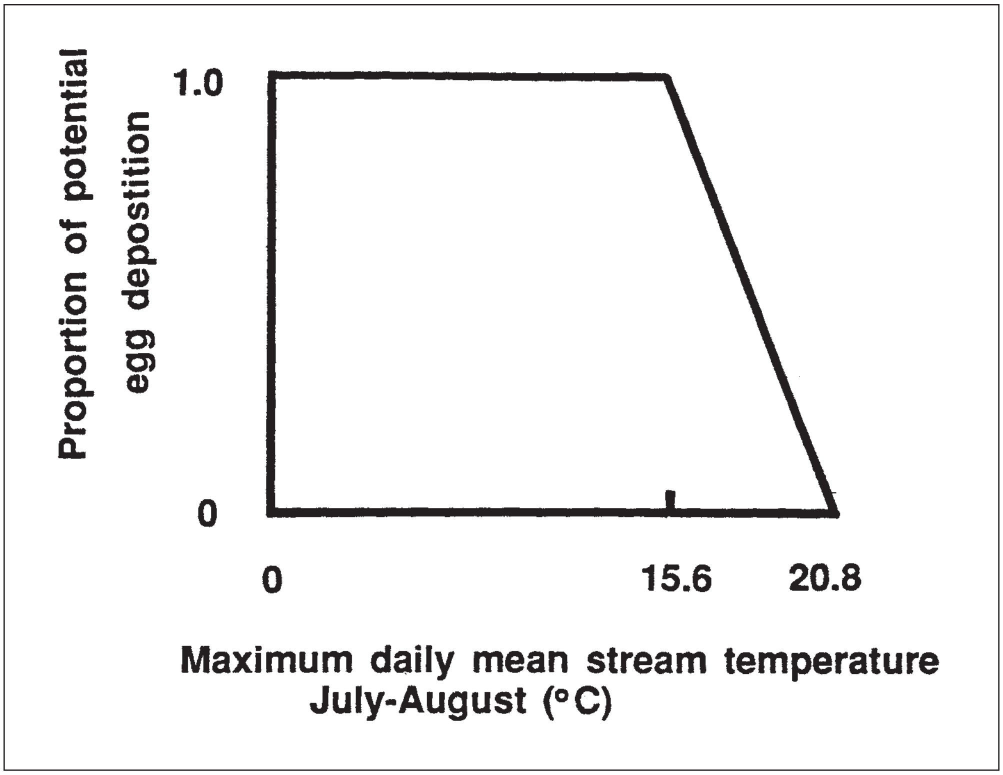

Figure 29—Relation between egg deposition and high stream temperature in summer for pink and chum salmon.

$$FRY = E * FS * P_1 * P_2 * P_3 * P_4 ,$$

where
FRY = number of fry surviving to emergence,
E = number of eggs deposited,
FS = background survival rate,
P_1 = fine sediment factor,
P_2 = fall temperature factor,
P_3 = bedload shift factor, and
P_4 = winter low-flow factor.

Each of these factors can assume a value between 0 and 1.0, depending on physical conditions. Background survival rate is assumed to be 0.20 for pink, chum, and coho salmon.

The fine sediment factor (P_1) is calculated from the concentration of sediments < 3.0 mm (fig. 30). Currently, the model defines fines as those particles < 3 mm in size and assumes a ratio of 60:40 of fine to coarse particles in sediment inputs.

Cold water temperatures during spawning in October and November (P_2) are presumed to have a deleterious effect on early egg development and survival. The model currently assumes that if average stream temperature in October and November drops below 2 °C, egg-to-fry survival is reduced by 50 percent. The model uses this relation for all three salmon species.

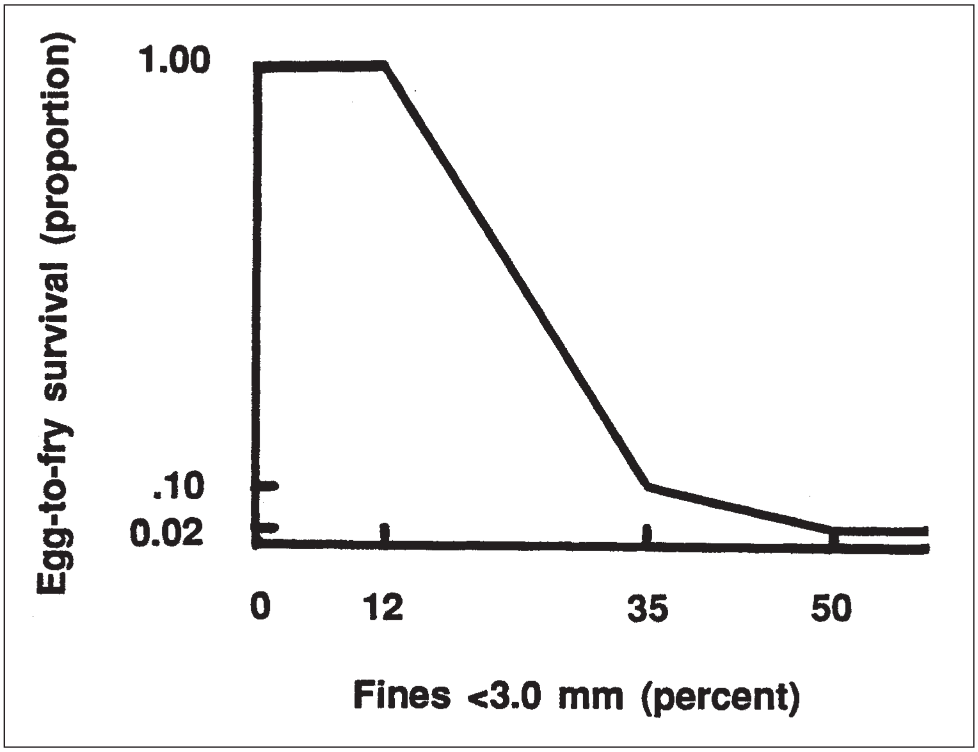

Figure 30— Egg-to-fry survival as a function of percentage of fines.

During large storms, shifts d gravel used for spawning cause mortality because of physical damage to eggs and alvins and because of downstream transport to unsuitable sites. In the model, the proportion of eggs lost because of shifting gravel is assumed to be directly related to the proportion of the bedload shifted by the peak fall storms (provided by hydrology submodel) as given below:

$$P_3 = 1 - \text{bedload shift.}$$

Abnormally low streamflows in winter are expected to reduce egg-to-fry survival because of exposure and desiccation of eggs and alvins. The winter flow factor affecting egg survival is calculated as:

$$P_4 = LWQ/ LALWQ ,$$

where
P_4 = winter flow factor affecting egg-to-fry survival,
LWQ = low winter flow, and
LALWQ = long-term average low winter flow.

After emergence, pink and chum salmon fry migrate seaward. The first ocean-age year-class of pink and chum salmon, thus, becomes the number of fry calculated as described above, summed over all stream reaches. Coho rear at least 1 year in fresh water.

Freshwater Rearing of Coho

Coho are produced in several reaches in a watershed, depending on area of spawning gravel, and then are allocated throughout the watershed by rearing potential. Thus, an area having no coho spawning habitat may rear many coho depending on the rearing habitat. Freshwater rearing is divided into two periods, summer and fall-winter. In summer, rearing potential sets the upper limit of number of fry; in fall-winter, mortality, primarily from freshest, reduces fry numbers to some degree depending on severity of fall and winter storms and available protected area.

Rearing habitat consists of mainstream pools and side channel areas. Mainstream pool area for each reach is calculated as:

$$AM = TA \ast PP \ ,$$

where
AM = mainstream pool area (m^2),
TA = total surface area (m^2) of the reach, and
PP = proportion of total surface area in pools.

The proportion of total stream area in pools depends directly on the amount of large debris present (fig. 31). Side channel area is assumed to be constant.

The total rearing potential for a reach is given by:

$$RP = (AM + ASC) \ast FPM \ ,$$

where
RP = rearing potential (number of fish),
AM = mainstream pool area,
ASC = side channel area, and
FPM = rearing potential per pool area (number fish/m^2).

The FPM depends on streamside shading; more open reaches allow greater rearing potential per unit area because of greater food production (fig. 32).

Although reduced shading may increase stream productivity and thus increase rearing capacity, it may also cause dangerously high water temperatures in summer. If the mean daily water temperature in any reach exceeds 25°C, 100 percent mortality occurs.

Mortality in fall-winter depends on how much protected area is available, such as side channels, pools, undercut banks, and rubble area. The total protected area is calculated as:

$$PA = C_1 \ast ASC + C_2 \ast AM + C_3 \ast UB + C_4 \ast RA \ ,$$

where
PA = protected area,
ASC = side channel area,
AM = area of pools,
UB = area of undercut banks,
RA = rubble area, and
C_1, C_2, C_3, C_4 = protective value of a unit of habitat (the values for C_1 [side channel], C_2 [pools], C_3 [undercut banks], and C_4 [rubble] are, respectively, 1.0, 1.0, 1.0, and 0.25).

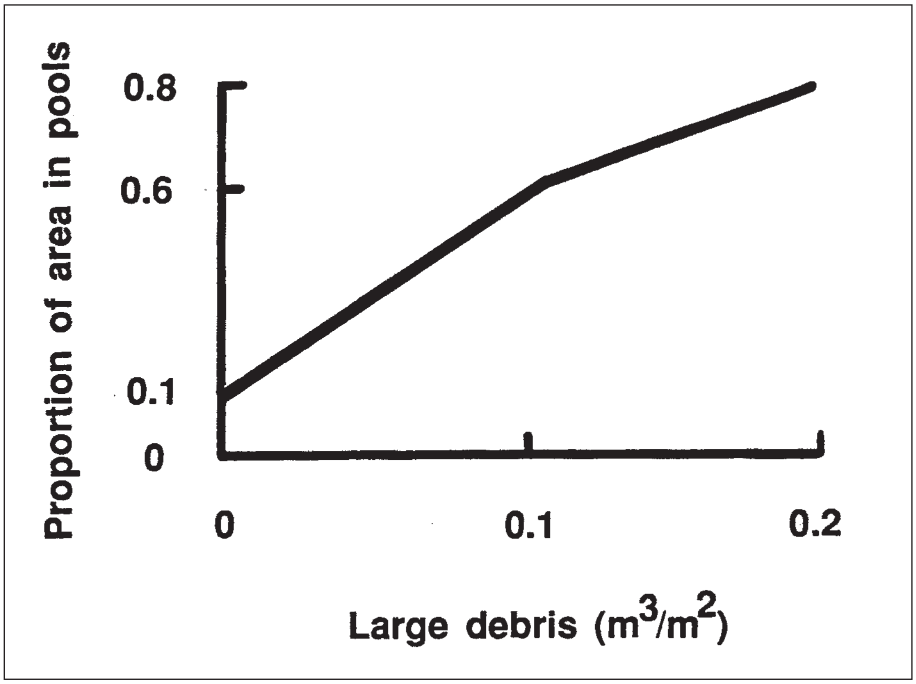

Figure 31—Proportion of area in pools as a function of volume of large debris per unit area of reach.

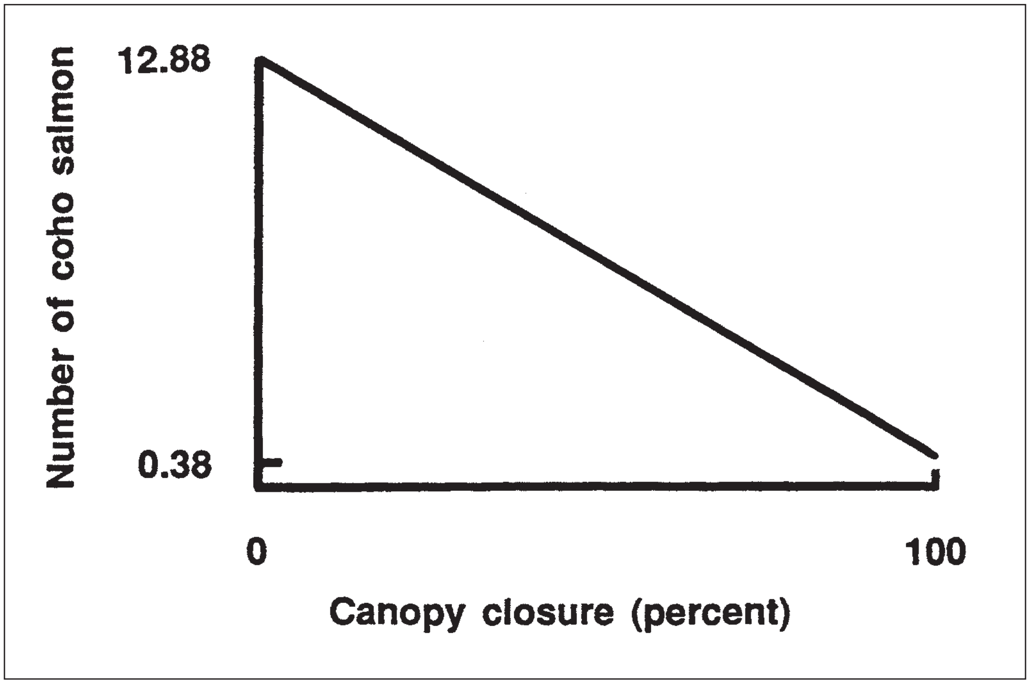

Figure 32—The effect of shading on density of coho fry per square meter of pool area.

Current evidence points to large organic debris as a major component of rearing habitat for fry in summer and juveniles in winter. In the model, the area of large pools is directly related to large organic debris (fig. 31). The presence of debris, independent of its role in pool formation, is believed also to be an important determinant of habitat. The model does not include this contribution to rearing habitat.

Intense fall storms reduce the protected area actually available (fig. 33). Protected area is reduced if stormflows are sufficient to cause bedload to shift; a 75-percent reduction in protected area results when a 100-percent shift in bedload occurs.

Winter survival of rearing fish is calculated from the protected area (fig. 34). If there is no protected area, only 10 percent of the rearing fish survive per year. If 30 percent or more of the stream area is protected, 25 percent of the fish survive each year.

Survival of second-year coho is 1.6 times the survival of first-year coho. Cold water temperatures in January and February further reduce overwinter survival (fig. 35).

Migration of Smolt

After a year in fresh water, some of the coho migrate to the sea. The percentage of 1-year-old fish that migrate depends on temperature the previous summer, which regulates growth. A high summer temperature leads to a larger percentage migrating after 1 year (fig. 36). All remaining coho migrate to the sea after 2 years.

Ocean Survival

Once fish migrate to the sea, they are subject to natural mortality, marine harvest, and freshwater harvest. Annual survival rates in the ocean without harvest are assumed to be 0.02 (pinks), 0.20 (chums), and 0.10 (coho). Coho and pink salmon spawn after 1 year at sea, and chum salmon spawn at 2, 3, and 4 years.

Fish Harvest

Fish harvest may occur in the ocean and in fresh water. A mixed-stock fishery occurs in the ocean and can consist of both commercial and sport harvest. A terminal fishery occurs in fresh water or in the ocean near the mouth of the river and consists of commercial, sport, and personal-use harvest.

The mixed-stock fishery is not localized near the mouth of the river. Thus, it is not selective on stocks from a given watershed. A fixed commercial harvest rate is specified by the user. For coho, a fixed sport harvest rate is also input by the user. All remaining fish return to the watershed of origin, where they are available for escapement and terminal harvest by commercial, sport, and personal-use fisheries.

Two methods are available for allocating fish in the terminal fishery. In the first method, the potential personal use is assumed to be 1 percent of the desired escapement unless a logging camp is present, which doubles the potential harvest to 2 percent. The potential sport harvest is then calculated. If the sum of the two potential harvests exceeds the available fish, all fish are allocated to the two fisheries in proportion to the potential harvest in each, and escapement is zero. If the sum of the two potential harvests does not exceed the available fish, both potential harvests are met, and the remaining fish are escapement. This allocation usually leads to a decimated population at some point in a simulation.

