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The Genesis of FORPLAN: A Historical and Analytical Review of Forest Service Planning Models

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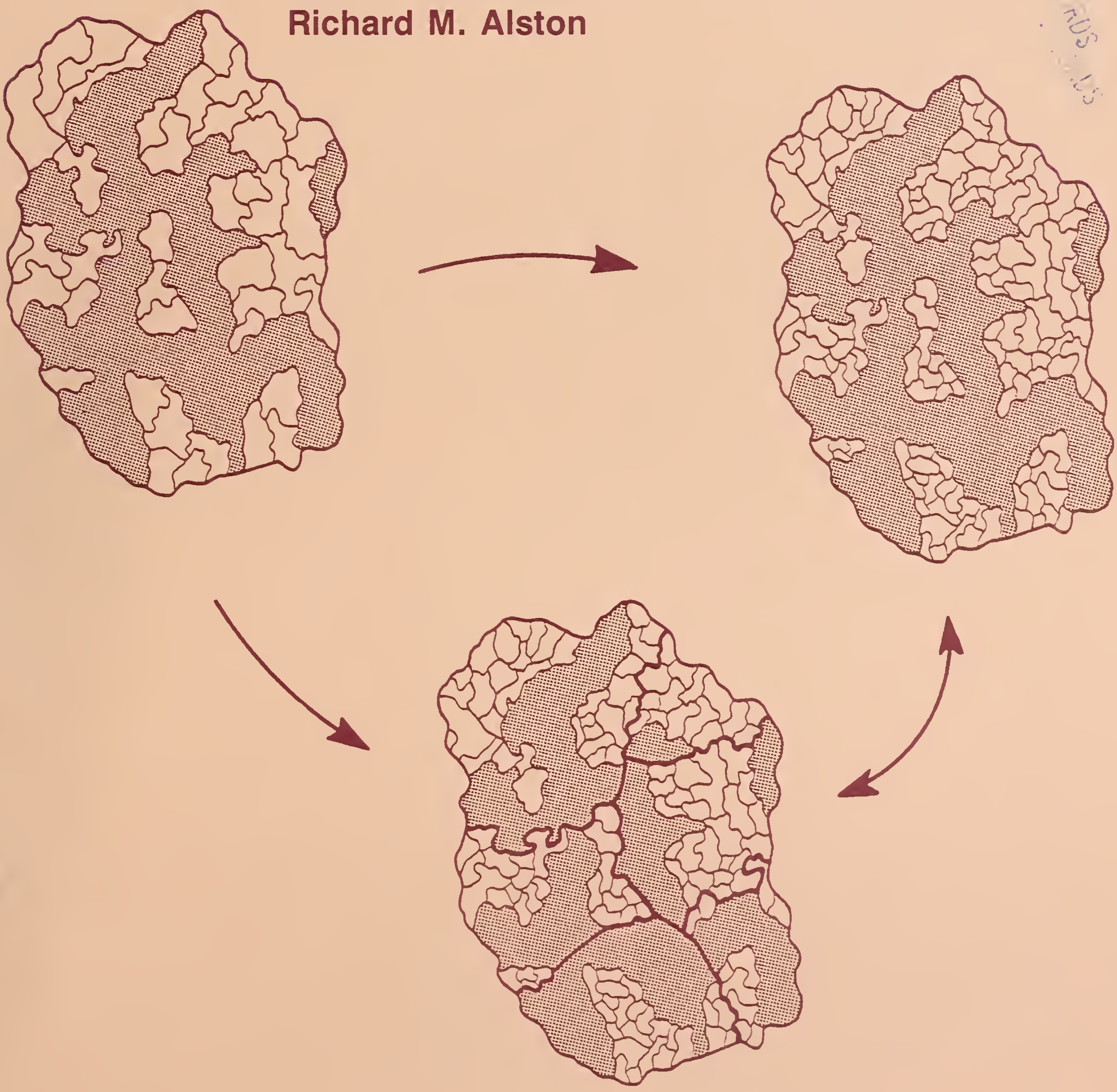

