

ENVIRONMENTAL IMPACT ASSESSMENT MODELING AND LAND-USE PLANNING¹

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Abstract. Describes a computerized planning system useful for examining the physical, economic, and environmental consequences of alternative wildland use decisions. The system consists of a set of simulation models linked to a geographic data base by an information storage and retrieval subsystem. System structure is discussed in the context of an integrated system model developed to facilitate an evaluation of the environmental consequences of alternative land uses and manipulations at varying scales of space-time resolution. Uses to date suggest that the system is a valuable aid to land-use planners if they possess the information required to calibrate the models.

Additional keywords: System simulation, wildland management, computerized planning system, resource data base.

INTRODUCTION

Decisions affecting the nation's wildlands are being made at the federal, state, and local levels at an ever increasing pace. These decisions, often made on a piecemeal basis, result in the allocation of the nation's wildlands to a set of uses expected to satisfy current and future needs of society. In many instances, these land-use decisions have significant impacts on the economy, environment, society, and the land itself. Thus, closely related to the land allocation process are the consequences of the land-use decisions and specific management activities associated with a particular land use. Ideally, both aspects of the land-use planning process should be considered simultaneously; however, in practice the two are often treated independently. Consideration of these two factors has stimulated the development of comprehensive planning systems which encourage decision makers to adopt a holistic rather than an elemental approach to wildland use planning.

¹The research reported in this paper was funded by the National Science Foundation's Research Applied to National Needs Program through grant GI-34460.

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*In Proceedings of SAF Workshop on
Systems Analysis and Forest Resource
Management.*

The objectives of this paper are to (a) describe the structure of a computerized planning system useful for examining the physical, economic, and environmental consequences of wildland use decisions and accompanying manipulations of the forest ecosystem, and (b) discuss the characteristics of alternative system models capable of predicting the consequences of such decisions at differing scales of spatial and temporal resolution. The system consists of a set of simulation models linked to a geographic data base by an information storage and retrieval system. Thus, the system integrates decision modeling with data base management and design. The geographic data base and the simulation models have been developed using the Snohomish River basin as a test area. This basin of approximately 1.2 million acres is located on the west slope of the Cascade Mountains in western Washington. The forest lands within the study area are used for a multiplicity of uses and hence provide an ideal area for model development and validation.

OVERVIEW OF SVEN SYSTEM

The basic design criterion underlying the development of the Snohomish Valley Environmental Network (SVEN) was to construct a set of simulation models capable of being operated independently as well as linked together in a multi-resource system model. Each model describes a major component or subsystem of a managed forest ecosystem. While it was not feasible to model all facets of each selected subsystem, an attempt was made to include at least one example of each major model type. The major subsystems included in the study are (a) forest production, (b) outdoor recreation, (c) fish and wildlife, (d) forest insects, (e) meteorological, hydrologic, and atmospheric processes, and (f) information storage and retrieval. A very brief description of the models included within each of these subsystems follows.

The forest production subsystem is composed of three models. These are (a) timber production, (b) timber harvesting, and (c) forest residue reduction. These models complement each other in simulating the environmental, physical, and economic effects of alternative forest management practices. The timber production model consists of a set of growth functions used to simulate the growth of forest stands over time if managed according to a prescribed set of management practices. Included in the model are regeneration, fertilization, and thinning alternatives. The model is capable of handling either clearcutting or shelterwood harvest operations. The timber harvesting model reflects the harvesting of stands using several options such as tractor, helicopter, balloon, highlead, skyline, and mobile crane yarding systems. The harvesting model also includes the amount and cost of road construction, assuming different standards, and the use of buffer strips along streams. In addition to generating the volume of logging residue resulting from a harvest operation, the forest residue reduction model contains several options for disposing of residue. Options include broadcast burning, hand piling and burning, and mechanically chipping or crushing.

The primary objective of the recreation model is to predict the demand for outdoor recreation activities as a function of (a) socioeconomic and demographic variables, (b) dominant land use, and (c) land management decisions. A second objective is to simulate the resulting environmental impacts associated with these land uses. The procedure developed by Chicchetti, Davidson, and Seneca (1969) was adopted for the purpose of estimating the number of user days for each of 11 recreational activities. The overall approach was to predict the level of various recreational activities for a population unit given its socioeconomic characteristics and the availability of various recreational resources. The procedure was designed to predict recreational activities which are either area or site specific. In addition, the approach can be used to project future activity levels for a changing population and changing recreational resources. Once the number of user days for each of 11 activities are determined, the resulting environmental impacts are generated.

The wildlife model simulates the population dynamics of black-tail deer as influenced by land-use decisions, man-induced manipulations of the ecosystem, and recreational hunting pressure. Although attempted, it was not possible to develop a fisheries population dynamics model that could interface with the other SVEN models. This was primarily due to the extreme spatial and temporal requirements of a realistic fisheries model. Instead, an exhaustive summary of the published literature relating the effects of land use on aquatic resources has been compiled and made available in the form of an indexed information retrieval system.

A pest management model simulates the interrelationships between the population dynamics of the Douglas-fir bark beetle, an array of host material, and management control tactics. The model permits a large array of alternative control strategies to be evaluated. Presently, all impacts are evaluated in physical terms.

The main objective of the hydrologic model is to quantitatively simulate responses of the hydrologic system to manipulations of the forest ecosystem. Since a unit area yield prediction approach was adopted, the hydrologic model contains considerable flexibility in predicting mean monthly water discharge for variable size watersheds. Further, flow rates and water quality parameters can be measured at any point within a watershed once the contributing area is defined. In addition to predicting mean monthly runoff, the hydrologic model predicts the following water quality indices (a) suspended sediment, (b) water temperature, (c) dissolved nitrates, and (d) dissolved oxygen.