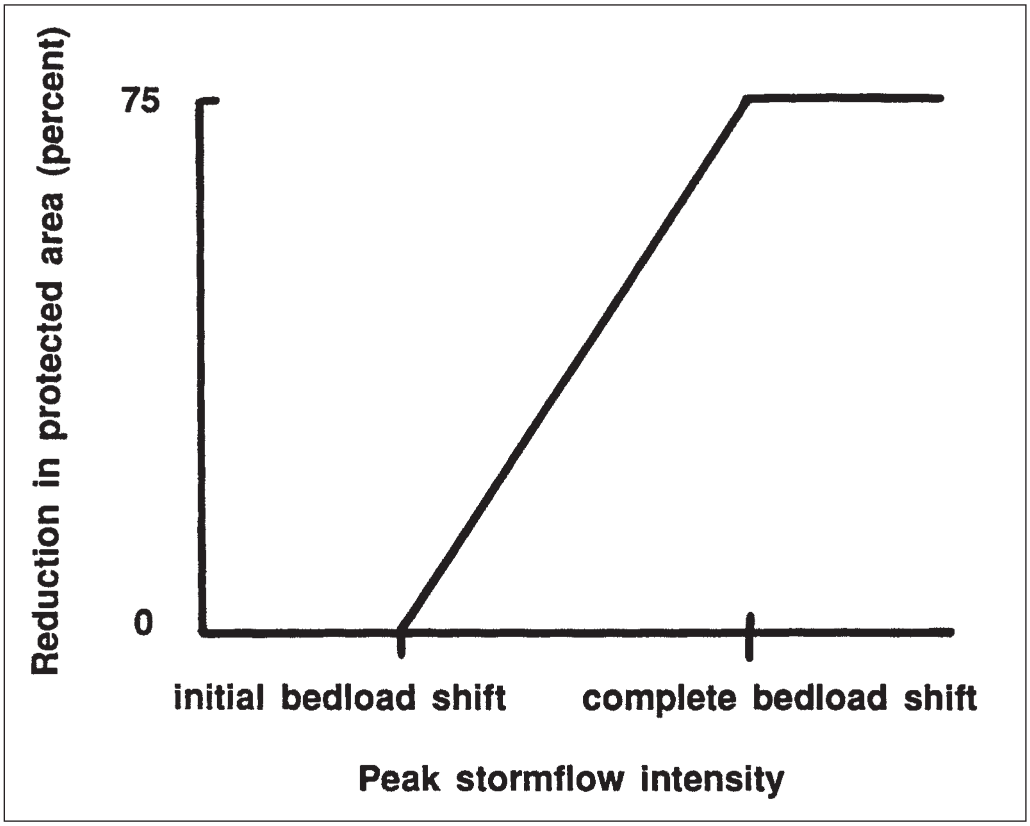

Figure 33—Effect of fall storms on protected area for wintering coho.

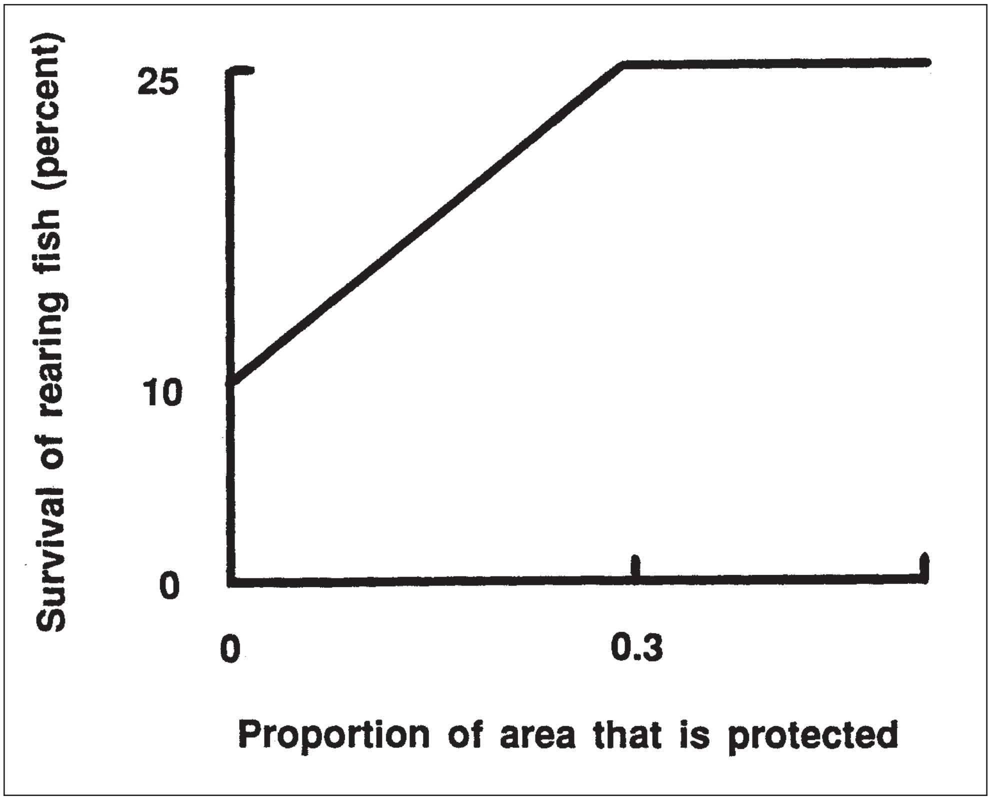

Figure 34—Winter survival of rearing coho as a function of proportion of area protected.

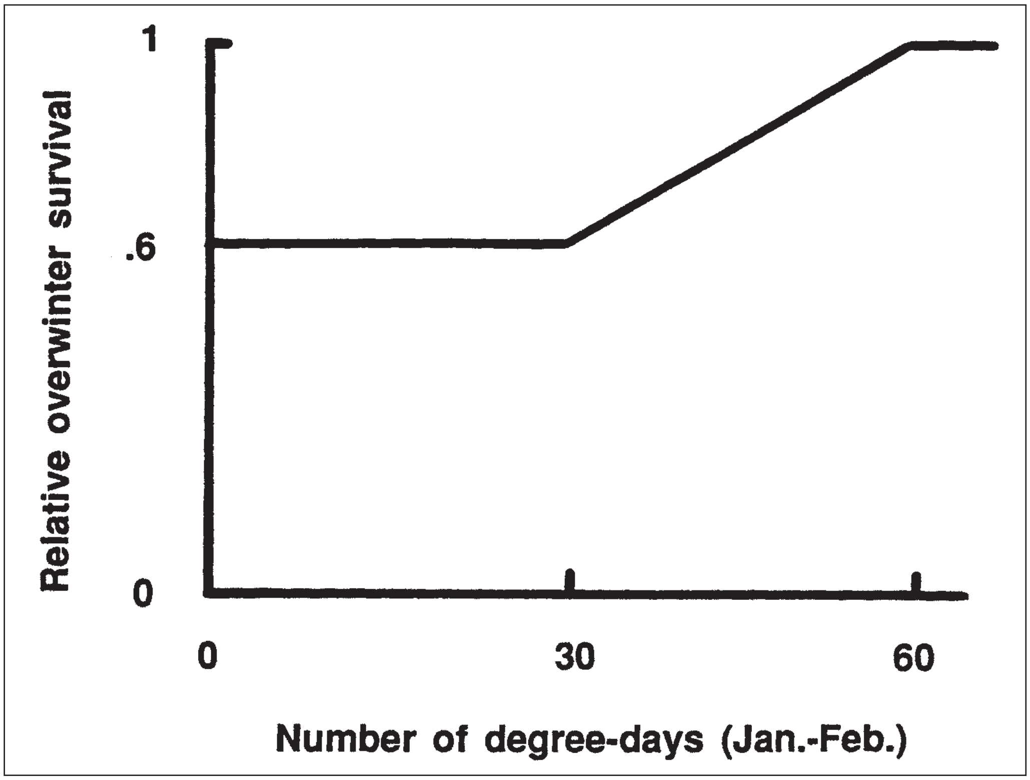

Figure 35—Effect of low winter water temperatures on overwinter survival.

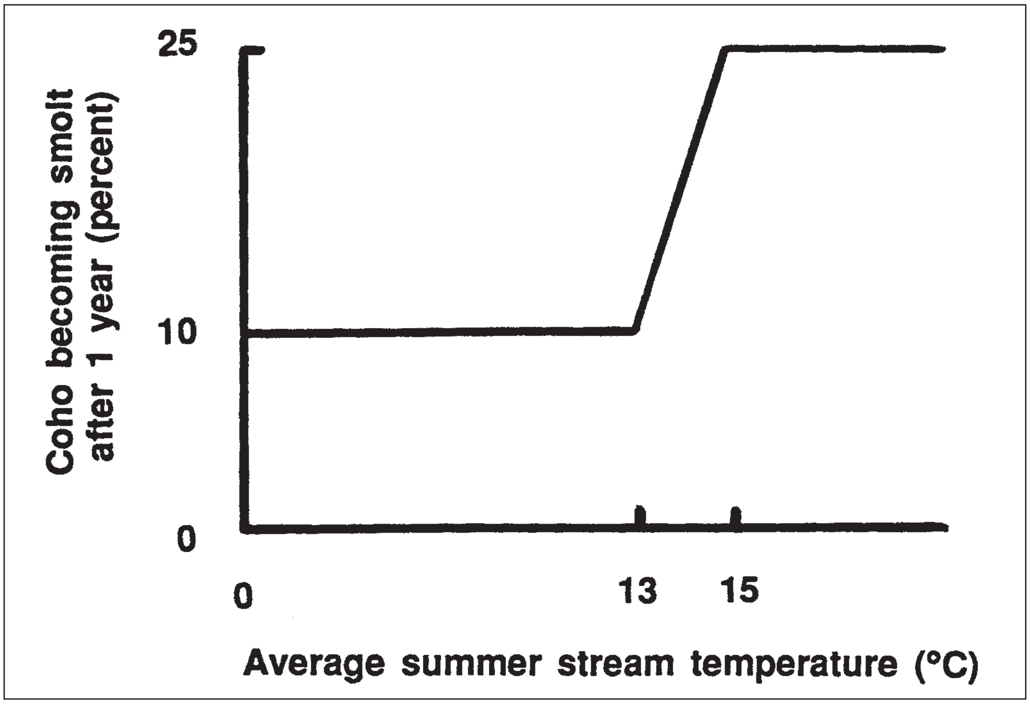

Figure 36—Percentage of coho that become smolt after 1 year in fresh water as a function of average stream temperature the previous summer.

In the second method, fish are allocated by priority and are harvested only if surplus fish are expected. Personal use has first priority and occurs if the expected number of returning fish exceeds desired escapement. The personal-use harvest is 1 percent of desired escapement unless a logging camp is present, which doubles the harvest to 2 percent. This harvest occurs even if it reduces escapement below desired escapement. Sport harvest has second priority, but will occur only if the potential sport harvest does nat reduce escapement below desired escapement. Whether or not the sport harvest operates, fish in excess of desired escapement are allocated to the commercial fishery.

The only sport-fishery species modeled in SAMM is coho salmon. The freshwater harvest depends on the fishing effort, abundance of fish, and access to sites within the watershed. Fishing effort is based on past fishing success and presence and size of nearby human operations.

The model considers two human populations, one nonlocal and one local. Total fishing effort is the sum of the effort of these two populations. The nonlocal population contributes a Potential number of annual fishing days, which is input by the user. This potential can be changed over time by a constant number of fishing days per year to account for growth in demand for sport fishing.

The potential number of nonlocal fishing days is achieved only if success in the previous year (measured as catch per unit effort) exceeds some minimum level below which demand will be reduced (fig. 37). Nonlocal effort each year is given by:

$$ENL = CF \ast PD ,$$

where
ENL = total nonlocal effort,
CF = factor from figure 37, and
PD = nonlocal potential fishing days (user input).

The local effort is calculated from the following:

$$EL = (EMP \ast DF) + DFL ,$$

where
EL = total local effort,
EMP = total employment in watershed (person years),
DF = days fished per person year of employment, and
DFL = user-specified fishing days by the rest of the local population.

Access for sport anglers is markedly affected by road construction. Increasing access by anglers will increase vulnerability of fish to being caught. This process is modeled by:

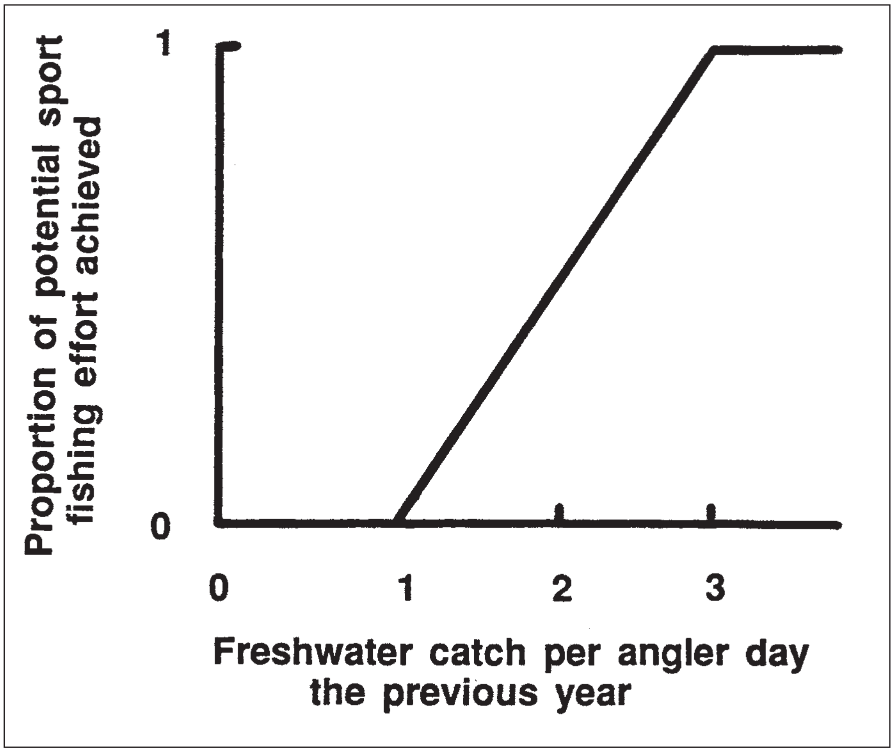

Figure 37—Freshwater sport fishing effort by nonlocal populations as a function of success in the previous year.

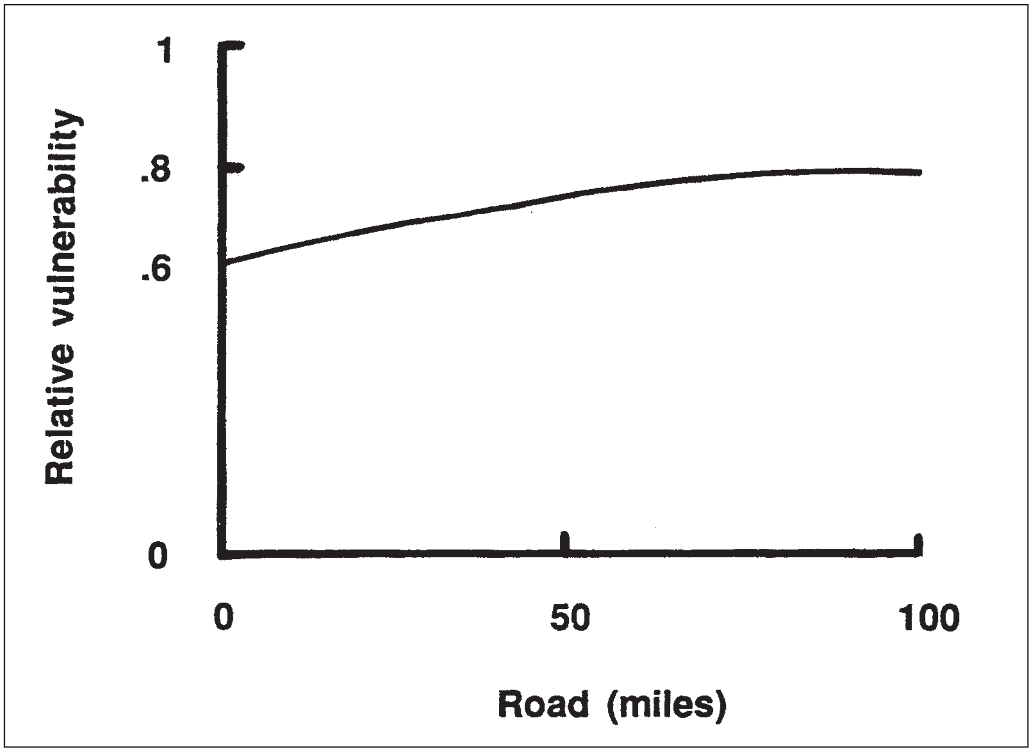

Figure 38—Relation between relative vulnerability of fish in fresh water and access by anglers.

$$VR = 0.5 + 0.5 * [1 - e^{(-roads * p)}] ,$$

where
VR = relative vulnerability,
e = base of natural logarithms,
roads = total miles of roads, and
p = catchability parameter that determines the Vulnerability of fish to access by anglers (fig. 38).

