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EXPERIENCES WITH THE DESIGN AND APPLICATION OF WILDLAND-USE MODELS[1]

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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. Applications of the system are briefly discussed. While the models performed satisfactorily it is clear that decision-makers consider much more than that which can ever be incorporated into a model structure at the present. Further, results demonstrate that often there is little incentive for decision makers to utilize models unless they are tailor made, easy to use and compatible with existing institutional patterns.

1. Introduction

Managers of the nation's wildlands are under pressure to satisfy the growing desires of the American people from a static or shrinking land base. A growing population, increased leisure time and mobility and an awareness about the environment combine to create a source of pressure which accompanies any major land use decision. For example, certain segments of society advocate massive land withdrawals for wilderness or national parks to promote the preservation of the native flora, fauna and naturally endowed beauty for future generations. Others promote increased utilization and development of our wildlands for commodity resources such as timber, forage and minerals. Both groups act in a manner consistent with their perception of the best use of the resources to meet current and projected demands. With much at stake, conflicts are inevitable. This results in pressure being applied to the nation's wildlands managers in an effort to resolve the conflict in the most satisfactory and expeditious manner.

Decisions affecting the nation's wildlands are being made at all levels of government at an increasing pace. These decisions, often made in a fragmentary manner, result in the allocation of the nation's wildlands to a set of uses expected to satisfy societies needs. 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 particular land use programs. Ideally, both aspects of the land-use planning process should be considered simultaneously; however, in practice the two are often treated independently.

Because wildland systems are complex aggregations of physical, ecological, cultural and political subsystems, comprehensive policy analysis and systematic long-range planning are necessary precursors of effective wildland management. As with other complex problems facing society, resource managers have turned to the techniques and procedures of systems analysis and operations research in an effort to provide a sound framework for policy and decision analysis. As shown by Bare and Schreuder (1976) operations research tools have been successfully utilized to aid decision-makers in a wide variety of resource management situations. Consequently, public and private resource organizations have greatly expanded their efforts and capabilities in this direction. Nonetheless, substantial progress remains to be made.

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2. Objectives

Despite the efforts of many analysts, the lack of an adequate supply of wildland use planning models still prevails. While countless single discipline and/or single resource models exist, multi-resource system models are almost nonexistent. For example, if one is interested in timber management or wildlife management as separate resources - numerous models are available. However, if one is interested in examining timber and and wildlife management problems or timber, wildlife and hydrology problems simultaneously, very few, if any, models are available.

Partially in recognition of this fact, the National Science Foundation, engaged with the College of Forest Resources, University of Washington to develop a comprehensive methodology for evaluating the physical, economic and environmental consequences of alternative wildland use decisions and attendant manipulations of a forest ecosystem. Both the land use allocation and impact assessment aspects of the wildland management problem are included in this project.

The underlying charge of the research team was to develop a multi-resource planning system which could be used by policy analysts, as well as middle managers, to evaluate alternative wildland management programs and their subsequent impacts. Specifically the research team was to develop a system which: (a) utilized existing knowledge and information, (b) was capable of handling land areas as large as several hundred thousand acres, (c) could monitor non-point sources of pollution, (d) could dynamically reflect the state of the forest ecosystem over time subjected to management, (e) was capable of representing various levels of space-time resolution and (f) was easy to use and interpret.

The methodology adopted by the research team to meet these objectives is embodied within a set of computer simulation models which are directly linked to a geographic data base. This design permits the in-place evaluation of alternative land-uses at various scales of spatial resolution. Further, the simulation models may be operated independently, or they may be interfaced together in the form of a system simulation model. Simulation was selected as the appropriate methodology primarily because of its flexibility in meeting the above set of objectives. Optimizing models were rejected because concise statements of goals and objectives governing our wildlands are usually nonexistent. Without such statements it's not possible to design an optimal land management program. However, in the absence of such a clear goal structure, simulation may prove useful as a means for examining alternatives to gain an understanding of the magnitude of the trade-offs.

Each model included in the system 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. Before describing the application of these models to some actual decision-making situations, a brief overview of the system of models will be presented.

3. Overview of Project Models

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 timber harvesting model reflects the harvesting of stands using several options such as tractor, helicopter, balloon, highlead, skyline, and mobile crane yarding systems. 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, piling and burning, and mechanically chipping.