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K. Norman Johnson is, as a look at the references section will confirm, the most important source of information on many aspects of the evolutionary processes described, and the authors have relied on several of his unpublished or otherwise difficult to obtain papers. The tireless efforts of Norm Johnson and his dedicated Forest Service coworkers Tom Stuart (Lolo National Forest, then Land Management Planning, Fort Collins, CO; now Sperry Univac, Minneapolis, MN) and Sarah Crim (Land Management Planning, Fort Collins; now Timber Management, Pacific Northwest Region) in developing many of the concepts discussed herein made this paper possible. Assessing the significance of their work in a historical context made the paper necessary. The importance of the early work by Daniel Navon, especially the development of Timber RAM on which foundation much rests, is acknowledged by all. Larry Davis, currently Professor of Forest Management, University of California, Berkeley, was the Department Chairman of Forestry at USU during the early stages of Johnson's work. We drew on his intimate knowledge of the historical evolution of planning models and his expert advice on several technical aspects of our subject. As this work proceeded Dennis Schweitzer, Land Management Planning in the Washington Office of the Forest Service, suggested avenues of additional research that significantly improved the final product. To these and the many reviewers who influenced this endeavor the authors say "thanks" and absolve them for errors of omission and commission.

RESEARCH SUMMARY

The art of forest management planning in the Forest Service, U.S. Department of Agriculture, has evolved at a fever pitch pace in the past three decades. The most important changes that influenced planning include rising demands for all products of the forest, environmental activism, environmental laws, and land management legislation. The movement has been away from independent and functional analysis toward multidisciplinary, then integrated evaluation of all functions and alternative actions in the context of ecosystem management. Comprehensive changes in the tools of analysis were needed. From the late 1950's through the 1970's several computer models were developed, including the Timber Resource Allocation Method (Timber RAM), which was the foundation for subsequent improvements, and the Multiple Use-Sustained Yield Calculation Technique (MUSYC).

The FORest PLANning model (FORPLAN), evolving from Timber RAM, bridged the gap between functional resource planning and integrated land management planning. Contrasted to earlier models, FORPLAN was capable of analyzing much more sophisticated and complex questions concerning the interactions among the forest resources. It placed greater emphasis on integrating site-specific analysis with forestwide allocation and on scheduling an array of multiple-resource activities through time. The rapidly changing social, political, and legal environment demanded an even more integrated approach. With the resulting FORPLAN Version 2, the user can relatively easily specify the temporal and spatial aspects of identified problems. A major drawback is the ability of users to hide assumptions and the tendency to analyze a limited range of management strategies.

This study traces the historical development of models that eventually led to the use of FORPLAN by the Forest Service, and traces the shift from traditional single-resource scheduling to interdisciplinary, integrated, multiresource management planning.

CONTENTS

The Genesis of FORPLAN: A Historical and Analytical Review of Forest Service Planning Models

David C. Iverson
Richard M. Alston

INTRODUCTION

Planning for efficient use of the Nation's renewable resources has been long debated. The FORest PLANning Model (FORPLAN) and other sophisticated computerized models are currently used by the Forest Service in the development of land and resource management plans. The development of FORPLAN, like many other computerized systems, progressed rapidly. The present and future generations of land management planners and foresters alike might better perform their jobs if they understand the historical and evolutionary context of their tools and policies. This paper traces the development of the FORPLAN analytical tool with the parallel organizational development of decision making for land management planning in the Forest Service, U.S. Department of Agriculture. FORPLAN utilizes linear programming (LP). Much of our discussion centers on FORPLAN and use of other linear programming models for land management decision analysis.

Several themes are woven into the story of the evolution of the use of computer models in land management planning:

—Gifford Pinchot, the Forest Service's first Chief, emphasized wise use and planning as a means to ensure that resources would be used for the benefit of the whole Nation while at the same time preserving the productivity of the forests. That philosophy runs throughout the history of the Forest Service right to today and has remained intact despite the presence of changing issues.

—The tools needed in land management planning changed as the issues changed. The issues that changed involved the rising demands for forest products, environmental activism, environmental legislation, and land management legislation.

—Land management planning has moved away from independent and functional analysis toward, first, multidisciplinary, then integrated interdisciplinary analysis of all natural resources and uses of land. Consequently, planning has gradually shifted from a single-resource emphasis to an integrated multiresource emphasis.

—The new tools for planning made it increasingly feasible to plan in terms of both space and time, not just one or the other.

—The new tools enabled a greater emphasis on integrating site-specific analysis with forestwide allocation. Comprehensive planning of land use is now possible.