Finally, the total freshwater harvest is given by:

$$HF = (ENL + EL) * F * VR * VA ,$$

where
HF = freshwater harvest,
ENL = total nonlocal effort,
EL = total local effort,
F = fish available for freshwater sport harvest,
VR = relative vulnerability, and
VA = absolute vulnerability (user input).

The absolute vulnerability is the percentage of the entire spawning stock that will be caught in one angler-day of effort under full access conditions.

Model Documentation

Many of the relations in the fisheries submodel are based on experience in Alaska and the Pacific Northwest. Other relations rely solely on the professional judgment of participants in model development. The important model relations and assumptions are summarized in appendix 4. The relations describing the spawning, egg-to-fry survival, and ocean survival processes are well documented. Processes regulating overwinter survival of coho and effect of summer temperature on age of migrating smolt are not well documented.

The relations in the model that describe spawning, egg-to-fry survival, ocean survival, and harvest are documented with existing data. The relations describing many of the processes for species that rear in streams are presently neither well documented nor understood. Processes regulating success of rearing juvenile salmonoids are subjects of current research. New information on rearing processes will have to be incorporated in the model as the data become available.

Users of the model should bear in mind that many of the relations have been derived from work done in the Pacific Northwest in addition to southeast Alaska. Geographical differences will probably not change the shape of the relations but could conceivably shift the threshold values and saturation levels. The relation between coho rearing potential and canopy density, in particular, is known to differ between watersheds, depending on whether or not nutrients, such as nitrogen or phosphorus, limit primary aquatic production.

The behavior of the fisheries submodel, to a large degree, depends on inputs from other submodels, especially the hydrology and soils submodel. Most of the major effects of logging are, at least in conceptual form, represented in the whole model but need to be thoroughly examined and reviewed to assure that inputs to the fisheries submodel are appropriate. This is especially true for sediment and debris dynamics in the hydrology and soils submodel and effective canopy closure in the timber submodel. These are probably the most important inputs to the fisheries submodel and are critical to its correct operation.

Changes after logging depend on the timber harvest practice used: clearcutting to the streambank, stream cleaning after harvest, salvage of timber from the stream channel, or use of buffer strips (Swanson and Lienkaemper 1978, Toews and Moore 1982). Management actions, such as use of buffer strips, substantially alter debris dynamics. Because debris dynamics is, in reality, directly linked to alternative management’ actions, such management actions and their consequences for debris movement, timber costs, and revenues may be built into future versions of the model. Comparisons of costs and benefits of different management alternatives could then be done.

6

The Deer Submodel

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Introduction

The deer submodel simulates changes in the population of Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) resulting from changes in the vegetative characteristics of their habitat, varying snowfall, and hunting mortality. Habitat is defined in terms of overstory characteristics (canopy cover, tree height, basal area, stems per acre, and timber volume), understory characteristics (abundance and quality of fort~s, shrubs, and lichens), and prevailing depths of snow and slash. Most habitat characteristics are passed to the deer submodel from the hydrology and timber submodels (fig. 39). The deer population is composed of a number of hypothetical deer herds, each assumed to have access to one or more spatial units (home range) within a predator-free watershed. The flow of submodel calculations is shown in figure 40.

The deer submodel operates on bioenergetic relations and has three major components: deer energy intake, deer energy cost, and population dynamics. Deer receive all their energy from forbs, shrubs, and lichens, which vary seasonally in both quantity and quality.

The maximum biomass of forage occurring on a site varies as a function of site productivity and overstory canopy cover. Snowfall buries a certain proportion of each forage class in winter, thereby making it unavailable to deer. Slash in young clearcuts reduces forage

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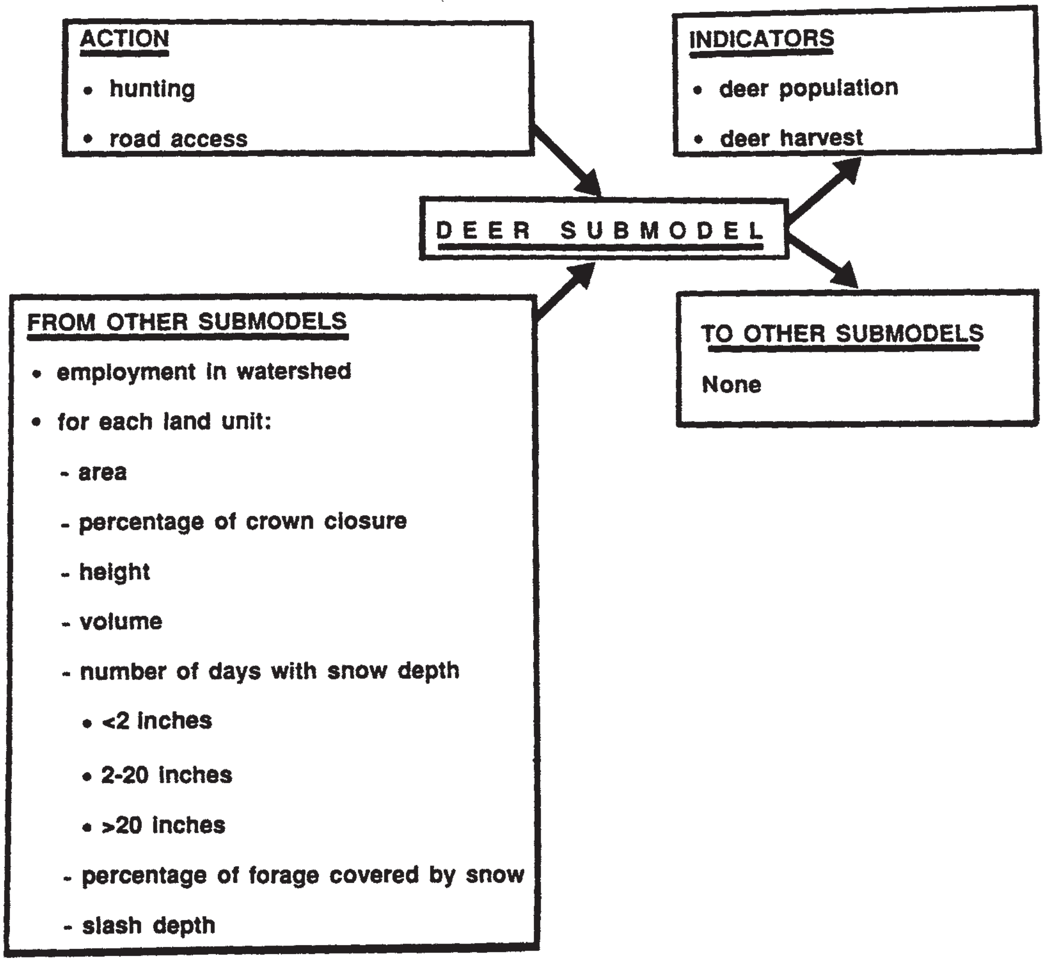

Figure 39—Information flow and system linkages for the deer model.

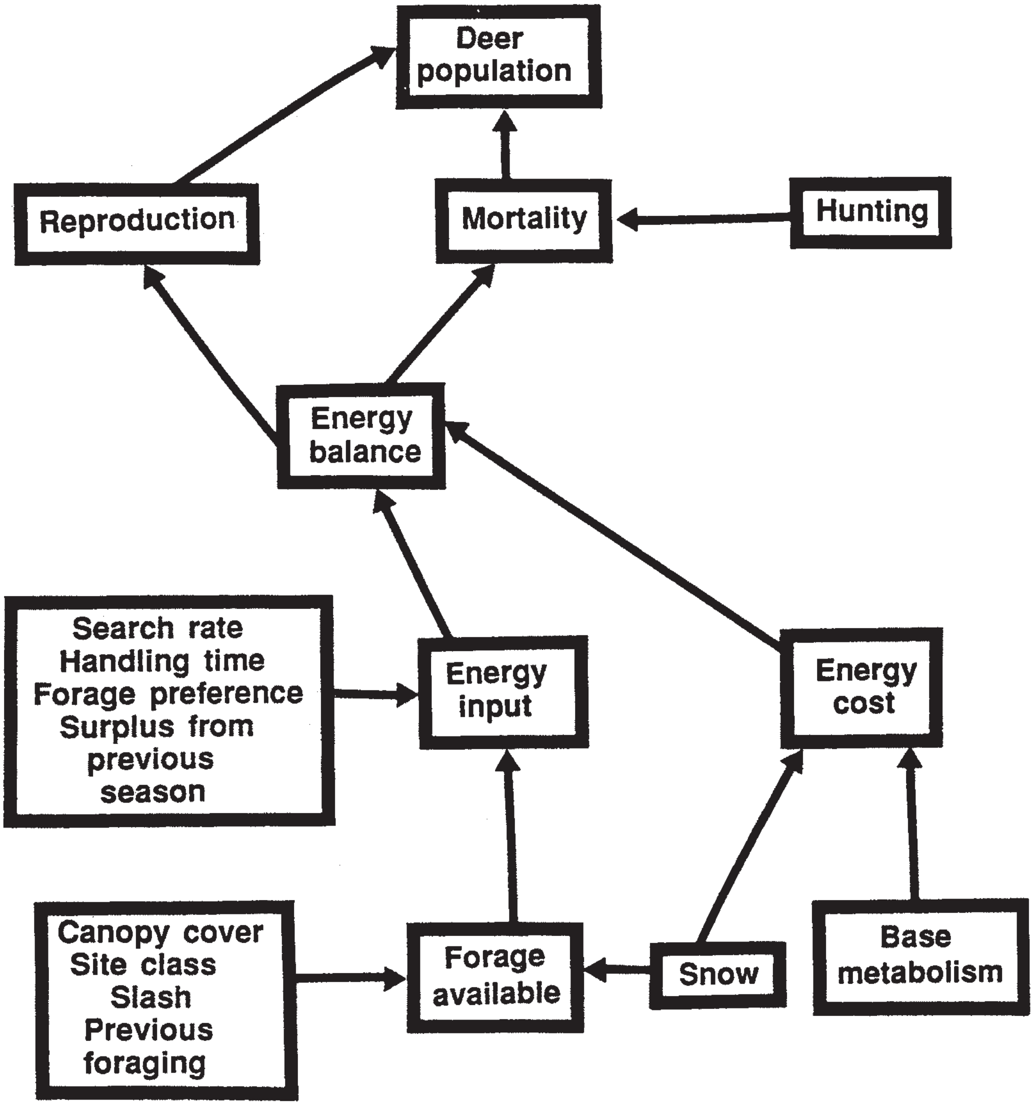

Figure 40—Basic structure and driving parameters for the deer submodel.

availability year-round. The rate at which forage grows back each summer is a function of intrinsic growth rates and the degree of use by deer in the preceding winter. Lichens, which are available only in old-growth stands Q250 years-old), are supplied at a fixed level year-round.

Forage intake rates vary as a function of forage abundance, preference for a particular forage class, searching rate, and handling time. The amount of energy obtained per unit of forage eaten is based on the gross energy of the forage and its digestibility factors, which vary seasonally and by forage class. The net energy available for growth and reproduction is equal to total digestible energy less the amount needed for nutrient metabolism.

Snow is an important variable in this model; it reduces the availability of forage and increases the energetic cost of locomotion. The ability of the canopy to intercept snow varies as a function of canopy cover (represented by tree height and basal area) in young stands and as a function of basal area per stem in old-growth stands. Large-diameter old-growth trees intercept snow most effectively. Other energetic costs to deer are related to active metabolic rates, which vary by age class of the deer and by season.

Reproduction and mortality vary by age class (table 7) and are a function of net energy balance at the end of the year. This net energy balance is the difference between energy intake and cost in each season, modified by the deficit or surplus carried over from the season before. Hunting mortality is additive at the end of summer and varies as a function of deer density, degree of hunter access, and hunter days of effort.

Within each home range, deer are allocated each season to spatial units by net energy availability. This allocation takes place at the beginning of summer (1 June through 31 October) and once during winter (1 November through 31 May).

Deer harvest is associated with hunting by local populations, residents of logging camps, and nonlocal hunters. Nonlocal hunter success in one year affects the effort in the following year by this source. Success by local and logging camp hunters does not affect the hunting effort in the following year.

Table 7— Definition of deer operational groups

Age class	Operational group
Years	
0-1	Fawns
1-2	Adults
2-3	Adults
3-4	Adults
4-5	Adults
5-6	Adults
>6	Adults

Model Stages

The deer submodel characterizes several natural processes important to the life cycle of Sitka black-tailed deer: understory relations, energy availability, effects of slash, effects of snow cover, feeding, energy balance, reproduction, natural survival, and hunting mortality.

Understory Relations

Deer are linked to forest management actions through changes in overstory, which alter understory production and forage quality. Snow and slash accumulations increase with logging or thinning of the overstory and influence how much of the forage produced is available to deer.

Factors controlling understory forage production in a forest environment are complex. Light and soil conditions are important, and other factors such as stand age and disturbance history can strongly influence understory development. In this model, understory dynamics for all stands, young and old, are represented as a function of tree canopy cover and SI class. The deer submodel keeps track of the edible plant biomass in each of three board plant groups: woody shrubs, herb, layer vegetation (fort~s), and arboreal lichens.

After clearcutting in southeast Alaska, understory biomass increases greatly in response to increased light. Understory biomass remains high as tree seedlings become established and the overstory canopy begins to develop. By 20-30 years after clearcutting, the canopy of most second-growth stands has closed over, effectively shading out the understory vegetation below. The hypothesized relation between canopy cover and understory production is shown in figure 41.

In addition to light, understory growth is determined by the soil conditions of a particular site. Deep, well-drained soils capable of sustaining rapid tree growth are also capable of supporting high levels of understory biomass. This potential, however, is seldom realized in forested sites because the amount of light reaching the forest floor (as indicated by canopy cover) is normally a limiting factor. The potential maximum biomass for shrubs and forbs in the absence of any canopy cover (for example, after clearcutting) is shown in figures 42 and 43, respectively. This potential, as modified by the effect of canopy cover (fig. 41), is used to calculate total shrub and forb biomass for all combinations of SI class and stand age class on spatial units in the model.

Lichens, which have received little study in southeast Alaska, are assumed to fall to the forest floor at a constant rate of 25 (kg/ha)/year in all old-growth regardless of SI class. Lichens are not present in clearcuts and young-growth stands (Rochelle 1980).

In general, herb, layer vegetation comprises forage of the highest nutritional quality. The evergreen forbs in this group (for example, *Coptis asplenifolia* Salisb., *Rubus pedatus* J.E. Smith, *Cornus canadensis* L., *Pyrola uniflora* L., and *Tiarella trifoliata* L.) are high in digestible protein and energy, but because of their low-lying growth form are largely unavailable under moderate and deep snow conditions (Hanley 1984).

Woody shrubs (for example, *Vaccinium* spp., *Oplopanax horridum* (Smith) Miq., and *Rubus spectabilis* Pursh) grow taller, but lose their leaves in winter, leaving relatively indigestible woody stems.