The objective of the atmospheric model is to provide quantitative estimates of pollutant concentrations resulting from emissions within the forest ecosystem. The forest management practice which most significantly affects air quality is burning forest residues for the reduction of fire hazard and the promotion of regeneration. Other sources of air pollution include wildfire and exhaust from motor vehicles. A mass

transfer or box model was selected as the most reasonable approach for determining the level of pollutants within the Snohomish River basin. Many atmospheric transport models are based on diffusion theory; however, diffusion type models were deemed infeasible since the mountainous terrain of the Snohomish basin and the nature of the pollution sources violate the underlying assumptions. The model focuses on how air quality standards would restrict forest management activities rather than how activities would influence air quality at a specific time during the year.

The information storage and retrieval subsystem links the resource data base (described below) and the simulation models discussed above. The information subsystem was designed to provide the capability of supporting the assessment of environmental impacts at various degrees of space-time resolution. The major purposes of the information subsystem are to (a) provide for efficient storage, retrieval and updating of information during execution of the multi-resource system model, (b) provide information to support model development, and (c) respond to queries requesting information in the form of maps, summaries, or listings.

A resource data base was developed to describe the resources of the Snohomish River basin. A cell size of 40 acres was selected to record the status of each cell in the basin. For convenience, the basin was subdivided into 20 major watersheds which provide the primary key when locating any specific cell. Each cell can be accessed by referring to its watershed identification, township, range, section, and cell number, or by referring to the x-y coordinates of the particular cell. Five files make up the resource data base. A cell file contains information which describes the status of each cell within the basin. Currently 47 attributes are used to describe the contents of each of these cells. These attributes relate to either (a) cell identification, (b) physical description, (c) soils data, or (d) timber inventory. A stream file operates in conjunction with the cell file. This file contains locational and identifying information for each stream in the basin. The stream file provides the capability for routing water throughout each major watershed and hence provides one of the most unique features of the SVEN system. A user may trace waterflow both upstream and downstream and/or define the watershed for any point within the basin. Interaction between the cell and stream files allows models to determine the factors affecting the hydrology of any point in the basin. Currently only locational and identification information is contained in this file. Other attributes such as stream gradient, streambed gravel condition, flow histories, etc., may be easily added as the information becomes available. The soils file is the third file which makes up the resource data base. This is a static file which contains information on the soil resources of the Snohomish River basin. A history file is used in conjunction with the multi-resource system model to provide (a) watershed summaries of selected attributes, (b) history of manipulations occurring during the simulation, (c) economic and demographic trend data, and (d) recreation facilities information. A management file contains the

managerial decisions concerning land use and manipulations for any particular run of the multi-resource model. It is essentially a static working file which is constant during any cycle through the simulator. The cell, history, and management files provide the main linkages between the various individual models when interfaced in the context of the multi-resource system model.

The SVEN information subsystem was primarily designed to interface directly with the multi-resource system model thus permitting rapid and efficient updating of the resource data base over time. Further, it was designed to support the mathematical modeling of nonpoint sources of pollution arising from forest management activities and land use decisions. To best attain these objectives, the subsystem was developed as a set of separate functions which could be called upon by model programs or user written programs. A control language allowing for simple and direct inquiry of the resource data base was developed. This control language--called SVENESE--permits users unfamiliar with data formats and calling sequences to access and utilize the full power of the SVEN system and resource data base. The SVENESE language only manipulates the SVEN cell file. The information handling capabilities of the SVEN system consist of the abilities to (a) access and update the attributes of a specified cell in a random or sequential fashion, (b) extract a set of cells each of which satisfy a given condition, (c) dump a cell set in numeric or English form, (d) summarize an attribute over a cell set, (e) plot an attribute over a cell set in a particular plotting region (single character, shaded, or three dimensional options are available), (f) modify a cell set by providing a FORTRAN subprogram containing the modification instructions, (g) define macro SVENESE commands, and (h) insert FORTRAN instructions in line with SVENESE commands. A system diagram of the information subsystem is contained in Figure 1 and a listing of a sample SVENESE program is shown in Figure 2.

SVEN SYSTEM STRUCTURE

The preceding discussion has briefly highlighted the essential components of the SVEN system. More detailed information on each subsystem may be found in Bare and Schreuder (1974), Ryan, Morison, and Bethel (1974), Bare and Cook (1974), Bare, Ryan, and Schreuder (1974), Atkinson, Bare, Schreuder, and Stenzel (1974), and the SVEN Annual Report (1974). Extensive documentation concerning each model is currently being prepared and will be available in monograph form early next year. The remaining portion of this paper will be devoted to a discussion of alternative frameworks for combining the simulation models into a multi-resource system model.

In designing a system that interfaces land-use planning with environmental impact generation and assessment, one is immediately confronted with multiple and conflicting objectives. Wildland use planning decisions are typically made for large land areas. Such decisions are normally