This paper's first section provides an overview of early attempts to build effective models supporting forest resource allocation decisions. Several models are introduced in their chronological order to create a context for the evolution of subsequent developments. The second section provides a more detailed look at three models—Timber RAM, MUSYC, and FORPLAN. Here we present a general discussion of questions that fostered model development and critically evaluate the limits inherent in the model structures. The third section, summary and conclusions, provides some general considerations and speculates on expected future use of computerized mathematical programming models in the context of land use planning. Appendix I presents the essential elements of linear programming, including a simple example. It is intended to provide the uninitiated with a framework for understanding the discussion in the second section. Those who have a strong background in linear programming may choose to skip this section. Appendix II provides a mathematical exposition of the various model structures discussed throughout the paper. The last appendix is a glossary.

SECTION I: HISTORICAL OVERVIEW

As a result of considerable ferment centering around a discussion of forest practices, Congress enacted on March 3, 1891, the General Revision Act, Section 24 of which has come to be known as the Creative Act of 1891. As later amended, the Act created forest reserves that were renamed National Forests in 1907. The passage of the Organic Act of 1897 and the Transfer Act of 1905 created both the agency—the Forest Service, U.S. Department of Agriculture—and the basic governing code that was to guide management of the National Forests for the next eight decades.

Today the Forest Service is responsible for the management of 191 million acres of forest land that annually produces an estimated 12 billion board feet of timber, 10 million animal unit months of grazing, 425 million acre-feet of water, 200 million recreation visitor days, and many other valuable outputs and environmental benefits. The responsibilities have evolved from custodial protection to intensive integrated management on an unprecedented scale. As demands placed on the resource base increased, so too did managerial demands for effective support in research, administration, and planning.

Planning is Not New

Forest planning is an ancient art. Professional forest regulation emerged in Germany in an attempt to ensure that the goals of management could be accomplished as fully as possible. The German influence on American forestry was evident both in practical application and underlying ideology (Alston 1983). Emphasis on forest planning was ensured when Gifford Pinchot became Chief of the Division of Forestry in 1898. In a publication addressed to the users of the National Forests (USDA-FS 1907, p. 25), Pinchot spelled out the essential elements of the multiple-use local planning idea that would dominate American forest policy in subsequent years:

> National Forests are made for and owned by the people. They should also be managed by the people. . . . This means that if National Forests are going to accomplish anything worth while the people must know all about them and must take a very active part in their management. . . . There are many great interests on the National Forests which sometimes conflict a little. They must all be made to fit into one another so that the machine runs smoothly as a whole.

Pinchot's view that forest conservation should include wise use and, when appropriate, protection from overuse as well as long-term preservation of the productivity of the forest reserves was to be implemented through planning. His influence has endured to the present. As Wilkinson and Anderson (1985, p. 23) have argued:

> Pinchot required planners to prepare detailed inventories, monitor the condition of the reserves, determine sustainable use levels, and exclude use from specific areas where necessary to protect the watershed and other resources. These four features were hallmarks of Pinchot's conservation planning. They became a fundamental part of Forest Service policy and in the 1970's received Congress's imprimatur in the NFMA [National Forest Management Act].

In 1911, under the direction of Chief Forester Henry S. Graves the Forest Service published The National Forest Manual (USDA-FS 1911) containing specific instructions to forest officers relating to the need for detailed forest plans to carry out the mission of the Agency. Three types of plans, differing only in scope and intensity, were identified: preliminary plans, working plans, and annual plans. The forest plans were to coordinate the various lines of work and provide for the most efficient administration and the best use of the forest resources possible at the least practicable cost. Where necessary the forest was divided for planning purposes into areas called "working circles," each of which would be managed for sustained yield. Timber management plans were to consider both biological and economic conditions. Final responsibility in the preparation of all forest plans rested with the Forest Supervisor, who would also be responsible to ensure that all preliminary or working data be kept on file for subsequent review. The emphasis in 1911 was on silvicultural management and data collection, but grazing, water, and other uses of the forest were also given attention.

The end of the first decade of this century saw the emergence of the themes that run throughout the history of Forest Service planning and that provide the cement binding the facts and events into a meaningful story. Functional planning emphasizing the characteristics of each major forest resource and its uses (timber, range, watershed, and so forth) would have to be technically accurate. But at the same time, resource specialists would have to realize that the forests—these systems within systems—could not be effectively managed or understood except in a holistic, interdisciplinary context. Emphasis on site-specific characteristics, such as soils, habitat type, and biological and social stability, would be necessary to allow for the adaptation of general principles of forest management to local conditions. Nevertheless, decentralized plans and decisions would have to be coordinated with actions taken in the Washington Office to ensure that local and national priorities fit within an overall framework compatible to both needs.