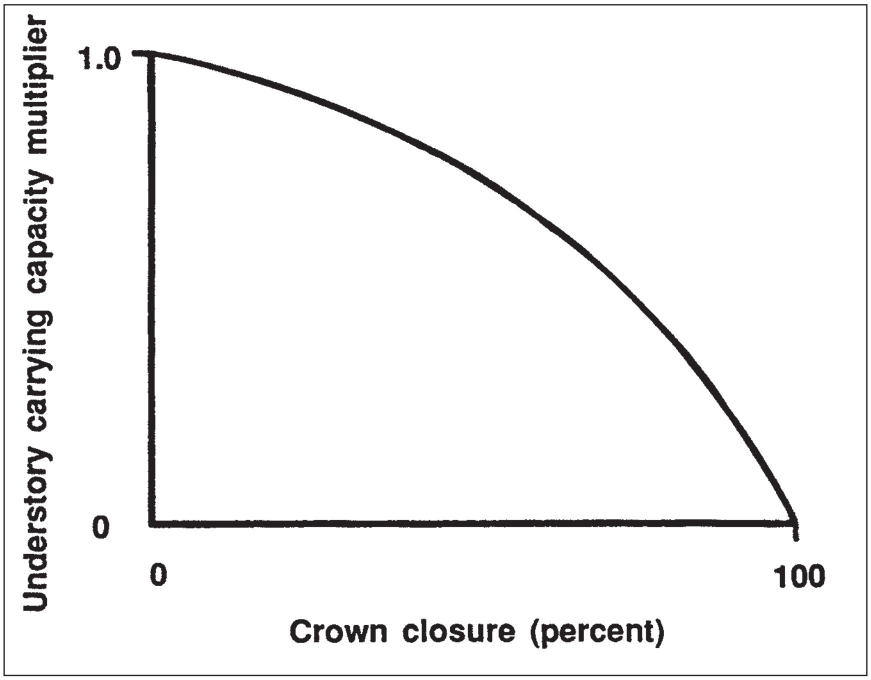

Figure 41—Proportion of potential carrying capacity achieved as a function of canopy cover.

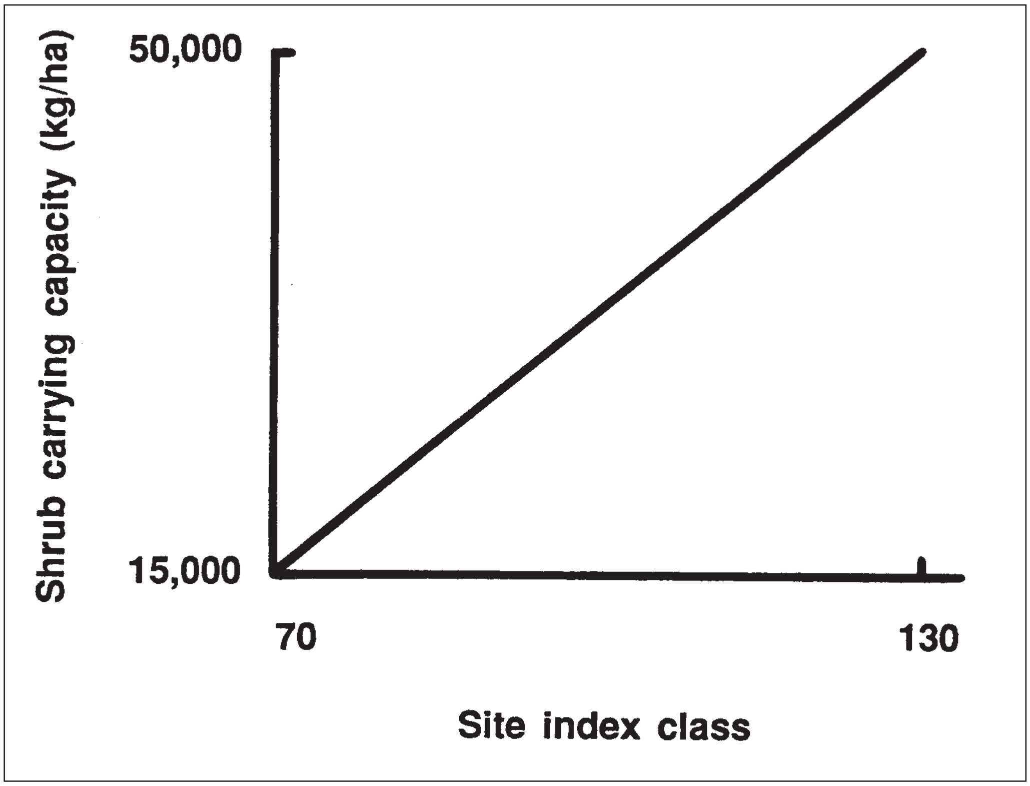

Figure 42—Maximum shrub carrying capacity as a function of site index class.

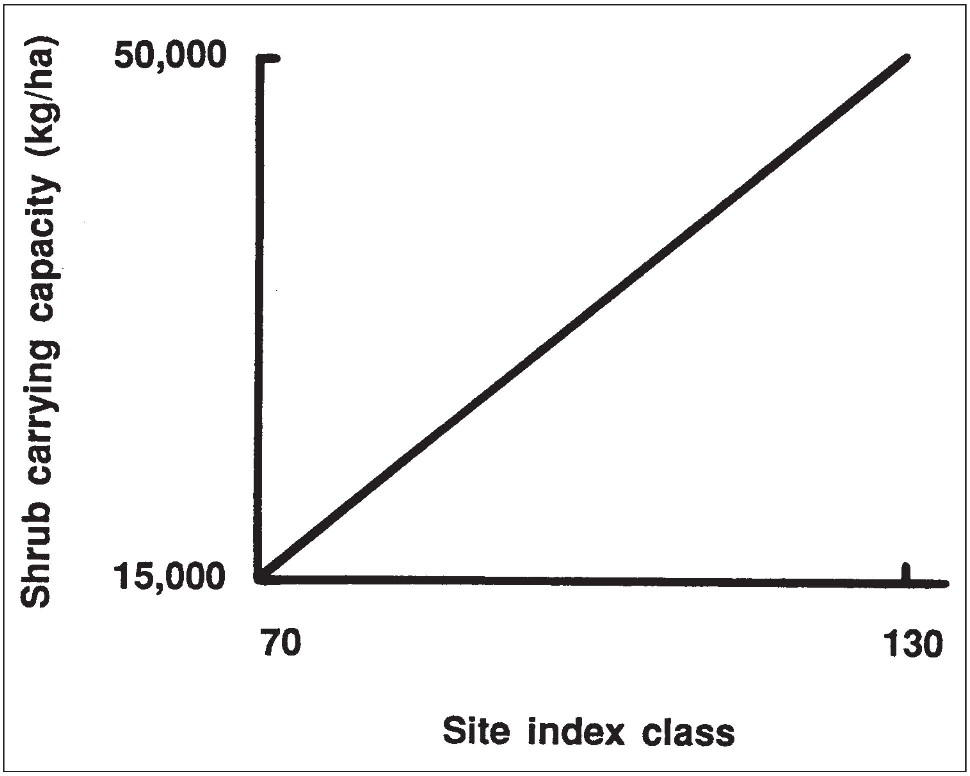

Figure 43—Maximum forb carrying capacity as a function of site index class.

Energy Availability

The energy available to deer for maintenance, growth, and reproduction is dependent on the types and quantities of forage ingested. All three forage classes (forbs, shrubs, and lichens) are assumed to have a gross energy equivalent of 4500 kcal/kg in both summer and winter.

The proportion of digestible energy available to deer differs by forage class and season. In late fall and early winter, plants grown under open light conditions in recent clearcuts are less digestible than plants grown under the shade of nearby closed canopy sites.

Variation in forage quality between open and forested sites is incorporated in the model via a 3-percent reduction in winter digestibility of forbs and shrubs on all sites having crown closures of less than 40 percent. Seasonal dry matter digestibility factors for forbs, shrubs, and lichens under canopies 240 percent are given in table 8.

Not all the digestible energy in plant material is available to the deer for maintenance and growth. About 15 percent of digestible energy is (lost to urine production and about 30 percent to heat of nutrient metabolism. The balance, termed true net energy, available from each plant type in winter and summer seasons is computed as follows:

$$TNE = GE \ast DMD \ast MEC \ast NEC ,$$

where
TNE = true net energy,
GE = gross energy
DMD = dry matter digestibility (variable),
MEC = metabolizable energy coefficient (0.85), and
NEC = net energy coefficient (0.70).

The true net energy available from each forage type, summer and winter, is given in table 9. The following tabulation of preference indices for each of the three forage types gives subjective factors based on observations of tame deer foraging in the wild and on studies of food habits.

Forage class	**Preference factor**
Forbs	0.6
Shrubs	.2
Lichens	.2

The model maintains a record of the biomass associated with each SI class and age class in each spatial unit. The total amount of shrubs available at the end of each season is described by:

Shrubs, end of season - shrubs, beginning of season + growth
- shrubs eaten - mortality.

Table 8—Percent digestible energy available by season and forage class

	Forage class		
Season	Forbs	Shrubs	Lichens
Summer	0.70	0.60	0.70
Winter	.60	.40	.70

Table 9—True net energy by forage class for summer and winter

Forage class	Summer	Winter
	Kcal/kg of forage	
Forbs	1740	1606
Shrubs	1473	1071
Lichens	1874	1874

A logistic model was chosen to represent shrub growth in year t:

$$B_t = r \ast B_t \ast (1 - B_t/K_t) \ ,$$

where
t = current simulation year,
B_t = shrub biomass in year t,
r = intrinsic growth rate, and
K_t = carrying capacity in year t.

Growth of both forbs and shrubs is reduced as a result of heavy grazing in the previous year by deer (fig. 44). The amount of summer shrub biomass available to deer is equivalent to the annual growth of the current year, or 13 percent of the total shrub biomass in a steady state, old-growth condition. Available summer shrub biomass is reduced by 40 percent in winter to reflect the biomass lost when the leaves are dropped. No shrub growth takes place in winter.

Unlike shrubs, forbs do not carry over from year to year. Only about 50 percent of the forbs available at the end of summer live into winter, and all forbs die during winter. Forbs grow back instantly at the beginning of each summer (intrinsic growth of 1.0), except when more than 50 percent of the biomass was consumed during the previous year by deer foraging (fig. 44).

Effects of Slash

The depth of slash resulting from various logging and thinning regimes is passed to the deer submodel from the timber submodel. Although deer suffer increased energy costs when they move through and over slash, they typically walk around slash in normal foraging activities. The primary effect of slash is to reduce the total amount of available shrubs and forbs in recently logged or thinned areas. The initial reduction in forage availability due to slash is given in figure 45. Forage availability increases over time as the slash decays.

Effects of Snow Cover

Snow is an important factor influencing habitat selection by deer in winter. Snow impedes movement, increases energy costs, and reduces forage availability. An average snow depth in each stand is passed to the deer submodel from the hydrology submodel, where the amount of snow intercepted by the canopy increases with increasing canopy cover and mean basal area per stem. The hypothesized effects of increasing snow depth on forb and shrub availability in the stand are shown in figure 46.

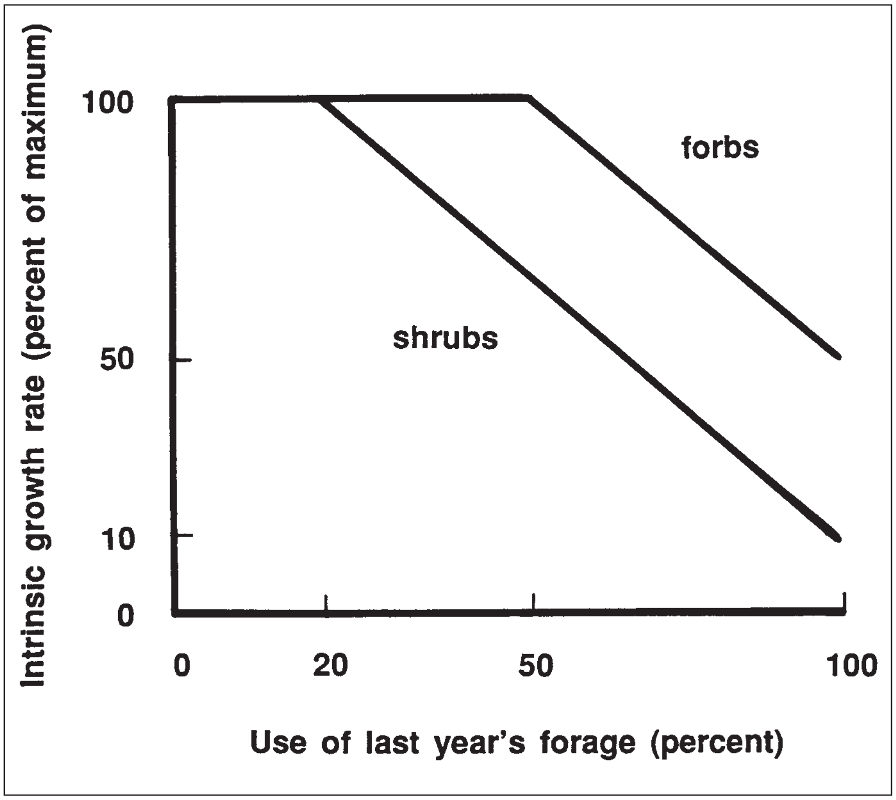

Figure 44—Effects of deer foraging on understory growth rate.

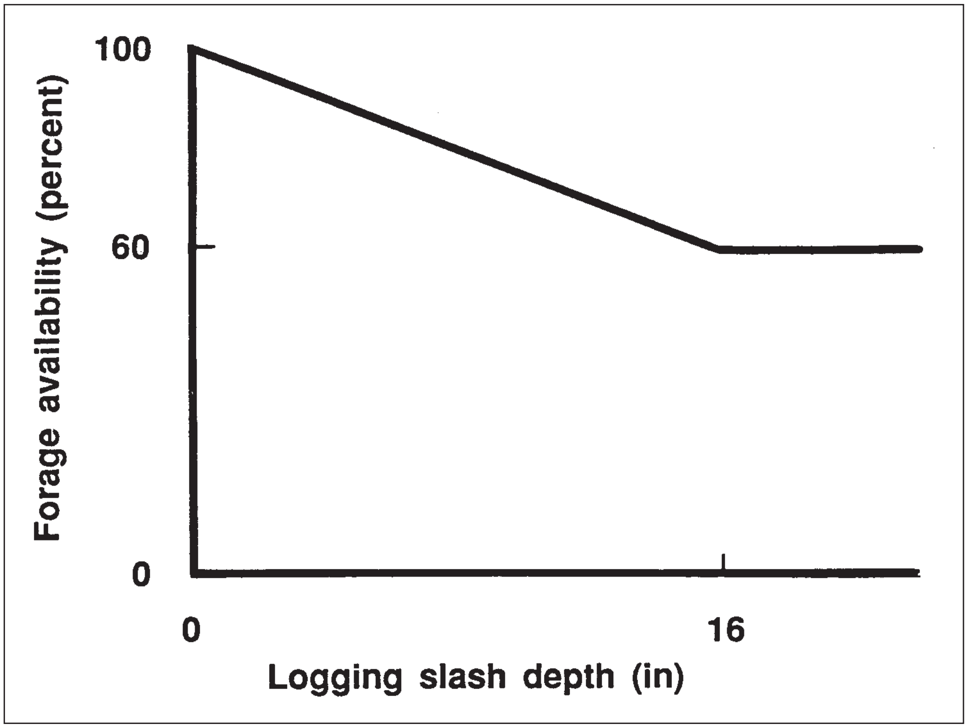

Figure 45—Effect of logging slash on forage availability.

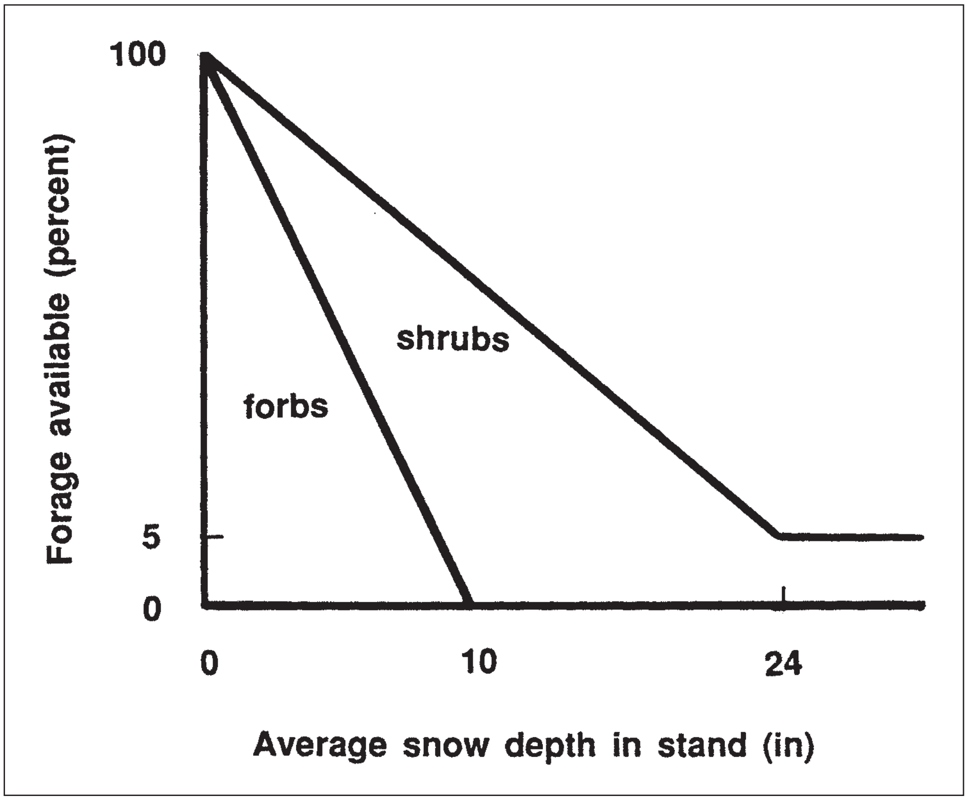

Figure 46—Effect of average snow depth on forb and shrub availability.