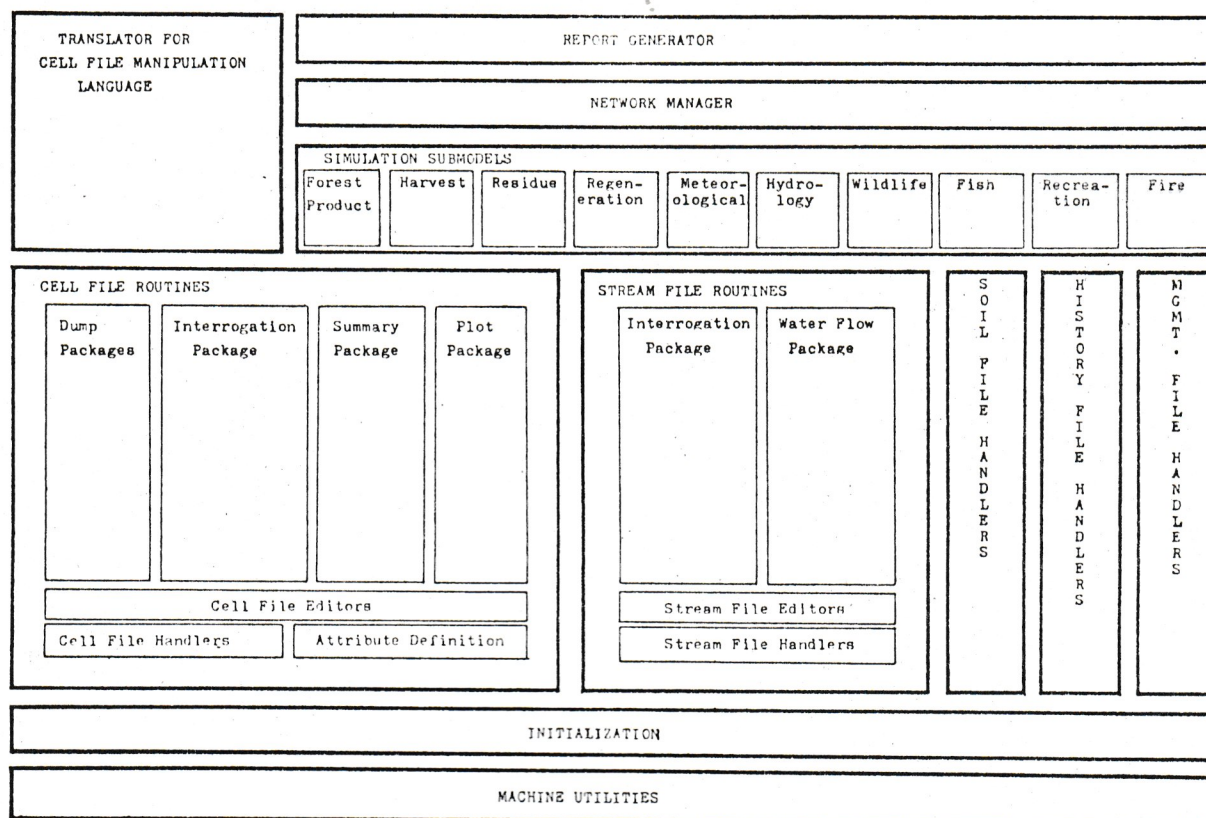


Figure 1. System diagram of SVEN information subsystem

based on analyses of impacts at very low levels of spatial resolution over long planning horizons. Conversely, environmental impact assessments require a much finer level of resolution and analysis. To design a system capable of handling both types of planning is a challenge and perhaps an impossibility. In an effort to resolve this dilemma, a tabulation of the significant characteristics of three alternative system models which possess the capability of supporting these two types of planning are shown in Table 1. The SVEN system incorporates alternatives I and II, labeled the single-cycle and multi-cycle models, respectively.

The SVEN single-cycle system model was designed to accommodate environmental impact generation and assessment associated with wildland use decisions and manipulations. This model utilizes the finest spatial and temporal resolution of the SVEN resource data base and models. While the design permits the in-place evaluation of management decisions, the large volume of location-specific input prohibits the use of the model for strategic planning which extends over a long planning horizon. To facilitate this latter level of planning, a more aggregate level of model is required. The multi-cycle model has been conceived to handle this level of planning. Cells are aggregated into resource management


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1  /*****
2  /*      A SAMPLE PROGRAM WRITTEN IN SVENESE      */
3  /*      THIS PARTICULAR PROGRAM MONITORS ASPECTS OF THE MID FORK SNOQUALMIE WATERSHED AS ALL THE HIGH YIELD DOUGLAS FIR IS HARVESTED. */
4  /*      LMIE WATERSHED AS ALL THE HIGH YIELD DOUGLAS FIR IS HARVESTED. */
5  /*****
6  /*      BEFORE      */
7  /*      PLOT AND SUMMARIZE FOREST TYPE IN THE MID FORK SNOQUALMIE WATERSHED. */
8  /*      ED.      */
9  /*****
10 PLOT (ELEVATION,FORESTTYPE) OF REGION(14) IN SHED 14 ;
11 SET PLOTOPTIONS FOR ELEVATION TO (CHARACTER,0,1000,100,
12     X.0123456789%) ;
13 PLOT (ELEVATION) OF REGION(14) IN SHED 14 ;
14 SUMMARIZE (FORESTTYPE) OVER REGION (14);
15 /*****
16 /*      SUBSET EXTRACTION      */
17 /*      DEFINE THE SET OF CELLS OF INTEREST      */
18 /*****
19 TAPE 10 = REGION (14) SATISFYING
20     FORESTTYPE IS DOUGLASFIR AND
21     TIMBERAGE ABOVE 150 AND
22     NOT (SLOPE IS VERYSTEEP) ;
23 JUMP TAPE 10 IN ENGLISH ;
24 PLOT (VOLUME) OF TAPE 10 IN SHED 14;
25 /*****
26 /*      SET ALL THE DOUGLAS FIR CELLS IN THIS SUBSET TO ZERO      */
27 /*      AND REFLECT THE CHANGE IN THE CELLFILE      */
28 /*****
29 CELLFILE = TAPE 10 PROCESSED BY HARVSTR;
30 /*****
31 /*      AFTER      */
32 /*      PLOT AND SUMMARIZE FOREST TYPE IN THE MID FORK SNOQUALMIE WATERSHED. */
33 /*      ED.      */
34 /*****
35 PLOT (FORESTTYPE) OF REGION (14) IN SHED 14;
36 SUMMARIZE (FORESTTYPE) OVER REGION (14) .

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Figure 2. Listing of sample SVENESE program.