During the 1920's timber management plans for working circles large enough to support local forest-based industries were prepared, and range allotment plans complete with maps and seasonal restrictions covered some 70 percent of approximately 7,000 allotments. Budgetary and financial plans to guide day-to-day operations were a major effort, and even some watershed, recreation, and wilderness plans were completed (Wilkinson and Anderson 1985).

By 1933 the concept of multiple use had been broadened beyond commodity uses of the forest to include outdoor recreation, wildlife habitat, environmental amenities, and esthetics (Towle 1982; Alston 1983). Emphasis was shifting from local and forest-level planning to national issues (Cameron 1928). The so-called Copeland Report (U.S. Congress, Senate 1933) broke with past practices of the Forest Service and the past justification of forestry itself. It called for a more flexible multiple-purpose management planning process that reflected national economic conditions. In light of the agricultural depression, this shift of emphasis toward community stability and employment opportunities is not surprising. The view that it is the responsibility of government to promote both local and national goals through land management planning became one of the enduring themes of public land policy. That the concept of national planning is controversial, then as now, is documented in Steen (1977) and Wilkinson and Anderson (1985). As Arthur Newton Pack (1933, pp. 160-161) saw it:

> Forest planning based on an hitherto untried scale - on a national scale - is needed now. A coordinated integration of forestry within the national scheme as a major agency of land use, based on adequate knowledge of conditions and backed by vigorous and effective leadership, is required along a united front wherein our land, administrative agencies both public and private, shall fit in and perform their allotted tasks.

For the next 20 years forest policy and planning were in flux. The 1930's concept of multiple use had not yet become strong enough to overwhelm the historical emphasis given commodity uses of the forest, especially timber, water, and range (McCloskey 1961; Alston 1972). Nor was it strong enough to alter Agency planning and decision-making processes that continued along traditional functional lines, with emphasis on local and regional concerns. Indeed, planning was sometimes little more than calculations made by District Rangers and Forest Supervisors on the backs of envelopes. Activity scheduling often consisted of recording in their ever-present Use Books how they hoped to implement the plans.

A national perspective and value orientation was achieved through Agency promotion policies and intense bureaucratic socialization (Kaufman 1960; Robinson 1975; Twight 1983). Technical timber management plans were written within the Forest Service, but Richard Behan (1978, p. 314) points out that prior to World War II plans "were largely academic. They were plans for the management of timber resources that nobody wanted, as long as the private, commercial, and industrial forests of the country continued to supply sufficient old-growth timber at a lower cost. The federal land harvests never approached a growth constraint called for by the plans because they were scarcely needed at all." Until altered by the events following World War II, especially the increased timber harvesting in response to the pent-up demand for housing, planning could be characterized as an attempt at coordination between various uses, within a hazily understood doctrine of multiple use and sustained yield (Behan 1967, 1981).

It could have been little more, given the inadequacy of data beyond that known professionally by those working on the ground. The magnitude of the timber survey and inventory process, which had been authorized by the McSweeney-McNary Act in 1928, was immense. Ivan Doig (1976) points out that on the eve of World War II only 45 percent of the forest area in the continental United States had been roughly and crudely covered, and only about half of the gathered data analyzed. Subsequent studies, such as that by Wikstrom and Hutchison (1971) that questioned the basic land classification scheme used for inventory and timber planning purposes, showed that estimates of what was available were often inaccurate and generally ignored consideration of such factors as accessibility, probability of successful regeneration, and soil stability.

Richard McArdle, former Chief of the Forest Service, tells us that planning started in earnest when some quasi-military missions were assigned to the Forest Service in World War II. From the missions evolved the development of timber plans, transportation plans, and myriad separate and generally unrelated planning efforts at the National Forest and Regional level (McArdle 1973).

In the postwar period between 1945 and 1960 the major timber management questions seemed relatively settled. They dealt with management of the transition between existing forests and fully regulated forests. For example: the length of the conversion period, optimal rotation length, and associated practices. We can obtain a clearer picture of the rudimentary state of planning by looking at the concept as it was applied to development of timber management plans.