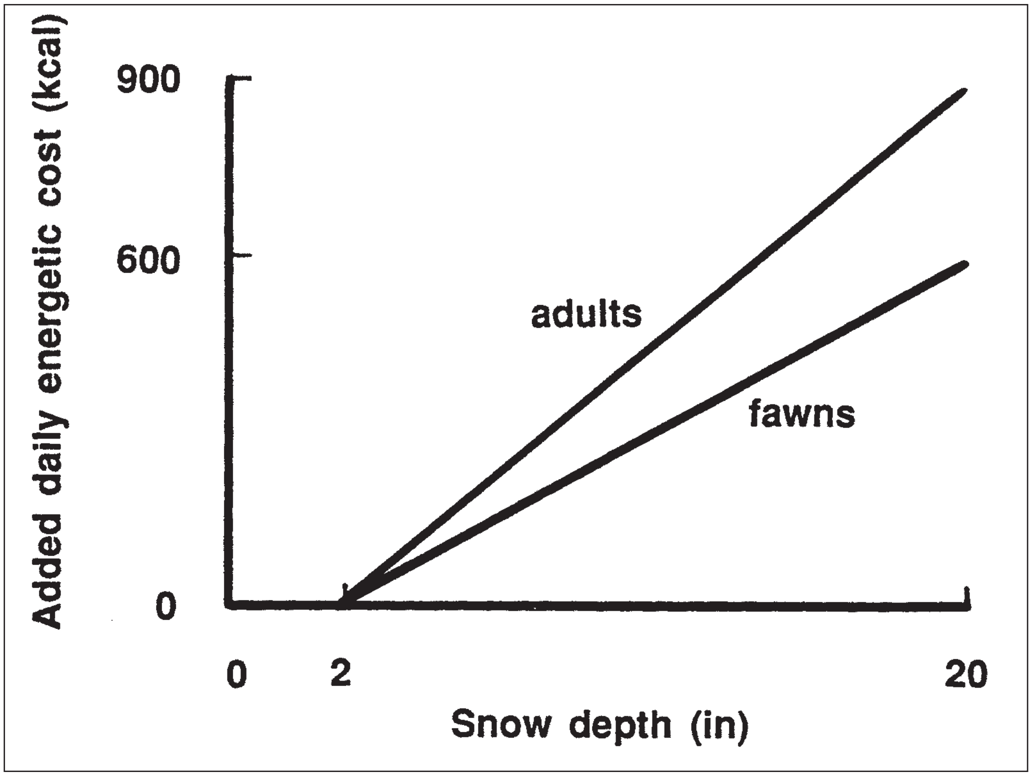

Figure 47—Added daily energetic cost to fawns and adults resulting from snow accumulation.

Energy costs increase with increasing snow depth (Parker and others 1984). When snow is <2 inches deep, deer experience negligible added costs. The added daily cost of moving through snow is shown in figure 47.

Feeding

Feeding is represented in a way that accounts for the effects of competition on forage abundance. The formulation used, taken from predation research (Charnov 1973, Holling 1959), calculates expected intake of each forage type by deer group (fawns and adults) as a function of deer density, forage abundance, search rates, handling times, and forage-specific preference factors:

$$E_{i,j} = (A_j \ast D_j \ast P_i \ast W_i)/[1 + (A_j \ast X)] \ ,$$

where
$E_{i,j}$ = the potential kilograms of forage group i consumed by deer group i in a season,
A_j = the rate of effective search by deer group j,
D_j = number of deer in deer group j,
P_i = the relative preference for forage type i, and
W_i = kilograms of plant group i available to deer across all age classes and spatial units in that population’s home range, and

$$X = \sum_{i=1}^{3} h_{i,j} \ast W_i \ast P_i \ ,$$

where
$h_{i,j}$ = handling time, or the fraction of a season required to digest and process a unit biomass of forage type i by deer group j.

The potential forage consumed is next modified by the total forage available to ensure that actual intake never exceeds the amount available. The following formulation is used to compute actual forage intake:

$$EAT_i = W_i \ast [1 - ez^{(Ti/wi)}] \ ,$$

where
EAT_i = the actual kilograms of plant group i ingested by all deer in the particular herd,
W_i = kilograms of plant group i available to deer across all age classes and spatial units in deer population’s home range,
e = base of natural logarithms, and
T_i = total deer herd requirements for plant group i, which also equals j = $E_{i,j}$ where j = number of operational groups in deer populations.

From the above equation, T,NV, is the instantaneous removal rate of forage type i from deer feeding. The forage eaten (EAT) is then allocated bad< to seasonal intakes per deer for each deer group in each herd. The forage consumed by each deer is assumed to be directly proportional to the forage requirements for the group relative to the requirements for the total herd. For example, if adult deer require 63 percent of the total forage requirements, they receive 63 percent of the total forage consumed.

Both fawns and adults are assumed to forage an average of 11 hours per day throughout the year. We assume they effectively search a 6-foot-wide strip and travel at 0.3 km/hour while foraging. This translates into an effective search of about 1.00 ha per day. The rates at which deer process ingested food are controlled by intake rates, rumen size, and passage rates. Intake rates generally are lower for woody browse than for green succulent vegetation, lower for fawns than for adults, and lower in winter than in summer. Handling times, which are the reciprocal of intake rates, are reported for fawns and adults, for summer and winter, and for each of the three forage classes (table 10).

Table l0—Summer and winter values for handling time by forage class

	Summer		Winter	
Forage class	Fawn	Adult	Fawn	Adult
	Days per kilogram			
Forbs	0.4	0.3	0.45	0.4
Shrubs	.6	.5	.8	.6
Lichens	.4	.3	.5	.4

Energy Balance

The net energy surplus or deficit available to deer is equal to energy intake (EAT1, minus energy cost (ECOST), plus any energy surplus (ESURP) from the previous season. Energy intake is the amount of forage consumed, multiplied by the true net energy available from each forage type. Daily energy cost (ECOST) is computed as follows:

$$\mathrm{ECOST}_{ij} = \mathrm{BMR}_{ij} \ast \mathrm{ARFAC}_{ij} + \mathrm{snowcost}\ ,$$

where

BMR = 70.0 1 (BW_{ij} 0.75);

ECOST_{ij} - daily energy requirement of deer group i in season j;

BW_{ij} ~ body weight of deer group i in season j;

ARFAC_{ij} = activity factor applied to basal metabolic rate to estimate active metabolic rate of deer group i in season j; normally varies from 1.25 to 2.0 (Moen 1973); and snowcost = added energy cost associated with locomotion in snow.

Active metabolic rates used to calculate energy costs are given in table 11. Seasonal energy costs are equal to the daily energy costs multiplied by the number of days in each season.

Deer are allocated to individual stands in the watershed by the net energy available in each stand. The net energy available equals energy available from the understory less the energetic costs of locomotion through snow in a particular stand.

To calculate energy surplus for an animal, we assumed there are 9.5 kcal/g fat and 5.7 kcal/g protein in each gram of reserves, and that body reserves are 70 percent fat and 30 percent protein. The mean energy value of body reserves, therefore, is:

$$8.4\ \mathrm{kcal/g} \ast ([0.7 \ast 9.5] + [0.3 \ast 5.71]).$$

Finally, we assumed that, on average, reserves of about 30 percent of the weight of adult deer and 15 percent of the weight of fawns can be expended before starvation.

Deer reproduction and mortality rates are structured by using the energy balance approach. Forage ingested is converted into equivalent energy, and, after accounting for energy costs due to snow, the net energy pool remaining determines reproduction and natural mortality. Hunting mortality is represented explicitly.

Table 11—Average body weight and dally metabolic requirements In summer and winter for adult and fawn deer

Item	Group	Summer	Winter
Average deer body weight (kg)	Adults	50	43
	Fawns	15	27
Daily metabolic rate (kcal/deer)	Adults	2632	1998
	Fawns	1067	1410

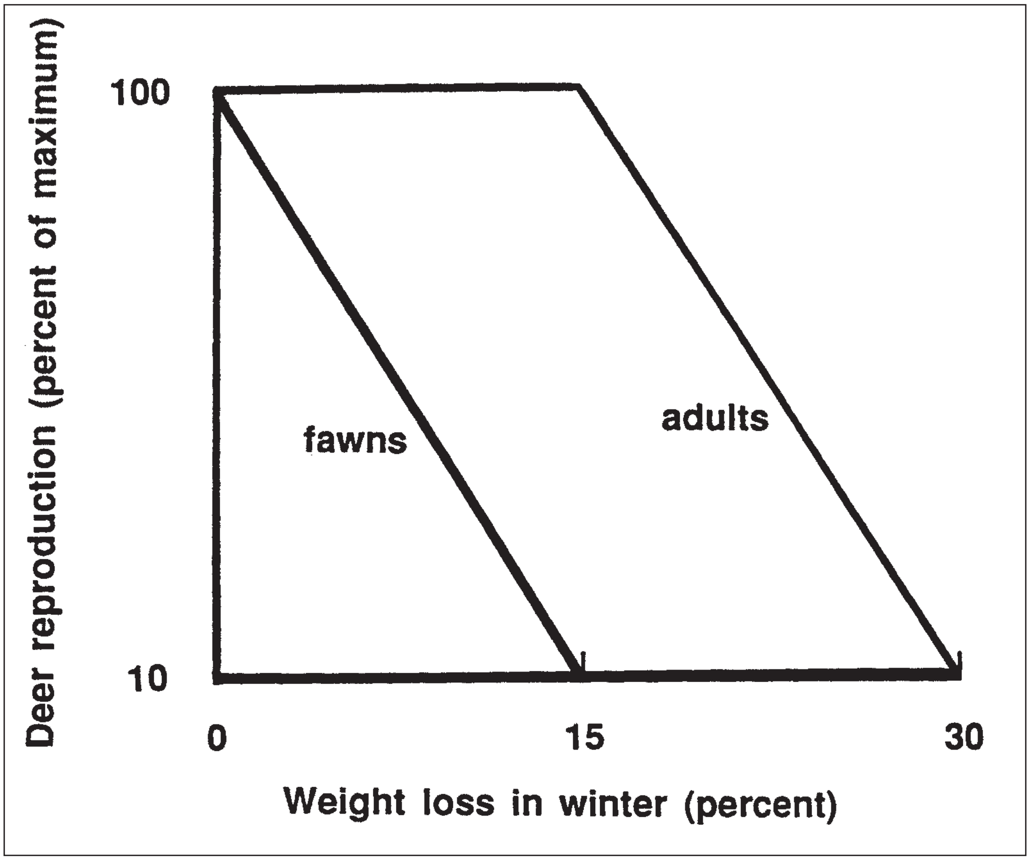

Figure 48—Effect of winter weight loss on deer reproduction.

Reproduction

Reproduction (R) is a function of the energy balance at the end of winter (fig. 48). Maximum fecundities, averaged over yearling and adult age classes are assumed to be 1.5 fawns per doe. Actual fawn production is equal to reproduction (from fig. 48) multiplied by 1.5 (the maximum).

Natural Survival

Survival of fawns and adults is, like reproduction, a function of net energy balance at the end of each season (fig. 48). When R is equal to 1, maximum survival of fawns (75 percent) and adults (90 percent) is realized. As weight loss increases, the value of R decreases, and the percentage of survival declines. Because their fat reserves are proportionately smaller, fawns suffer a greater mortality per unit of weight loss than do adults.

Hunting Mortality

The hunter population consists of three classes of hunters: local residents, loggers, and hunters from outside the immediate area. Local residents include individuals from nearby communities who ordinarily travel by skiff to the area for a day hunt. Loggers include those actively involved in logging who would not otherwise use the area. Outside hunters are those from communities beyond the immediate locale who travel to the area by aircraft, large vessel, or ferry.

The model requires user input for the maximum number of local hunters using the area and the number of days per hunter. The population of woods workers is computed in the timber submodel as a function of the volume of timber logged and miles of road built. The proportion of loggers that hunt and the number of days per season that each logger hunts are specified by the user. Maximum hunter days for nonlocal hunters is also specified by the user.

Loggers and local residents are assumed to exhibit no effort-response; that is, the number of hunter days spent by those hunters is independent of their success rate in the previous year. For the nonlocal hunter population, the hunting effort varies depending on success in the previous year (fig. 49).

The number of deer killed per unit of effort varies with deer density, from no deer harvested per hunter day at densities below 10 deer/mis, to a maximum of 0.5 deer per hunter day at densities in excess of 70 deer/rr\i2. Deer killed by hunters are removed at the end of each summer in direct proportion to the population in each age class within each herd.

In addition to the legal harvest of deer, a significant number are taken by poaching. The number of deer poached is expressed as a user-specified proportion of the legal harvest. The number of deer this represents is added to the legal harvest to arrive at total deer mortality.

Model Documentation

A summary of the sources for the deer submodel is given in appendix 5. Estimates of understory production, availability, quality, and digestibility as a function of season, SI class, and canopy cover are based on research conducted in southeast Alaska and on the professional judgment of the authors. Energy intake rates and energetic costs associated with basal metabolism, activity level, and snow depth are based primarily on work conducted outside Alaska. As shown by the frequent mention of "professional judgment" in the appendix, many of the parameters and relations used in the deer submodel either were unknown or were published in a form not directly transferable to the deer submodel. In those instances, specific relations were developed by extrapolating from existing data and by using professional judgment.

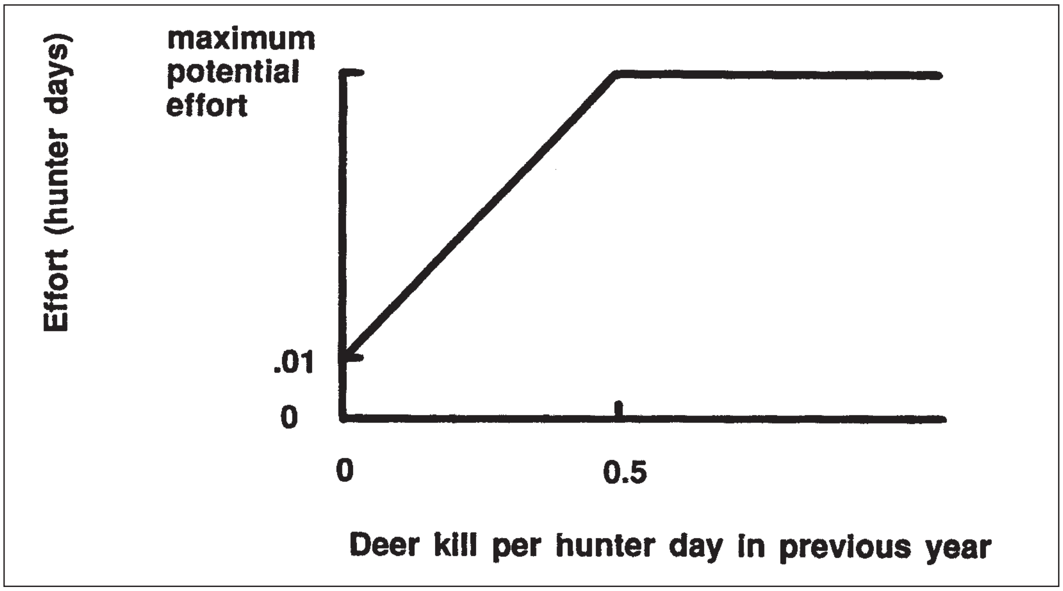

Figure 49—Annual hunter effort as a function of hunter success rate in the previous year.