Table 1. Characteristics of alternative system simulation models

Characteristic	I (Single- cycle)	II (Multi- cycle)	III
Spatial resolution (decisions)	Cell-stream	Resource management unit	Resource management unit
Spatial resolution (impact assessments)	Cell-stream	Resource management unit	Cell-stream
Temporal resolution	Monthly- annually	Multi-year	Multi-year
Primary planning level	Operational	Strategic	Tactical
Land inventory requirements	In-place	Aggregate	In-place
Location mechanism	External	External	Internal

units with impacts evaluated at this latter level of resolution. A prototype version of this system has been used to aid the development of an activity plan for the I-90 Corridor Study in the Mount Baker-Snoqualmie National Forest in western Washington. The model has also been applied to the middle fork of the Snoqualmie River watershed (Bare, Ryan, and Schreuder 1974). Currently, work is under way to extend and generalize this prototype. Because of its aggregate nature, the model is restricted in its ability to monitor site-specific environmental impacts occurring over short time periods. However, since location-specific decisions are not required, it does facilitate the evaluation of impacts over a longer planning horizon. A third alternative is also described in Table 1. Although not under development by the SVEN project, this system accepts management decisions on an aggregate resource management unit basis but carries out the simulation of environmental impacts at the cell-stream level of resolution. Such a system requires an internalized decision rule for allocating activities to specific cells. The difficulty with such a model is that each potential user of the system might wish to redefine these allocation rules, thus requiring a tailor-made system for each potential user. Since our objective was to develop a general methodology, action on this alternative system design was deferred.

DESIGN FEATURES OF SVEN SINGLE-CYCLE MODEL

For purposes of system design and integration, the subsystem models were grouped into a hierarchy involving five levels. Each level contains models which are similar in their primary function within the single-cycle multi-resource system model. In essence, these levels depict the precedence relationships for the execution of the various simulation models. The five levels and their order of execution are illustrated in Figure 3. Three driving systems are employed in the single-cycle system. As shown in Figure 4, these are (a) the biological process of timber growth, (b) the meteorological process of weather generation, and (c) the managerial process of intervention in the form of land-use decisions and management practices. The box labeled "Management Decisions" shown in Figure 4 represents the reading and formatting of management decisions for each active watershed during a given cycle of the simulator. A copy of the cell file data for each cell affected by a manipulation is also copied to the management file. The meteorology model generates the temperature and precipitation data for each of ten weather stations within the basin. The forest production model grows timber on the cells supporting forest stands. A summary of certain statistics for each active watershed is compiled and written on the history file for later use by other models.

As shown in Figure 4, the three driving systems may execute simultaneously or in any random order. Inputs to these three models originate from the cell file (CF) and the history file (HF). The information subsystem provides the linkage between the files and the various models. Therefore it controls the passage of information from a file to a model, as well as the subsequent update of a file to reflect the actions of a particular model. This approach for interfacing the models provides a flexible and powerful framework with considerable upwards compatibility. Since the models themselves do not directly interface, additional models can be added with modest effort. We feel that this is an important step in the development of a general land-use modeling methodology.

The second level of the SVEN single-cycle simulation model incorporates the man-induced manipulations and land-use decisions imposed on the ecosystem. As shown in Figure 5, four models are included at this level. These are (a) timber harvesting, (b) residue reduction, (c) forest regeneration, and (d) outdoor recreation. These models communicate indirectly with the driving systems via the management (MF), cell (CF), and history (HF) files. The information flow is again controlled by the information subsystem. The harvesting model implements the logging, thinning, fertilization, road building, and buffer strip decisions. These decisions along with a copy of the initial cell file are read from the management file. The timber attributes of affected cells, new road information, and the volume of forest residue are updated on the cell file. The history file is updated to reflect changes in the watershed summary for each active watershed. The residue model implements the decisions affecting the disposition of forest residues. The