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 selected environmental impacts associated with these land uses. The model provides an estimate of the number of user days for each of 11 recreational activities. These estimates depend on the socioeconomic characteristics of the target population and the availability of various recreational resources. Both area and site specific activities are included. Once the number of user days for each of 11 activities are determined, selected 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 hydrologic model simulates responses of the hydrologic system to manipulations of the forest ecosystem. A unit area yield prediction approach was adopted, to allow 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 atmospheric model provides 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. Emission factors for particulates, hydrocarbons and carbon monoxide are generated for the burning of forest residues.

The information storage and retrieval subsystem links the resource data base (described below) and the simulation models. The information subsystem was designed to provide the capability of supporting the assessment of environmental impacts at various degrees of space-time resolution. 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 permits users unfamiliar with data formats and calling sequences to access and utilize the full power of the system and resource data base.

A resource data base was developed to describe the resources of the Snohomish River basin - the study area. A cell size of 40 acres was selected to record the status of each cell in the basin. The cell file presently contains 47 attributes to describe the contents of each cell. A stream file operating in conjunction with the cell file contains locational and identifying information for each stream in the basin. The stream file provides the capability for routing water throughout the basin. 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.

4. System Design Considerations

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 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. Adding to the difficulty is the necessity to interface the various single discipline models so that an assessment of the impact of a decision can be made. Differences in the temporal resolution of the individual models also produces complications. Lastly, the need to examine non-point sources of pollution requires the ability to handle the in-place evaluation of land management practices. This necessitates that a geographic data base work in conjunction with the models.

There are many ways to assemble a multi-resource system model using the previously discussed individual simulation models as building blocks. One strategy is to directly link each stand-alone model by developing a master or executive routine. A second strategy is to disassemble each model into its component parts and then reassemble all models together in the form of a single system model. Both approaches have been tried during the course of our project. We have found that the latter strategy is preferred even though it is very time consuming, expensive and difficult. Other factors such as level of spatial and temporal resolution, length of the planning horizon and land inventory requirements also influence the type of interface used to link the stand-alone models.

The important characteristics of three schemes for building a multi-resource system model are depicted in Table 1. Alternative I

Table 1. Characteristics of alternative system simulation models

Characteristic	I	II	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	External

is designed to accommodate environmental impact generation and assessment associated with wildland use decisions and manipulations. This model utilizes the finest spatial and temporal resolution possible. 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.

Alternative II has been conceived to handle this level of planning. Cells are aggregated into resource management units with impacts evaluated at this latter level of resolution. A prototype version of this system (discussed below) 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). 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. 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.

A fourth alternative could be added if resource management units were further aggregated into watersheds. At even lower levels of spatial resolution, watersheds could be combined into river basins to facilitate the simulation of regional impacts. However, as the size of the response unit increases the ability to adequately monitor site-specific environmental impacts decreases. Each analyst must use judgement when rationalizing this trade-off.

5. Assessment of Applications

Some of the models described above have already been used by resource management agencies to aid the solution of wildland management problems in western Washington. Presently the Washington State Department of Natural Resources (DNR) is undertaking an evaluation of the models for possible use on State owned timberlands. Significant alterations in the linkage between the models and the data base will be necessary before the DNR can use the system. When completed, this will represent the most complete utilization envisioned at this time.

The DNR hired one of the modelers who helped develop the system in an effort to insure a smooth transfer of technology from the University to the agency. In addition to providing an easy interface between research and management this promotes the application of the models to real-life problems. Without this there is little incentive for either group to worry about application of the models.

The first application to be reviewed involves the use of the timber production, harvesting, hydrology and resource information subsystems in a watershed just east of Seattle in the Cascade Mountains. The Mount Baker-Snoqualmie National Forest was interested in preparing an activity plan and environmental analysis in the I-90 corridor. This area, which is traversed by Interstate 90 as it winds its way up the western slopes of the Cascades from North Bend to Snoqualmie Summit is of particular concern because it is an area of high timber values, heavy recreation use, rough terrain and high watershed values. Because of the area's sensitivity, the Forest Service was anxious to critically examine all feasible alternative management plans for the area.

An alternative II-type model was used to examine management alternatives submitted by the Forest Service. Because of the short time involved in the study, the University performed all of the computer analyses while the Forest Service developed the data baseand the alternatives to be examined. Very few changes in the original model were requested. Our job was finished after we provided the Forest Service with maps and computer output from the various simulation runs. They then interpreted and incorporated the results into the final plan that was eventually drawn up for the area. Interested user groups were also involved in the planning process, but did not contact us directly. While the model results did not dictate the final plan, they were used to confirm earlier suspicions concerning which type of management to perform in the area.

Overall, both parties involved felt the project was successful. We learned how managers go about planning and they learned how our models and information system performed on the job. However, it is doubtful if the project would have succeeded in the time allotted had we not been involved in actually doing the computer analysis.