7

Using the Model SAMM: Implications for Management

Lawrence D. Garrett, Roger D. Fight,Dale L. Weyermann, and Joseph R. Mehrkens[1]

Introduction

This paper documents the development of the prototype model SAMM, which projects multiresource impacts of management actions in southeast Alaska forests. The concepts represented in the model, although not new, represent a significant extension of available knowledge of Alaska multiresource interaction. Managers and analysts are cautioned, however, that formal validation of these concepts is not complete.

The model represents an integration of the knowledge of scientists and specialists involved in research and management of natural resources in southeast Alaska. Development of many of the algorithms has evolved through interaction of these specialists in conjunction with analysis of available data.

The prototype model as currently developed is appropriate for evaluating relative changes in and integration of resources at the watershed level as a result of management action. The manager is cautioned that the model has not been tested against observed data for accuracy of predictions. Submodel structure and outputs and overall model linkage and performance have been subjected to intense review by a panel of experts. It is the opinion of this interdisciplinary panel, who drafted this report, that submodel structure, linkages, and outputs represent a state-of-the-art understanding of multiresource integration in southeast Alaska. Until tested against an observed data set, the model should be used only to characterize relative change in resource outputs as a result of management action.

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To simulate the effects of management actions on various natural resources, the component models are integrated in a cascade fashion; that is, tree stocking affects herbage and water yield, which in turn affect sedimentation and wildlife habitat. There is currently little feedback in the system. Feedback mechanisms can be included as sufficient knowledge is developed on interacting effects.

Like all analytic models and systems, SAMM has limitations. Analysts and managers should understand these limitations, especially as they relate to the potential applicability and transportability of the model.

Model Applicability

Analytical models like SAMM represent abstractions of the real biological world. They are imperfect and at best represent a simplistic description of extremely complex biological, ecological, and socioeconomic processes (Goulding 1979, Taylor 1979, Valentine 1978). Development of models such as SAMM must be constrained to conform to managers' requirements for brevity and simplicity; that is, the model is designed to capture the real world in the fewest variables possible and with a limited amount of complexity in the variable interactions.

The analyst is almost always limited by available data in structuring a biologically reasonable system that also affords predictive capability. Most established guidelines recommend limiting the variables in the system to a small subset providing the predictive efficiency appropriate to the intended use. The inclusion of all variables affecting the natural process is normally undesirable because of restricted data availability, marginal increases in predictive efficiency, and increased cost with increased data requirements and system complexity.

Any application of SAMM will be constrained by how similar or dissimilar the biological communities to be evaluated are to the community or communities defining it. Even in similar biological communities in southeast Alaska, considerable variation can occur in biological growth, physiographic characteristics, and climatic conditions. The analyst therefore should have trained professionals evaluate the effectiveness of the model in any new or questionable area. If unacceptable predictions are found, the model or submodels, or both, must be recalibrated or reformulated with data sets representing the new area.

Most of the resource submodels in SAMM were developed from resource data from southeast Alaska or from information provided by scientists and specialists working there. Where possible, information transported from other regions was modified to fit conditions in the southeast. When data were not available, model outputs were compared to the literature and evaluated by professionals working in the specific resource areas.

To build a simulation model, data are generally needed for three different procedures: model development, calibration, and testing or validation. Data for these procedures are severely lacking for southeast Alaska, which caused reliance on panels of experts, made up of resource scientists and specialists, for development of model relations. This is one weakness affecting potential use of the system by managers. These first approximations are not necessarily in error; however, without observed data bases for testing, validation of predictive accuracy is impossible.

Model Transportability

Managers should be cautious in applying SAMM, or any biological Model, to areas other than the one the model was developed for. The transportability of SAMM relates directly to how parameters and data used to develop the model differ across the southeast Alaska region. The degree to which SAMM, or any other process model, is transportable depends on three major factors:

1. How similar are natural and physical processes in the area of application to those in the area of development; that is, would a different model structure be more accurate? For example, does an impervious soil layer cause most precipitation to run off as surface flow rather than percolate through the soils and enter streams as subsurface and surface flow?

2. How accurately do variables describe natural processes in the new area vs. the area where the model was developed; that is, are the same variables appropriate and adequate? WiIl relations among model variables and model structure be the same in the new area? More simply, are deer and overstory the conflicting resources? Or is it understory and deer? Are the variables describing the resource interaction the same in both areas?

3. How different are data describing a variable, both in diversity and variability? Do tree form and soils vary radically from site to site? Does precipitation occur as frequent light rain or infrequent severe storms, or as both but in different seasons?

The more that processes, variables, and data from one area are similar to those from another area, the more likely a given model can be transported and adequately calibrated to the new area (Goodall 1972, Pilgrim 1975). In many cases, the more generalized the model and the more closely it represents natural processes, the greater the success. This is not always true but is a general guide.

Analysts should evaluate existing submodels for use in any new area under consideration before making any changes. This requires testing to determine the predictive capability in the new area. If a particular submodel does not have predictive efficiency but the natural processes seem properly defined by existing variables, the model should be recalibrated to data sets representing the area and resource.

If the accuracy of predictions after calibration is unacceptable, the existing submodel should be replaced with a resource model with proven predictive capability for the specific area. If one does not exist, it should be developed from data or knowledge adequately representing the resource and area.

We do rot mean to imply that statistical tests are the only accepted criterion for model assessment. Statistical significance, when it can be determined, should be used to assess model usefulness. Statistical tests normally represent limited variable and data ranges; final evaluations of the utility of a model to the forest manager must incorporate a wider range of knowledge. Knowledge gained from professional experience and information taken from the work environment are also important in determining model credibility (Goodall 1972, Goulding 1979, Pilgrim 1975).

Potential users of SAMM must be aware of the above limitations and understand how the limitations will constrain the future applicability and transportability of this model.

Model Verification and Validation

The SAMM model needs additional evaluation and testing to determine its predictive capability and usefulness to managers. Management models like SAMM are created for specific purposes, and the adequacy or validity of a model can be evaluated only in terms of that purpose. To evaluate a model means to develop an acceptable level of confidence that predictive evaluations conducted and inferences drawn from the model are acceptable and applicable. Thus, the concept of validation is one of degree; it is not an either-or notion. The degree of model validation considered acceptable for SAMM depends entirely on management confidence in available evaluations and inferences drawn from the model. No magic formula exists for assessing such a concept. For management models, this remains a deliberate management decision.

Evaluating Predictive Capability

Extensive sets of data for multiresource analysis and testing are not available for southeast Alaska. When independent data sets are not available, a model cannot be fully evaluated in a rigorous statistical sense. Successful application of the following procedures nonetheless will increase confidence in a model by both managers and analysts:

1. Qualitatively examine the model structure. In general, the variables and their linkages in ecosystems are similar; there are physical and natural theories supporting basic structures and their differences. The model must conform to these theories, which can be readily confirmed through the literature.

2. Compare specific output with that from previous studies. Even if no other model is directly comparable with the model being tested, it is often possible to identify specific structures and outputs from other studies that can be compared to related structures and outputs generated by the model. Such comparisons may be subjective. Agreement among a majority of such comparisons is a positive indication of validity.

3. Prepare a sensitivity analysis of model variables. Sensitivity analysis is an examination of the response of a model to systematic incremental changes in variables. The magnitude, direction, and form of the response are analyzed both qualitatively and quantitatively.

Sensitivity analysis can demonstrate how sensitive the results or outputs of the model may be to the variable values used. In general, both theory and previous research have characterized variables the outputs should be most sensitive to. If the response by the model is highly sensitive to certain variables differing from theory or previous research, additional effort should be directed at model structure.

Sensitivity analysis by varying the input values over a wide range can yield information on the impact of decisions if the external environment changes. If slight changes in inputs lead to significantly different outputs, then caution in implementation is indicated, and viable alternatives, or built-in controls, should be developed.

Sensitivity analysis can provide valuable clues for possible modifications to the model. The analysis can indicate what parts of the model can be simplified, for example, by changing from a Monte Carlo routine to the use of a mean value or by dropping a whole subsystem from the model. The analysis can also indicate where it might be fruitful to model relations in more detail.

4. Establish confidence intervals for population parameters. Confidence intervals can often be established around the estimates of population parameters. Most statistical texts provide suitable formulas if a normal distribution can be assumed. This is not as restrictive as might appear because most large samples are approximately normally distributed, and in any case, the characteristics of most simulation models cause the central-limit theorem to hold for their outputs.

5. Have a peer review of model structure and outputs. Review by peers of the model's formulation, composition, responding, and output help to build confidence in the validity of the model. The value of this process may be limited, however. As noted previously, all assumptions, interpolations, extrapolations, and approximations should be explicit. Even then, due to model complexity or perhaps even to lack of time to trace variables through the model, there is no guarantee that reviewers will achieve any more than a very basic understanding of what the model is doing. This process therefore may give a misleading impression of the confidence of peers in the ability of the model to achieve the intended objectives.

A Final Note on Model Evaluation

This model, like any model of a complex biological-physical-economic system, is necessarily incomplete. It is a highly simplified representation of a real system and contains conceptual biases and incorrect data. It does, however, represent a synthesis of the knowledge of a diverse group of scientists and managers who worked with-the system on a regular basis. The assumptions and simplifications applied in building the model were a first attempt at an integrated system model capable of exploring the implications of a wide range of management options in southeast Alaska.

The accepted form of model evaluation involves extensive validation. If the model passes various tests including both statistical and professional judgment, it is classified as "valid." In truth, no biophysical model can be totally valid because a is, by necessity, simple in comparison to the real world. In any case, the more tests a model survives, the greater the confidence that can be placed in its predictions. Model outputs cannot be accepted as absolutes; they should be used as guidelines to suggest ideas and issues requiring action. The major contribution a model can make is to efficiently display the relative probable changes occurring in several resources as a result of management action.

No matter how much effort goes into testing a model, one cannot, a priori, identify the limits of predictive power or robustness. invariably, a real-world process not included in the model will eventually cause a divergence between model and observation. But management decisions have to be made in a world of uncertainty, and models have been proven useful in helping managers deal with this uncertainty.

Evaluating the model as outlined above is partially intended to de-emphasize the quantitative nature of the model output and concentrate more on the qualitative aspects. Managers are not only interested in the absolute numbers of resources over the next 150 years but also in how the resources respond qualitatively, given various imposed management actions or natural perturbations. In other words, SAMM is also intended:

1. To develop an understanding of how robust the forest system is when stressed.

2. To determine if there are management actions completely inappropriate over time and, more importantly, to identify those actions that can partially or completely mitigate an adverse impact.

3. To come to some agreement on the quantity, quality, and kinds of information needed to both improve our understanding of the system and help us monitor its health.

Status of SAMM and Example of Outputs

The southeast Alaska multiresource model is comprised of many algorithms that define how each submodel is to operate and how the four submodels are linked. The algorithms are in a computer program written in ANSl FORTRAN 77. A graphic interface for SAMM is accomplished with commercial software designed for IBM PC/ATs[2]. The complete model can run on a microcomputer, minicomputer or mainframe computer of any design, if appropriate reprogramming is accomplished and compatible graphics software is linked to the model.

Status

Currently, SAMM is programmed for IBM PC/ATs or full compatibles. Access to the current model is through the individual designated as the leader of the SAMM technical committee under the interagency memorandum of understanding (see footnote 2, chapter 1). The current leader of the technical committee is Donald J. DeMars, Forestry Sciences Laboratory, Juneau, AK 99802. Model development was managed by the Project Leader for Economics of Forest Land Management, Forestry Sciences Laboratory, Portland, OR 97208-3890.

A users guide is in preparation for the software. Operation of the software without a users guide requires training by a specialist skilled in computer operation and knowledgeable of the SAMM structure.

Outputs derived from the model are dependent on three primary factors:

1. Required inputs to the model that describe the physical character of a watershed to be evaluated.

2. Required inputs to the model that describe the current state of the resources being modeled: timber, water, fish, and deer.

3. Required management actions to be performed, such as harvest, thinning, stream cleaning, fish harvest, or deer harvest.

Given the specified inputs, the model will project changes over time in the state of the resources given interactions of management, natural occurrence, and the resources themselves.

Example of Outputs

The following examples provide simulated resource outputs from a southeast Alaska watershed covering several thousand acres. The watershed is dominated at the start by unmanaged old-growth hemlock and spruce. Twenty-five percent of the area is clearcut in year 20. The area is then naturally reforested. Management activities included in the simulation are clearcutting, stream cleaning, natural reforestation, and road building. The area is assumed to have SI classes from 70 to 130 represented and to cover a normal spectrum of physiographic conditions.

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[2] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Figures 50-56 are actual outputs from the model. They illustrate effects of real parameters operating in the model, including maximum snow depth, timber growth, timber harvesting, deer density, road building and use, proportion of fine sediments, large organic debris, and fish spawning. Parameters illustrated occur in the four major submodels: timber, deer, hydrology, and fisheries.

Timber and snow—Clearcut logging, followed by regeneration and eventual crown closure of the new stand, directly impacts several resources in the system. Figure 50 relates recovery of canopy cover in stands clearcut in year 20. Yearly maximum snow depth over the 100-year cycle is given in figure 51. Peaks are noted in years 27, 36, 40, 47, 62, and 77. Excessive snow depths are detrimental to deer, especially when the depths exceed 20 inches in recently harvested stands.

Deer—When extreme snow depths coincide with timber harvest, considerable impacts can occur in deer populations. This results from reduced browse availability due to snow and slash and increased energy cost for the deer from moving through deep snow. Figure 52 demonstrates the combined effects of snow and timber harvest on deer density. The harvest activity in year 20, combined with heavy snows, severely impact populations for 20 years after year 20. As the timber stands regrow, deer populations are maintained but at lower levels than could be maintained in old-growth stands.

Hydrology and fisheries—figures 53-56 illustrate the impact of road building (year 15) and timber harvest (year 20) on fisheries. Creation of large debris during logging operations actually can have a positive effect on returning adults (fig. 53). Large debris is important in creation of pool, protective, and rearing areas.

Fine sediments are also created from logging and road building activities (fig. 54). Logging causes a gradual increase in fines entering streams and then a decrease over time until levels build up again. Road construction and use creates a much greater amount of fines entering streams. This is from the settling of the bed of a new road and the abrasive action of tires on road surfaces. The road building and logging scenario has a sharp peak for proportion of fine sediments in the year of logging, which is due to road use. This peak is from a 1-year input of fines, so its effect is primarily focused on one year-class of fish. This explains the jagged appearance of the dotted line in figure 55, because one year-class is dramatically affected by the sediments while the other year-class is at sea.

Fine sediments wash out of a system faster than coarse sediments, resulting in a period when the proportion of fines in the system is below that for a steady-state system. As the coarse materials wash out, the proportion of fines return to steady-state conditions. This is an advantageous situation for pink salmon and results in slightly higher long-term fish numbers after logging. The 40-year cycle in fish populations is due to the long-term cycling of precipitation simulated in the hydrology model.

The dynamics of coho salmon fisheries are more complex. Coho are affected by the proportion of fine sediments but to a lesser degree than are pink and chum salmon. Coho dynamics are also driven by:

1. Available spawning gravel area.

2. Large debris added or removed during logging.

3. Proportion of streambank that is cut.

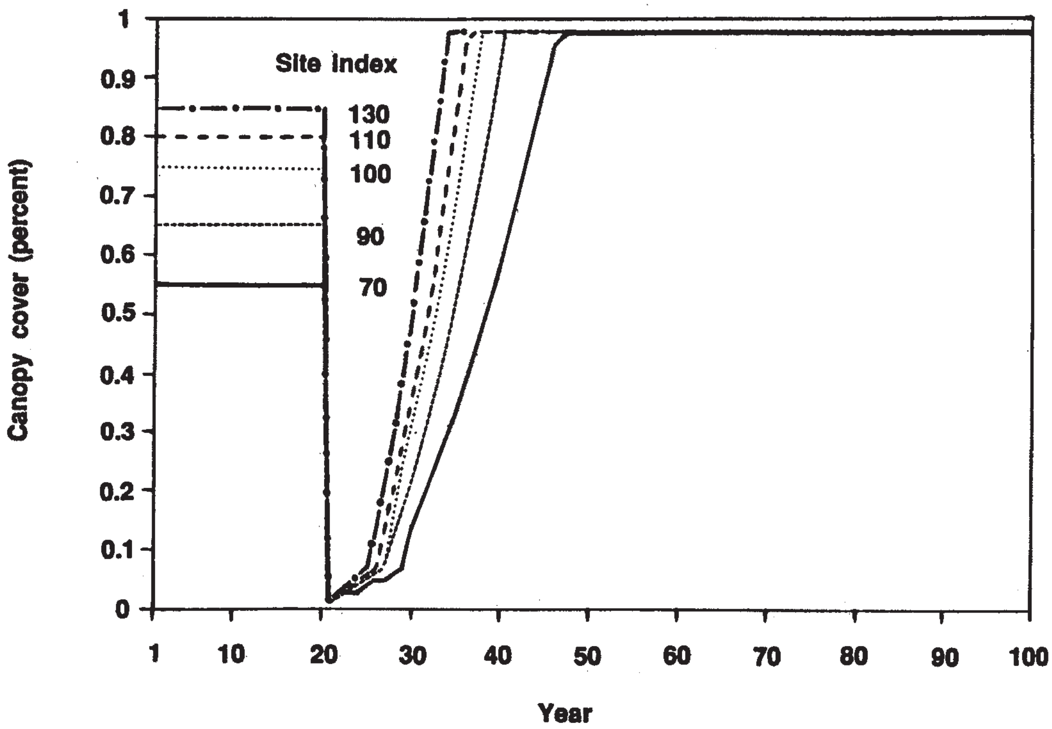

Figure 50—Percentage of canopy cover for five site index classes.