Ira J. Mason, Chief of the Division of Timber Management in the Forest Service, put it bluntly (Gross 1950, p. i):

> The Forest Service policy is to apply sustained-yield management to the national forests, working circle by working circle.... The forester's ideal is the normal forest where age-class distribution is such that perpetual cuts can be made annually of the same amount, equal to the annual growth. If such perfection should be achieved, the management plan objectives would be merely to maintain it. The ultimate objective of sustained-yield management is the development of a fully stocked normal forest.... Since there are no national forest working circles with stocking and age-class distributions closely resembling a normal forest, the intermediate objectives for the period for which the management plan is prepared [must consider problems associated with timber dependent communities, but otherwise should aim] for more rapid progress towards normal age-class distribution [as soon as practicable].

L. S. Gross wrote the handbook that served to combine understanding and knowledge of local conditions and existing policies into a working tool called the timber management plan. Brevity, without loss of important detail, was an essential goal of his effort. Again, the questions to be answered in a management plan are clear (Gross 1950, pp. 1,4):

> Each management plan must be realistic [and] should evaluate present conditions and trends in terms of future developments, but it should prescribe the most intensive silvicultural practices which can be given practicable application.... Periodic revisions often will stipulate more intensive forest practices than seemed desirable when the original plan was prepared. A timber management plan is essentially a plan of operation covering a period of years. The usual plan should outline in a general way the policies and objectives for the first rotation, or an equivalent period. Details of the action plan should cover the first cutting cycle or the first budget period. No one can foresee the future sufficiently well to make detailed plans which can be followed throughout the next 100 years or more....

And to make matters worse, stated Gross (1950, p. 19), although "numerous formulas have been developed [to aid area and volume regulation]...many are highly theoretical [and] most imply the availability to the management planner of a wealth of data on inventory, age classes, growth rates, etc." The formulas, nevertheless, were widely used to prepare timber activity and harvest schedules, which were statements of when, where, how, and how much timber should be cut and grown to reach owner objectives. As such, timber activity schedules formed the heart of forest management.

Planning timber activity schedules was and is a major focus of both the Forest Service and some private firms.

For much of this century, simple formulas sufficed in setting timber schedules. These formulas generally were divided into two kinds: area control and volume control. Regulation could be achieved by "allocating the cut" on the basis of (1) the area to be harvested each year, (2) the volume to be removed annually, or (3) a combination of area and volume.

With area control, the emphasis was on annually cutting an area equal to the area to be annually harvested in a proposed "fully regulated forest." This approach was familiar to foresters in Germany and other European countries, where centuries of intensive management had resulted in forests with relatively equal areas belonging to each age class. However, problems arose when the approach was applied on the relatively unmanaged American forests. Areas varied in the volume of harvestable timber. There was the possibility of rather large fluctuations in the volume removed each year even though a constant number of acres were treated. There was also the possibility that by judiciously scheduling the compartments to be cut, it would not be necessary to cut exactly equal areas each year.

In practice, the usual result was variation in area scheduled for cutting from year to year in the interest of more regular volume yields. Of course, regularizing the volume was desired to "sustain" timber-dependent communities. But rising and falling prices for the output of mills made the demand for such regular volumes somewhat questionable. As Gross (1950, p. 18) put it:

> It may be necessary to make some silvicultural sacrifices to bridge otherwise lean years. In developing the allowable annual cut the management planner may find it desirable to permit limited overcutting in two ways: (1) When markets are good for less desirable species or products, they may be cut more heavily; and (2) in periods of poor markets, better species and more valuable products may be overcut, if necessary to sustain the community. Skillful manipulation is necessary, however, to insure that the actual cut is substantially in balance with calculated cut, preferably by budget periods.

With volume control, calculation procedures focused on the volume to harvest annually. Under European influence and the leadership of Gifford Pinchot, volume control was used to ensure that the annual allowable cut did not exceed annual growth. By the 1920's, however, it was apparent that this made little sense in the American context, particularly in the Pacific Northwest, where slow-growing old-growth forests predominated. If the "growth equal cut" formulas were continued, the old-growth forests would dominate the calculation and extend the length of time required to convert the forests to full production potential. For this and other reasons, planners in the 1920's sought a more flexible formula (Wilkinson and Anderson 1985). The most popular one, which appeared in 1922 and continued in use well into the 1950's, was Hanzlik's formula:

$$\text{Annual cut} = \frac{V_m}{R} + I$$

where

R = rotation length for young-growth stands
V_m = volume of merchantable (old-growth) timber
I = forest growth (increment in immature stands).