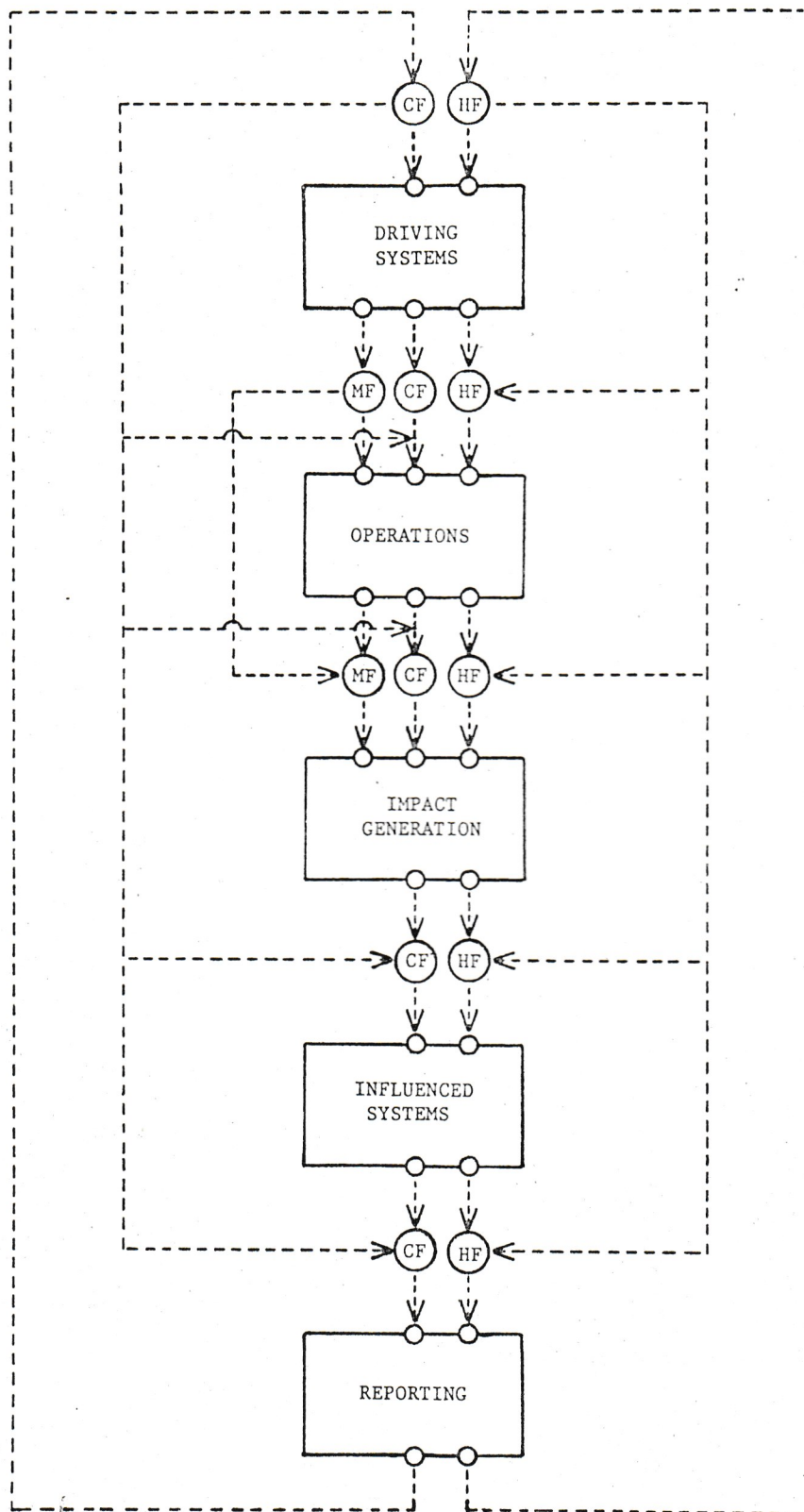


Figure 3. Design of SVEN single-cycle model.

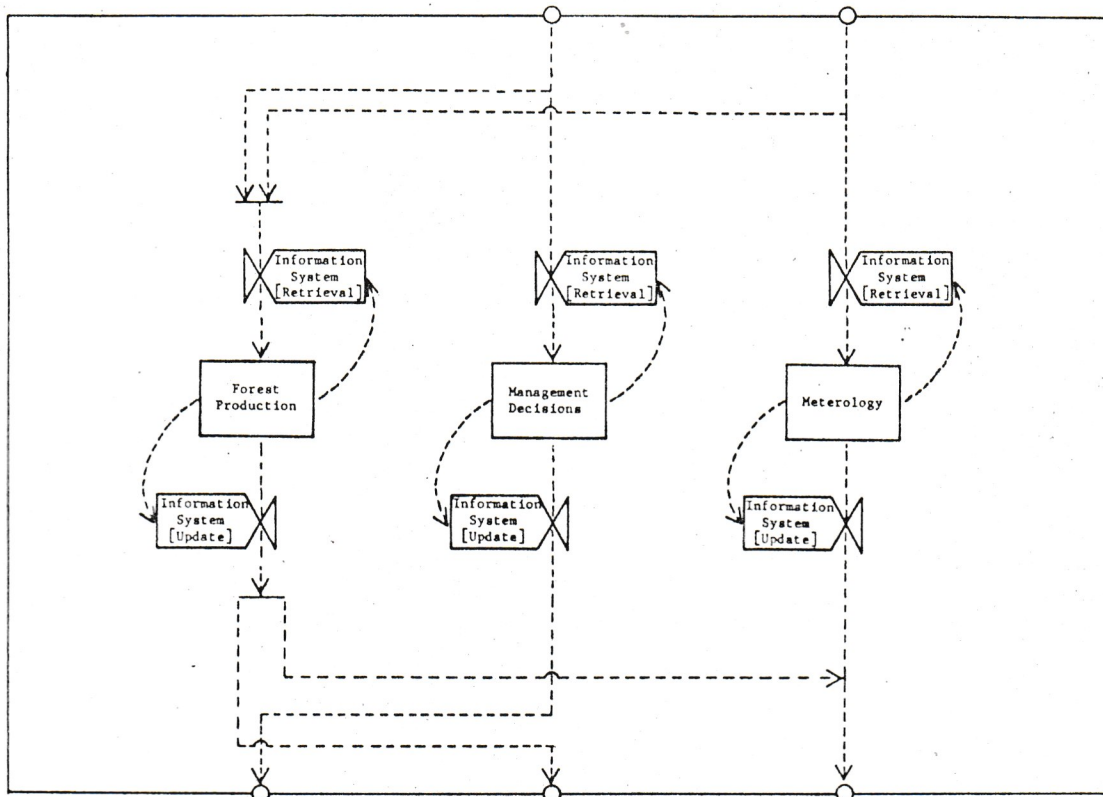


Figure 4. Driving systems of single-cycle model.