The second application concerns the utilization of recreation subsystem. The first attempted application came about as a result of three dam projects contemplated by the U.S. Corps of Engineers. The main objective of these dams was to provide better flood control in the Middle Fork of the Snoqualmie River. This became especially urgent after the disastrous December 1975 floods. In addition to providing flood control, the dams were to create a series of reservoirs. King County was interested in purchasing and developing land in the general area affected by the dams to provide additional recreation opportunities. King County and the State of Washington were also interested in achieving some semblance of land-use planning in the area which was being subjected to heavy land speculation and development pressures. Finally, public sentiment was about evenly split between advocates and opponents of the dams with both groups arguing their case rather vehemently.

As a result a committee was set up by the governor of the State of Washington to provide an unbiased assessment of the pros and cons of the proposed dams. The members came from the counties of King and Snohomish, the Corps of Engineers, the Interagency Committee for Outdoor Recreation, the Parks and Recreation Commission, and representatives from citizens groups. Since there appeared to be relatively little disagreement on the desirability of flood control, the committee focused its attention on the potential impacts of the dams on a wide variety of recreation activities.

The Recreation Subsystem seemed to be ideally suited to evaluate the recreation use of the area with and without the proposed dams as well as the impact of proposed land-use alternatives, including the development of additional recreational facilities. A contract was signed between the University and the different parties involved to use the subsystem in this way. As a result a large number of computer runs were made and the resulting outputs were used to evaluate the alternatives suggested. To this extent the subsystem was "used." However, the user parties only provided inputs and then digested the outputs. They did not attempt to understand, change or run the model. Thus they obtained only superficial familiarity with its potential. This in turn was largely due to the extreme time constraint they were under to complete the various evaluations and report back to the Governor. Also, most of the committee members were heavily involved in their own work and the committee assignment constituted an overload. Not withstanding this, a considerable amount of work was performed by these people. Finally, and perhaps most importantly, the subsystem was not constructed with the particular objectives of this application in mind and as a result was not altogether appropriate. Ideally, time and effort should have been expended to make it more closely suit the objectives of the project.

Another application of the recreation subsystem is much more elaborate and extends over a much longer time period than that discussed above. The Interagency Committee for Outdoor Recreation requires recreation use projections through the year 2000:

(a) To appropriate and allocate funds to counties for the purchase, development, management and maintenance of recreational facilities.

(b) To satisfy federal requirements in order to qualify for a large number of federal funds and matching monies.

Thus they are interested in acquiring a model similar to the recreation model which operates on a county-by-county basis. Presently, the recreation subsystem is a regional model which has the capability of generating recreation usage in the Snohomish River Basin as a result of a variety of land use, management and facility capacity decisions and a large number of socio-economic variables. The model is presently being expanded state-wide on a county-by-county basis under a 2-year grant to the University with heavy personnel involvement from the Interagency Committee. It involves a survey of recreation participation, an inventory of all existing recreational facilities (by county) and a reestimation of the coefficients of the original recreation model as well as a drastic simplification of the system. Since the Committee assigned one of its personnel specifically to this project some degree of success in the acceptance and application of the (modified) recreational subsystem is almost assured. In fact, an effort is under way not only to modify the original model from a regional to a county level but also to expand it to the three-state area of Oregon, Washington and Idaho.

Another application involves the work of a private consulting firm on the West Coast. This firm hired one of our modelers to aid them in applying some of our models to problems of their clients. This is a medium of information exchange often recommended as the most efficient means of transferring knowledge from the research community to the real-world. It is too early for us to speculate on the success or failure of the present endeavor. Further, we hesitate to make any general statements concerning the efficiency of this approach of technology transfer.

6. 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 suer-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.

Applications to date have generally been successful. However, most users have been more interested in securing quick answers to their problems than in trying to thoroughly understand the model being placed at their disposal. Thus, it is doubtful if the goal of technology transfer is being accomplished. Further, decision-makers run the risk of adopting models that are not appropriate to their needs in their quest for rapid solutions to their problems. Decision-makers must also recognize that many important non-quantifiable factors are omitted from most models. That is, public sentiment, political pressures, institutional constraints, etc. are important elements that are usually omitted from formal models. The decision-maker must recognize this and interpret model results accordingly.

Our experience also indicates that most decision-makers will only consider using a model if it is readily available, tailor made and easy to use. There is little incentive to use a model if extensive training is required. Again, the time element referred to above is the critical variable. The challenge for modelers is to develop comprehensive models which can be tailor-made in very short time spans.

7. Literature Cited

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