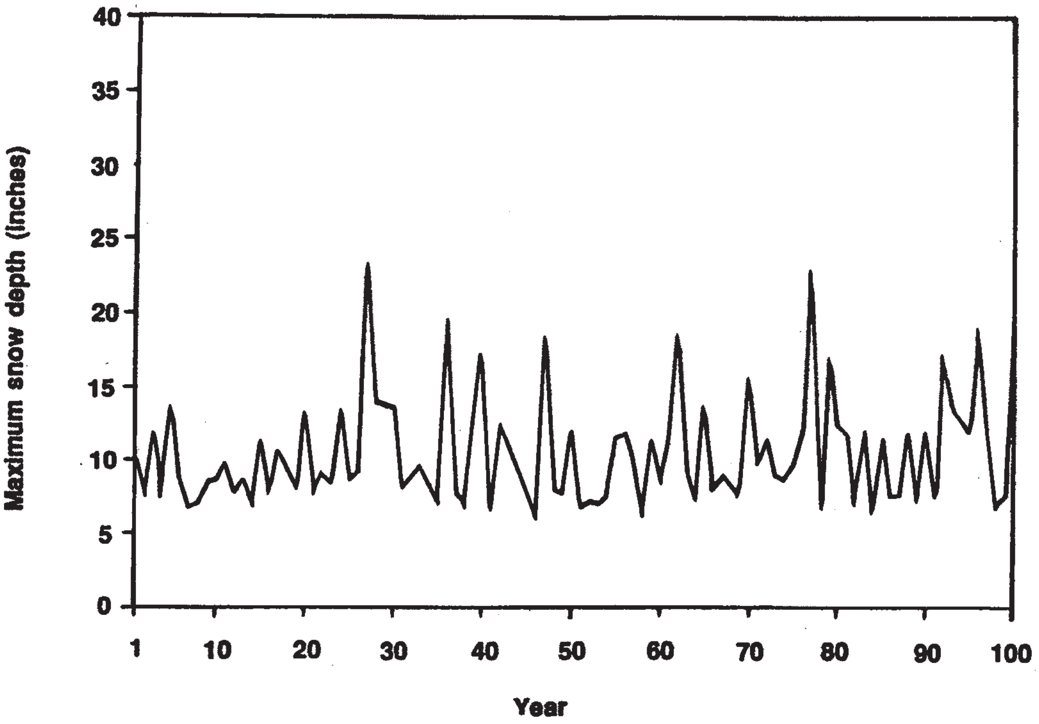

Figure 51—Maximum annual snow depth at sea level in the south part of southeast Alaska.

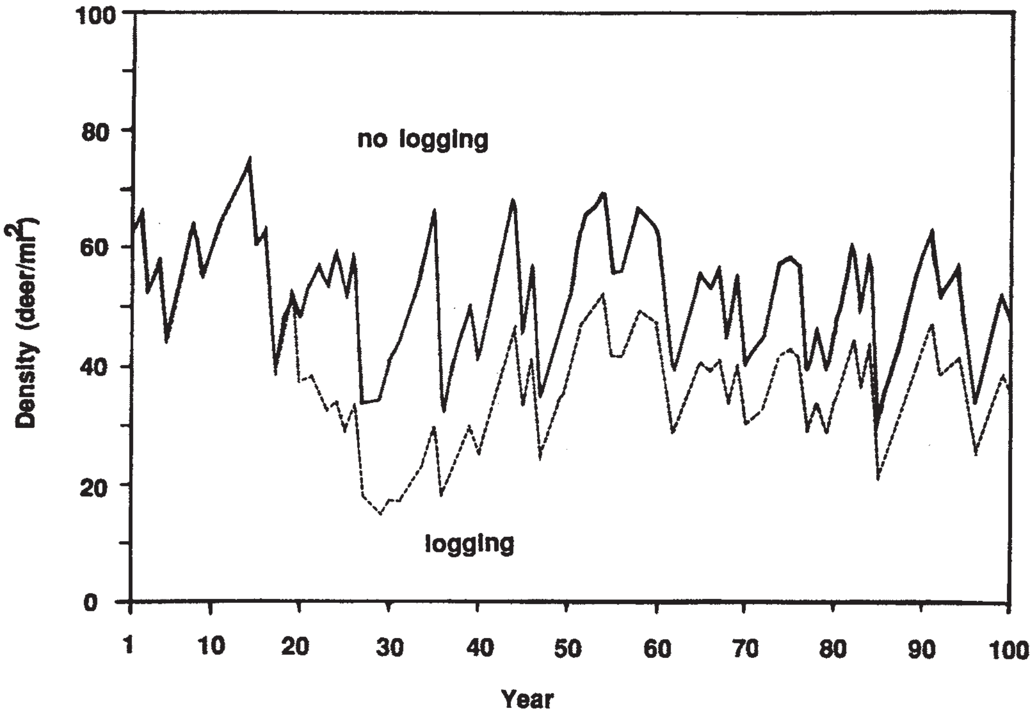

Figure 52—Deer densities in a watershed under average snow conditions, with and without logging.

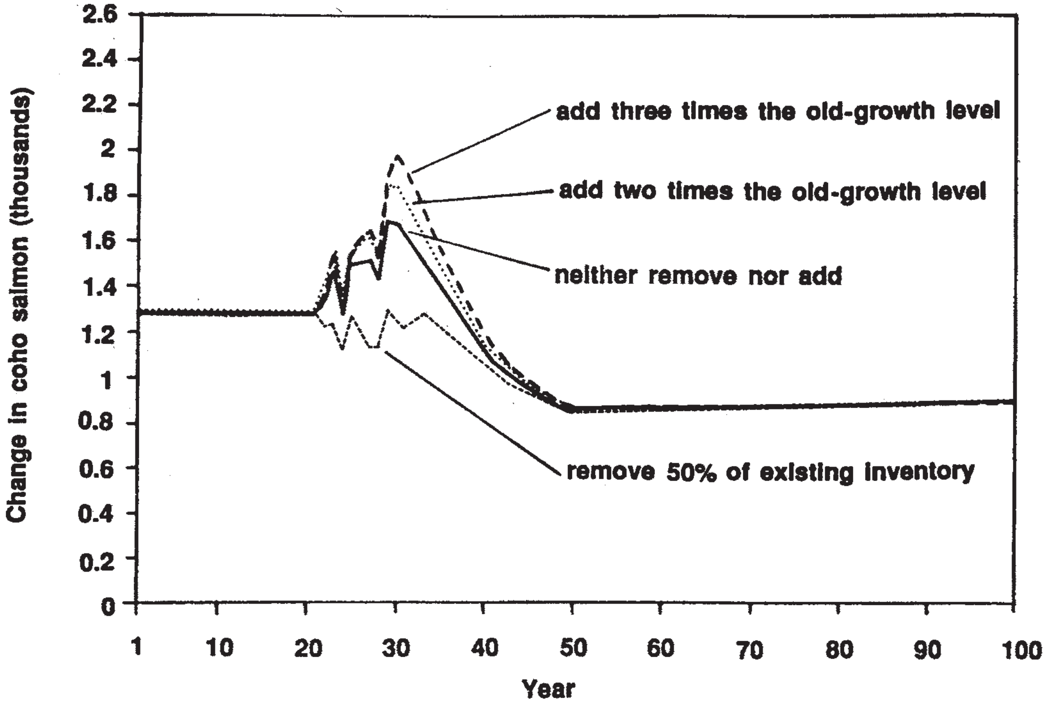

Figure 53—Change in number of coho salmon spawners due to rearing pools being formed by large organic debris.

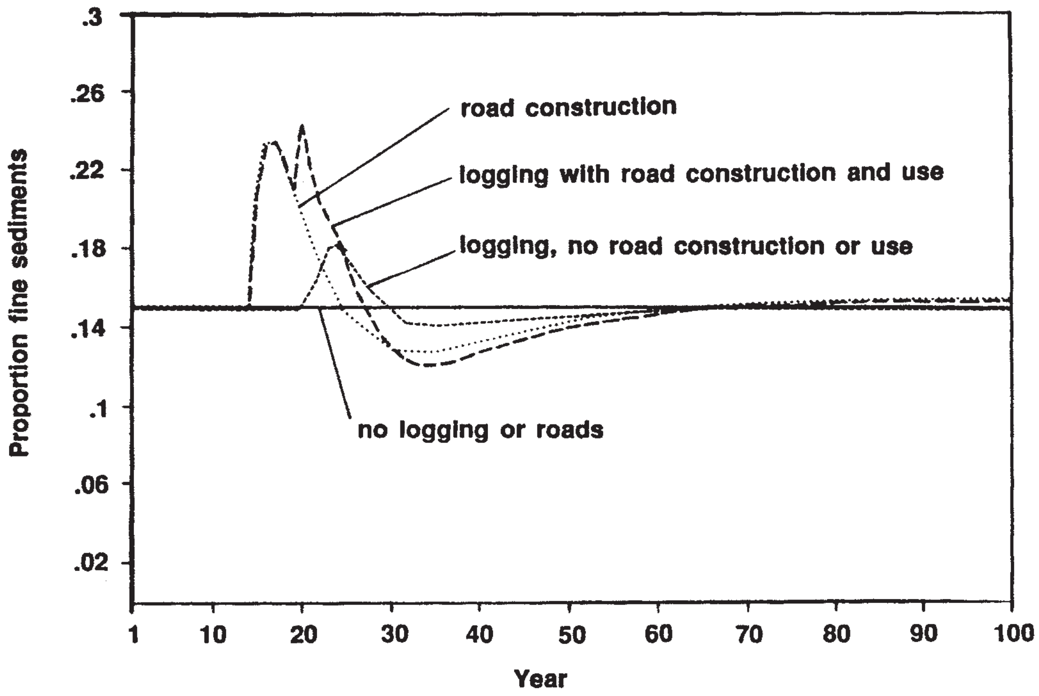

Figure 54—Creation of fine sediments in streams as a result of logging, road construction, and road use.

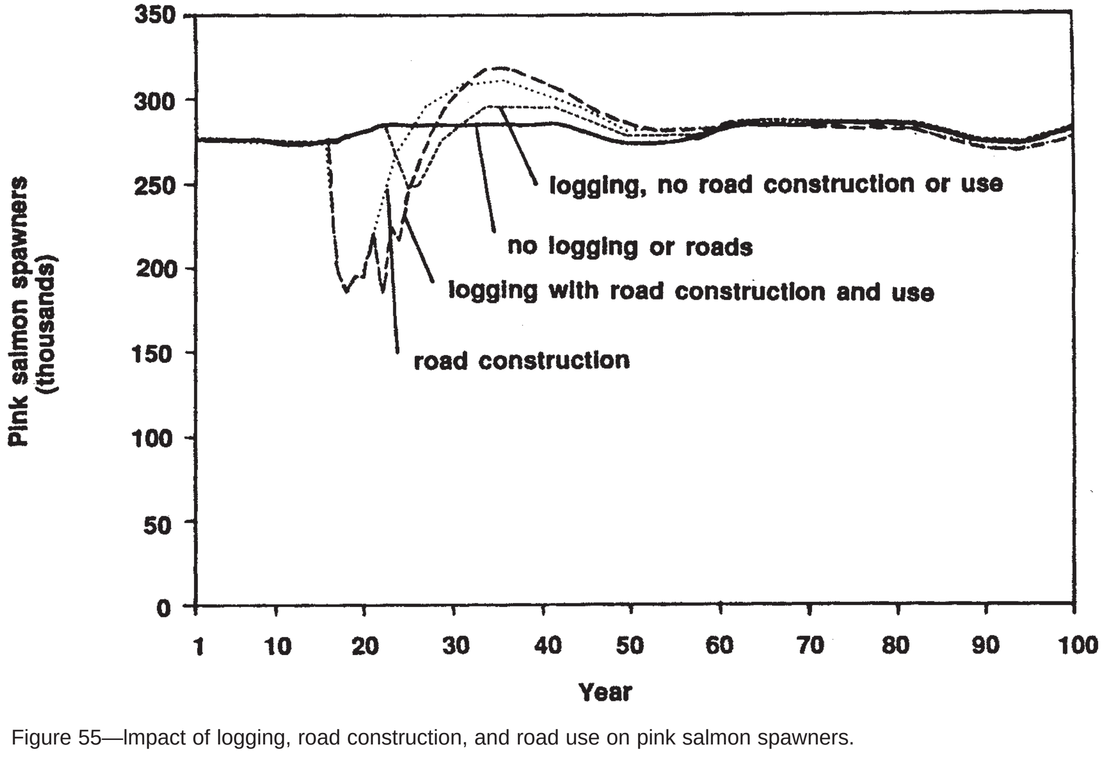

Figure 55—Impact of logging, road construction, and road use on pink salmon spawners.

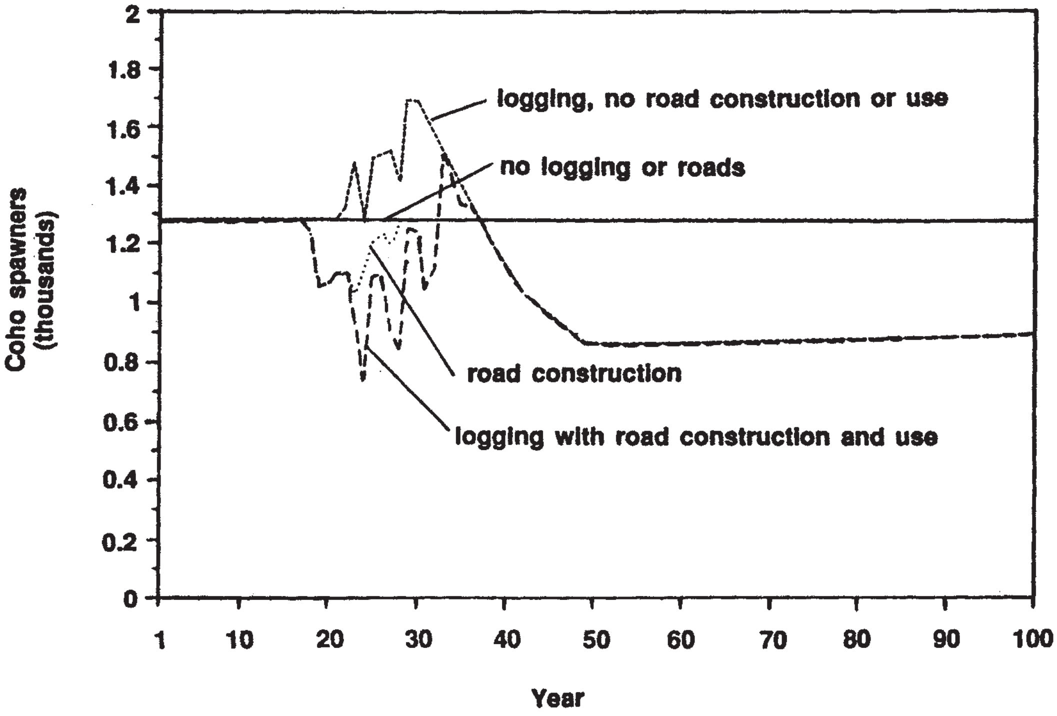

Figure 56—Impact of logging, road construction, and road use on coho salmon spawners.