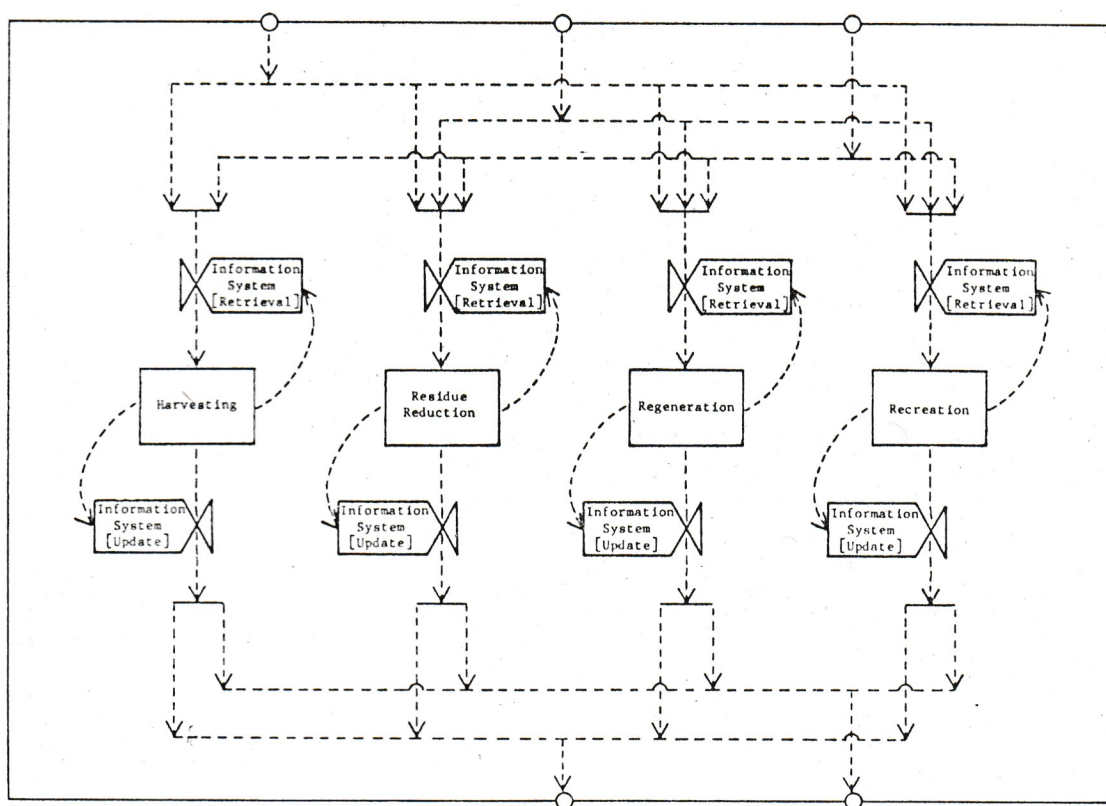


Figure 5. Operations in single-cycle model.

cell file is updated to reflect changes in residue volumes as affected by these decisions. The regeneration model implements the method of regenerating previously harvested stands and updates the cell and history files to reflect these decisions. The recreation model computes the demand for each of 11 recreational activities and the subsequent generation of pollutants. The cell and history files are updated to reflect changes resulting from recreation-oriented land-use decisions.

The third level within the single-cycle model contains models which simulate the various environmental impacts which result as a consequence of the operations carried out at the second level. A record of all operations within a given cycle are maintained and summarized on the history file. Thus, as shown in Figure 6, the atmospheric and hydrologic models obtain their inputs solely from this file. The hydrology model computes monthly flows for each desired point in the basin as well as the water quality statistics at these same points. The atmospheric model computes the probability of exceeding air quality standards for a given average daily emission. Emissions in the form of particulates are generated by the burning of forest residue. The forest insect model requires pest control decisions from the management file and summaries of the availability of host material from the history file. Changes in the status of host material and beetle populations are reflected on the cell and history files, respectively.

The fourth level of the SVEN single-cycle simulation model represents those subsystems being modeled as passive or influenced systems. Only the wildlife model is active at this level. As illustrated in Figure 7, this model interfaces with the recreation and regeneration models via the cell and history files. Recreational hunting pressure affects the mortality rate of the deer herd and the population of the deer herd affects regeneration success within the regeneration model. The effects of these decisions are reflected on the cell and history files, respectively. Also shown in Figure 7 is the fisheries subsystem. The effect of simulated manipulations and land-use decisions can be evaluated by consulting the indexed retrieval system. No direct link exists between this subsystem and the single-cycle model.

The fifth level of the system includes the reporting of results for a given cycle of the simulator. This system depicted in Figure 8 produces summaries, listings, and maps of all activities and impacts undertaken during the previous cycle. Summaries, listings, and/or plots showing the status of the basin at the conclusion of a cycle may also be requested. In addition, a time history for any desired output variable from any past cycle may be retrieved and displayed. This provides the capability of following the level of impacts and activities over time. Upon completion of a cycle, the updated cell and history files are retained for future use during the next cycle. The management file is destroyed as new decisions for the next cycle are read and formatted for execution.

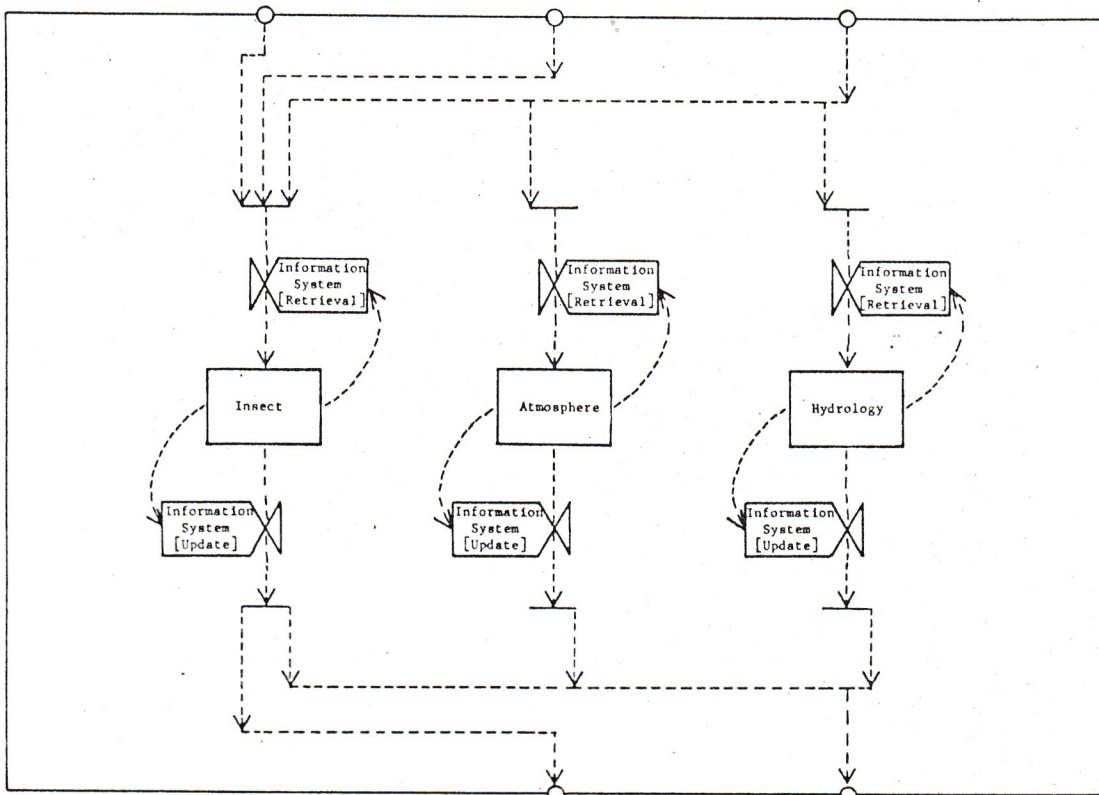


Figure 6. Impact generations systems in single-cycle model.

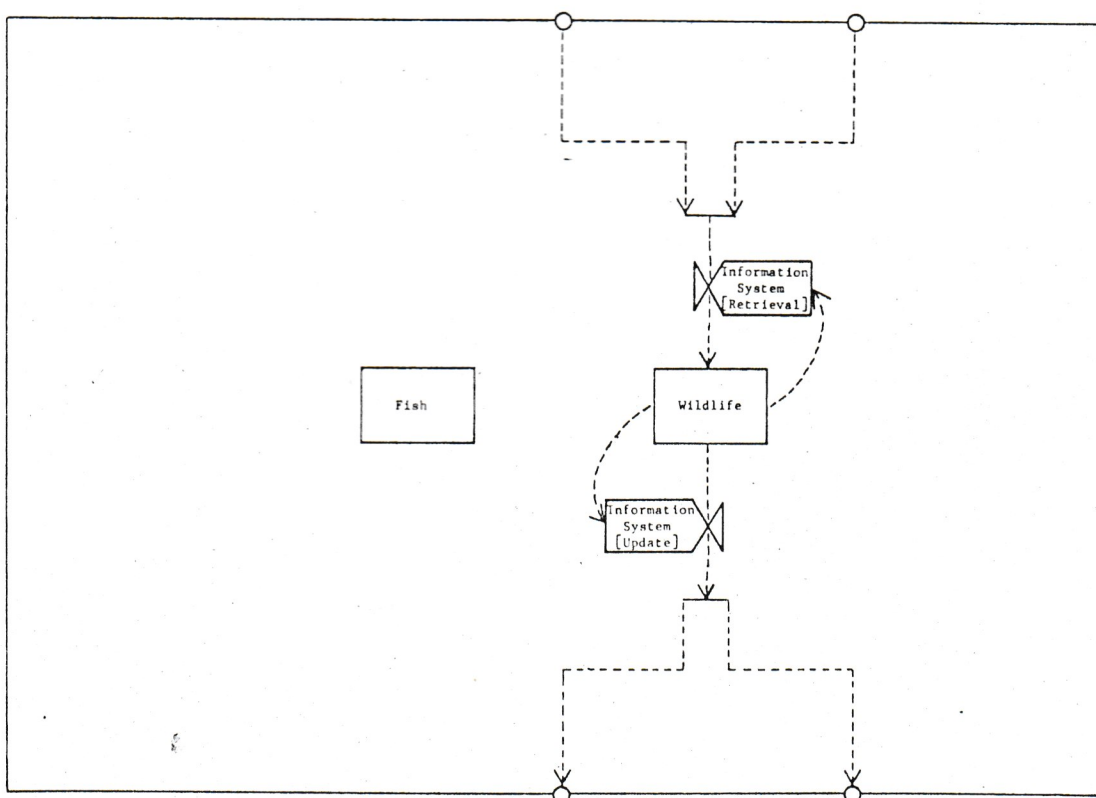


Figure 7. Influenced systems in single-cycle model.