Depending on the amount of roads built and used, the impact of roads may be an increase in coho spawners for 10-20 years, after which the population declines significantly below that under old-growth timber conditions (fig. 56).

Metric and English Equivalents

When you know:	***Multiply by:***	***To find:***
Length and Distance		
Inches	2.54	Centimeters
Centimeters	0.393	Inches
Feet	0.304	Meters Meters
	3.280	Feet
Yards	0.914	Meters
Meters	1.093	Yards
Miles	1.609	Kilometers
Kilometers	0.621	Miles
Volume		
Quarts	0.946	Liters
Liters	1.056	Quarts
Cubic feet	0.028	Cubic meters
Cubic meters	35.314	Cubic feet
Gallons	3.785	Liters
Liters	0.264	Gallons
Gallons	0.0037	Cubic meters
Cubic meters	264.17	Gallons

When you know:	***Multiply by:***	***To find:***
Acre-Feet	1,233.48	Cubic meters
Cubic meters	0.000811	Acre-feet
Area		
Square feet	0.092	Square meters
Square meters	10.764	Square yards
Square yards	0.836	Square meters
Square meters	1.196	Square feet
Acres	0.404	Hectares
Hectares	2.471	Acres
Weight		
Pounds	0.453	Kilograms
Kilograms	2.204	Pounds
Short tons	0.907	Metric tonnes
Metric tonnes	1.102	Short tons
Speed		
Feet/second	0.304	Meters/second
Meters/second	3.281	Feet/second
Miles/hour	1.609	Kilometers/hour
Kilometers/hour	0.621	Miles/hour
Volume Per Unit of Time		
Cubic feet/second	0.0283	Cubic meters/second
Cubic meters/second	35.315	Cubic feet/second
Temperature		
Fahrenheit (°F)	(°F-32)(5/9)	Celsius
Celsius (°C)	(°C)(9/5)+32	Fahrenheit

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Appendix 1: Economics of Forest Management

Table 12—Value by timber volume class[a]

Volume class	Value/mbf
Mbf	Dollars
0-8	205.50
8-20	251.50
20-30	285.50
30-50	309.00
>50	322.50

[a] All revenues are equated to 4th quarter 1981 from base year 1980 data (ID 30 applied Amendment 68 of Alaska Region Timber Sale Appraisal Handbook, FSH 2409.22). All revenue values from cedar are entered as $1000/mbf. These are applied to second-growth commercial thinning and final harvest as well as to old-growth.

Table 13—Unit costs of timber management activities

Activity	Unit Cost
	Dollars
Hauling costs	(1.50/mbf)/mile
Mainline road construction	175,000/mile
Temporary road construction	120,000/mile
Road maintenance	(.45/mbf)/mile
Site preparation	40/acre
Planting	480/acre
Precommercial thinning	350/acre

Table 14—Logging costs for various harvesting types and timber volume classes[a]

Logging systems	Volume class (mbf)				
	0-8	8-20[b]	20-30[c]	30-50	>50
			Dollars		
High lead, up	143.83	125.63	108.68	89.49	83.49
High lead, down	176.50	149.48	126.6	102.67	94.32
Short skyline, up	137.43	119.31	103.58	85.24	82.48
Short skyline, down	156.37	134.11	115.02	94.33	88.75
Medium skyline, up	161.12	739.57	120.90	100.52	94.09
Medium skyline, down	186.28	159.71	136.93	113.67	105.95
Long skyline, up	186.37	162.15	141.08	119.00	111.78
Long skyline, down	251.92	215.94	185.10	156.19	146.10
A-frame	134.92	132.72	130.56	99.06	90.10
Helicopter				250.00	243.00
Tractor	107.17	100.89	94.98	78.75	75.72

[a] All costs are equated to 4th quarter 1981 from base year 1980 data (ID 30 applied Amendment 68 of Alaska Region Timber Sale Appraisal Handbook, FSH 2409.22).
[b] Increase costs 10 percent for all systems to reflect added cost of installing artificial anchors.
[c] Increase costs 2 percent for medium and long skyline systems to reflect cost of installing artificial anchors.

Table 15—Employment rates for logging activities

Type of activity	Employment rate
	Person year
Clearcutting	0.002/mbf
Road building	1/mile
Second-growth thinning	.0056/acre
Final harvest	.002/mbf
Planting	.0056/acre
Precommercial thinning	.0056/acre
Site preparation	.0056/acre

Appendix 2: Documentation of the Timber Submodel

Process and data	Sources and comments
Basal area table	Taylor (1934)
Basal area growth rate	Professional judgment; part of set of relations to simulate growth responses to thinning
Relation between maximum rate of basal area growth and stand age	Professional judgment; part of set of rela tions to simulate growth responses to thinning
Table of stem density	Taylor (1934)
Stem mortality as a function of the number of stems in existing stand and in a normal stand of the same site and age and as a percentage of maximum basal area	Developed; part of set of relations to simulate growth responses to thinning
Overstory height growth	Farr (1984)
Relation between mean stand height of trees 9.0 inches and larger and overstory height	Developed from permanent sample plot data
Number of trees 9.0 inches and larger	Developed from Taylor (1934, table 18)
Mean diameter of trees 9.0 inches and	Developed from Taylor (1934, tables 5

Process and data	Sources and comments
Timber volume	Chambers and Foltz (1979)
Development of canopy cover in stands less than 20 years old	Professional judgment; canopy cover develops very rapidly in young stands
Development of canopy cover in stands more than 20 years old	Professional judgment; presently a function of basal area; canopy cover is not regularly measured in stand inventories
Relation between canopy cover, stand type, and slope	Professional judgment; has little influence on understory forage and deer dynamics
Slash levels from various timber management activities	Professional judgment
Slash depth decay rates	Professional judgment
Old-growth wood values	Timber Management, USDA Forest Service, Alaska Region; regional averages are presently used; can adjust values to suit watershed-specific conditions
Revenue multipliers for second growth	Mehrkens (1983)
Road construction costs	Helmick and Anderson (1982); figures used are regional averages; can adjust values to suit watershed-specific conditions
Road maintenance costs	Helmick and Anderson (1982); figures used are regional averages; can adjust values to suit watershed-specific conditions
Logging costs	Alaska Region timber appraisal handbook (FSH 2409.22); Mifflin and Lysons (1978); figures used are regional averages adjusted by time and site-specific assumptions; can adjust values to suit watershed-specific conditions; these costs include falling and bucking, yarding, loading, depreciation, and overhead; costs for the 0-8-mbf class have been extrapolated from costs in higher volume classes

Process and data	Sources and comments
Hauling costs	Professional judgment; Helmick and Anderson (1982); costs include road hauling costs only to the boundary of the watershed; values estimated from Alaska Region transportation planning guide
Young-stand management costs	Mehrkens (1983)
Employment rates	Mehrkens (l983)

Appendix 3: Documentation of the Hydrology Submodel

Process and data	Sources and comments
Natural inorganic sediment inputs	Swanston and Swanson (1976)
Loadings of inorganic sediments from mass movements in clearcuts	Swanston and Swanson (1976)
Loadings of inorganic sediments from mass movements from roads	Swanston and Swanson (1976)
Loadings of inorganic sediments from surface erosion from roads	Reid and others (1981k Reid and Dunne (1984) Paustian (1987); Paustian and others (1987); Paustian (personal communication[1]); quantities and rates are based on extrapolations from published data and preliminary analysis of ongoing monitoring information
Fractions of fine and coarse inorganic sediments in loadings from all sources	Professional judgment; the assumption that fractions in all types of input are the same means that relative loadings are similar in logged and unlogged situations
Loadings of organic debris	Professional judgment; extrapolations made from published data; Swanson and Leinkaemper (1978)
Fractions of small and large organic debris in loadings	Professional judgment; the assumption that fractions remain constant means that rela tive loadings are similar in logged and unlogged situations

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[1] Personal communication, S.J. Paustian, hydrologist, USDA Forest Service, Chatham Area, Tongass

Process and data	Sources and comments
Equilibrium levels and movement rates of inorganic sediments and organic debris	Can be estimated by a hydrologist from knowledge of stream gradients and water shed characteristics
Probability of debris torrents and stream types that have potential for debris torrents	Professional judgment
Dynamics of undercut banks	Preliminary data from Murphy and others (1984, 1986) coupled with professional experience and judgment; initial values and dynamic processes need to be supplemented and verified over a larger sample area
Size distributions of peak fall storms	Size distribution developed from maximum precipitation and frequency data (U.S. Department of Commerce, Weather bureau); must be calibrated for each general region of southeast Alaska
Relation between velocity of water in peak fall storm and degree of bedload shift	Professional judgment
Maximum bedload shift for each stream reach	Professional judgment; must be estimated for each drainage
Mean monthly precipitation	Monthly multipliers must be used; U.S. Department of Commerce (1978)
Long-term cyclical variation in precipitation	Professional judgment; developed from long-term record
Short-term variation in precipitation	Developed from long-term record and professional judgment
Mean monthly temperature	National Oceanic and Atmospheric Administration (1982)
Short-term variation in temperature	Professional judgment; developed from long-term record
Effect of elevation on temperature	Professional judgment

Process and data	Sources and comments
Rate of snowmelt	Professional judgment; traditional snowmelt models are too complex for purposes of this model
Evapotranspiration over the year	Extrapolated from Patric and Black (1968)
Change in maximum evapotranspiration from logging	Professional judgment; shape of the curve reflects the general changes in evapotranspiration in recent clearcuts
Soil water capacity	Soil resource inventory field manual, USDA Forest Service
Infiltration rate	Professional judgment
Base flow rate	Can be estimated by using general concepts outlined in Fetter (1980)
Equation for changes in stream temperature	Brown (1970)
Equation for potential rate of heat absorption against stream discharge	Environmental Protection Agency (1980)
Monthly solar angle	Smithsonian Miscellaneous Collections (1966); the date 15 should be used for each month
Effect of tree height and canopy cover on snow interception rates	Professional judgment

Appendix 4: Documentation of the Fisheries Submodel

Process and data	Sources and comments
Relation between available spawning area and summer low flow	Graybill (1974) and Wickett (1958) support the conceptual relation but do not provide the specific relation used in the model
Estimates of gravel requirements	Reiser and Bjornn (1979k data provided cover a broader area at a coarser resolution than is included in the model and were adjusted accordingly
Fecundities	Alaska Department of Fish and Game (unpublished data)[1]
Relation between egg deposition and high summer temperature	Lethal temperatures from Reiser and Bjornn (1979)
Fall temperature effect on egg-to-fry survival	Dong and Brannon (1980) extremely low temperatures (less than 2°C) cause high mortalities
Winter flow sedimentation effect on egg-to-fry survival	Tagart (1976) and Reiser and Bjornn (1979) large percentages of fine particles (<3.35 mm) cause high mortalities
Bedload shift effects on egg-to-fry survival	Wickett (1958) and Seegrist and Gard (1972) support the conceptual relation; it was assumed that the proportion of eggs lost would be proportional to the percentage of the bedload overturned

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[1] Elliott, Steven. Unpublished data. On file with: Alaska Department of Fish and Game, Douglas, AK 99824.

Process and data	**Sources and comments**
Impact of volume of large debris on rearing habitat	Murphy and others (1984k Murphy (unpublished data[2])
Impacts of streamside canopy on rearing habitat	Murphy and others (1981) show inverse relation between canopy closure and rearing density of juvenile salmonoids; summer mortality
Impacts of high temperature on rearing habitat	Reiser and Bjornn (1979)
Protected areas along side channels	Bustard and Narver (1975a)
Protected areas in pools	Murphy and others (1984)
Protected areas along undercut banks	Bustard and Narver (1975a, 1975b)
Protected areas of rubble	Bustard and Narver (1975a), Bjornn (1971)
Impacts of protected area on overwinter survival	Professional judgment
Impact of degree-days in winter on overwinter survival	Professional judgment
Impacts of temperature on migration of smolt	Professional judgment based on documented geographical variation that seems to be caused by different temperatures
Ocean survival	Alaska Department of Fish and Game, (see footnote 1)
Harvest rates	Alaska Department of Fish and Game Sport Fish Division; estimates for site-specific cases can be derived from regional estimates (see footnote 1)
Harvest allocation to fisheries	1982 allocation estimates are used

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[2] Murphy, Michael. Unpublished data on impact of large debris on rearing habitat. On file with: National Marine Fisheries Service Northwest and Alaska Center, Auke Bay, AK 99821.

Appendix 5: Documentation of the Deer Submodel

Process and data	Sources and comments
Understory response to forest succession	Wallmo and Schoen (1980), Alaback (1982)
Rate of canopy closure after clearcutting	Alaback(1982) professional judgment
Understory production as a function of crown closure	Alaback (1982) professional judgment
Understory production as a function of site index	Professional judgment
Lichen availability as a function of age class	Rochelle (1980)
Lichen litterfall rates in old-growth	Rochelle (1980); professional judgment
Nutritional quality of forage classes	Hanley and McKendrick (1983)
Gross energy of forage classes	Golley (1961), Bliss (1962)
Digestibility by forage class and season	Regelin (1979), Hanley and McKendrick (1983), Schoen and Kirchhoff (1984k professional judgment
Preference by deer of forage classes	From observations of tame deer and food habit studies (Schoen and Kirchhoff 1983)
Energy cost of nutrient metabolism	Moen (1973), Robbins (1983)

Process and data	Sources and comments
lntrinsic growth rate of forbs and shrubs	Professional judgment
Percentage of current annual growth or edible biomass each season	Alaback (unpublished data[1])
Effects of deer foraging on understory growth rates	Merriam (1966) professional judgment
Snow interception as a function of canopy cover and basal area per stem	Kirchhoff and Schoen (1987); professional judgment
Forage availability as a function of snow depth	Hanley (1984); professional judgment
Forage availability as a function of slash depth	Professional judgment
Energy cost as a function of snow depth	Parker and others (1984); professional judgment
Consumption rates as a function of forage abundance, search rates, handling times, and preference factors	Patterned after predation research (Holling 1959, Charnov 1973k specific algorithms developed by N.C. Sonntag[2]
Search rates	Collins and others (1978); professional judgment
Handling time as a function of forage class and deer group	Robbins (1983), Wickstrom and others (1984k professional judgment; model outputs especially sensitive to these parameters
Basal and active metabolic rates	Moen (1973), Mattfield (1974)
Energy content of body reserves	Van Es (1977), Torbit and others (1985)
Reproduction and survival as a function of winter weight loss	deCalesta (1975); professional judgment

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[1] Alaback, Paul. Unpublished data. On file with: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Juneau, AK 99802.

[2] Sonntag, Nicholas. Unpublished data. On file with: ESSA Ltd., Vancouver, BC V6Z 2H2.

Process and data	Sources and comments
Number of fawns produced per doe	Johnson and Larsen (1986); professional judgment
Maximum survival rates of fawns and adults	Taber and Dasmann (1976) professional judgment
Hunter effort as a function of success the previous year	Professional judgment
Harvest rates as a function of deer density	Alaska Department of Fish and Game (unpublished data3); professional judgment

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[3] Kirchhoff, Mathew; Schoen, John. Unpublished data. On file with: Alaska Department of Fish and Game, Douglas, AK 99824.

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Fight, Roger D.; Garrett, Lawrence D.; Weyermann, Dale L, tech. eds. 1990. SAMM: a southeast Alaska multiresource model. Gen. Tech. Rep. PNW-GTR-255. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 109 p.

The adaptive environmental assessment method was used by an interdisciplinary team of forest specialists to gain an understanding of resource interactions and tradeoffs resulting from forest management activities in southeast Alaska. A forest multiresource projection model was developed in the process. The multiresource model, “SAMM,” is capable of characterizing and displaying interactions of four major resources over a 150-year rotation: timber, wildlife (Sitka black-tailed deer), hydrology (streams), and fisheries (anadromous). SAMM is in a prototype stage of development; final testing is required before it can be used by managers for quantitative analysis. Sufficient development and evaluation has been done by the team of specialists to permit its use in qualitative assessments planning.

Keywords: Multiresource, forest management, systems, models, southeast Alaska, simulation.

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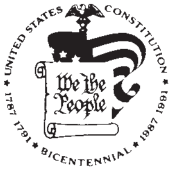

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