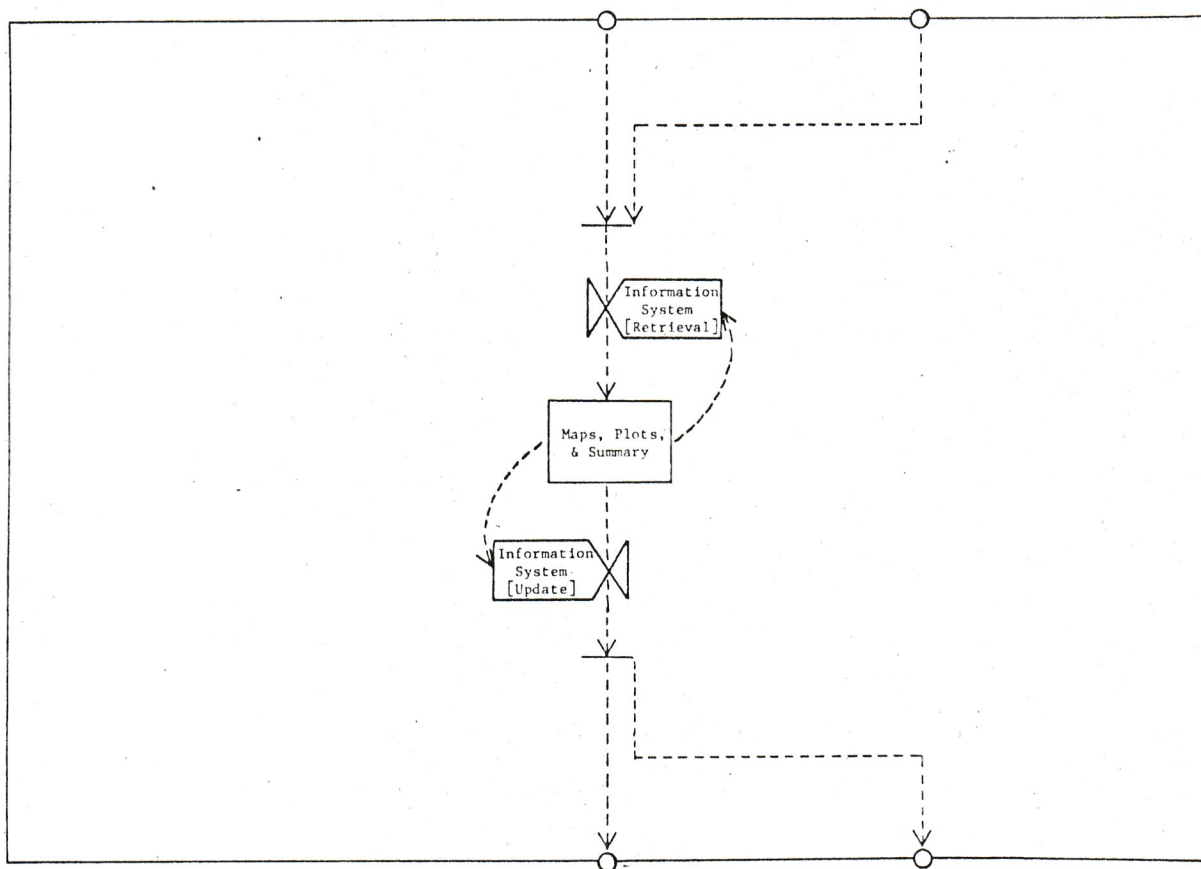


Figure 8. Reporting system in single-cycle model.

DISCUSSION AND SUMMARY

A computerized planning system capable of assisting wildland managers evaluate the physical, economic, and environmental consequences of alternative land-use decisions and management activities has been developed. The system consists of a set of simulation models directly linked to an in-place resource data base by an information subsystem. Models were developed for timber growth and yield, timber harvesting, forest residue reduction, outdoor recreation demand forecasts, black-tail deer and Douglas-fir bark beetle population dynamics, water yields and quality, atmospheric emissions, and meteorological conditions. An information storage and retrieval subsystem controlled by a user-oriented language links the geographic data base to the models. Thus, it updates the data base to reflect the actions of the models, and it passes information between the different models as they simulate the consequences of managerial decisions.

Characteristics of three alternative ways of linking the individual models together in the form of multi-resource system models were presented. Each configuration is capable of assisting wildland managers evaluate the consequences of their land-use decisions at different scales of spatial and temporal resolution. Further, each configuration is designed to aid managers working at different levels within the planning hierarchy. Therefore, the attractiveness of any one of these designs varies in relation to the objectives of the manager.

The design features of one of these alternatives--the single-cycle model--were discussed. The essential features were (a) subsystem models grouped into a hierarchy consisting of five levels, (b) models grouped at any given level execute simultaneously or in any random order, (c) five files of information make up the resource data base and provide information required by the different models, (d) models at the same level or different levels are not directly linked together; instead the information subsystem controls the passage of information between a model and a file stored on the resource data base, (e) due to the modular nature of the system, models can be added or deleted with a minimum amount of effort, and (f) the system model is very efficient--in a computer sense--since each model is represented by a separate program which executes independently within a given level of the system hierarchy.

Two multi-resource system models are currently under development. Documentation concerning both of these models will be available early next year. Prototype versions of these models have been developed and tested within the Snohomish River basin. Results indicate that the models do facilitate the evaluation of impacts of alternative land use plans if the user agency possesses the necessary input information. Required information consists of (a) in-place inventory data necessary to initialize the resource data base, and (b) empirical response data necessary to calibrate the subsystem models. Experience to date suggests that many wildland management agencies do not possess these two types of

information. In fact, the lack of reliable information was also a major problem throughout the development of the SVEN project. Nevertheless, utilizing the best available information, the system being developed should facilitate wildland use planning.

LITERATURE CITED

- Atkinson, W., B. Bare, G. Schreuder, and G. Stenzel. 1974. Evaluating environmental impacts from forest harvesting operations: A simulation approach. Pacific Logging Congress Loggers Handbook, Vol. 34, various pagination.
- Bare, B. and G. Schreuder. 1974. Wildland management and environmental quality: A multiple resource simulation model. Proceedings of a Conference on Nonpoint Pollution in Forest Resources Management, College of Forest Resources, University of Washington, Seattle, p. 44-52.
- Bare, B. and J. Cook. 1974. A multiple resource wildlands information system for environmental impact assessment modeling. Proceedings of S.A.F. Workshop on Inventory Design and Analysis, Fort Collins, Colorado, p. 220-245.
- Bare, B., J. Ryan, and G. Schreuder. 1974. Environmental effects of forest land uses: A multi-resource simulation-based approach. In Journal of Environmental Systems, Vol. 4, No. 4, p. 309-340.
- Chicchetti, C., J. Seneca, and P. Davidson. 1969. The demand and supply of outdoor recreation. Bureau of Economic Research, Rutgers University, New Brunswick, New Jersey.
- Ryan, J., I. Morison, and J. Bethel. 1974. Ecosystem modeling of a forested river basin. Water Resources Bulletin, Vol. 10, No. 4, p. 703-710.
- Snohomish Valley Environmental Network. 1974. Annual report for the period June 1, 1972, to May 31, 1974. College of Forest Resources, University of Washington, Seattle, 84 p.