The Hanzlik method was particularly designed to regulate the cut and to permit the rate of harvest to exceed growth where virgin stands predominated. The problem is to cut approximately equal volumes each year, but to spread the old-growth volume over a sufficient number of years so that second-growth stands will be ready for cutting by the time the last of the old growth is cut. Hanzlik's formula provided one solution, but others addressed the problem differently. More importantly, other questions were being asked then as now, such as best rotation length, best management practice, and alternative treatments.

Many modern questions remain essentially the same. Simple formulas stressing forest biology seemed sufficient for such a task, at least up to the time that people began to wonder about alternatives for management of future stands and to wonder about the economic efficiency and social responsibility of such timber regulation approaches. Raised today in a more complicated context, the old questions answerable by the old tools now require more sophisticated approaches.

Only with the coming of computer technology could the ramifications of considering such questions as the impact on future yields of precommercial thinning, commercial thinning, and fertilization be adequately handled. Without the computer it would have taken a lifetime to do the routine calculations required via the Hanzlik and other simple methods. But with the computer, opportunities presented themselves to blend area and volume control. In addition, modeling progressed to incorporate aspects of forest ecosystem management beyond the scope of early work in timber activity scheduling. With the advent of the computer, full-scale multiple-use planning would finally be possible on the National Forests.

But in 1950 much of this development was still to come. As Gross (1950) interpreted the situation, the Forest Service for the time being could at best experiment with the various models at hand with no commitment for any of them. The Forest Service continued to encourage efforts to evolve and use tools that would help in solving management problems. Gross (1950) provides examples from timber management plans as they existed in the late 1940's. Davis (1966) gave an exhaustive presentation of the simple classical formulas (for example, the Hanzlik formula) and area and volume control techniques that had up until that time sufficed in setting timber schedules. Subsequent developments are described in detail in Gaffney (1960), Alston (1974), Samuelson (1976), and Behan (1978).

The 1950's and 1960's Introduce New Challenges

Marion Clawson (1983) described the era from 1900 to 1950 as one that emphasized protection and preservation of forest resources. In practice, it was a process of custodial management. (See Dana 1956; Clawson and Held 1957; Shands and Healy 1977; Dana and Fairfax 1980.) The 1950's and 1960's, however, proved pivotal in the evolution of both national and individual forest planning practices. The 1950's, for example, have been described by Clawson (1983) as the decade of intensive management, while the 1960's and 1970's ushered in an era of "consultation and confrontation."

Following World War II the recovery in housing and construction was accompanied by a remarkable increase in the demand for timber. Rising stumpage prices stimulated increased western and southern timber harvests. The private forestry sector, particularly in the South, recognized that the time had finally arrived when investments in reforestation made financial sense. Given the shorter rotations in the South and the emergence of intensive forest practices on private industrial lands, the demand on public timber was increasing but not drastically so (Duerr and others 1979).

The situation was different in the West. In spite of Forest Service efforts to encourage sustained yield forestry, western forests seemed to be depleting at a rapid rate. This was particularly the case in the old-growth forests. Douglas-fir stumpage prices, for example, began a sustained rise following World War II, rising nearly 15 percent per year from 1945 to 1955 (USDA-FS 1957; Duerr 1960).

In the late 1950's timber harvest levels on commercial forest land (public and private together) seemed to be reaching the maximum sustainable yield, as established through analyses that emphasized single-rotation planning. Analysis of the timber supply situation, particularly in Washington and Oregon, became a major effort in the 1960's and 1970's.

Public foresters have long had a timber famine mentality (Bennett 1968), a pessimistic outlook revealed in early supply-demand studies by the Forest Service. These early studies were hampered by a shortage of data and had a tendency to lay blame for the Nation's forestry problems on private ownership and private silvicultural practices. Improved official timber trend studies in the 1940's and 1950's forecasted increased demand. But by this time pessimism had been replaced by an optimistic feeling that intensified forestry could overcome supply and demand problems well into the future.

Following the Copeland Report came more nationwide forestry problem analyses at increasingly frequent intervals. The Forest Service published reports in 1935 (*Forest Land Resources, Requirements, Problems, and Policy*), 1940 (*Forest Resource Conservation*), a reappraisal in 1948 (*Forests and National Prosperity*), and the Timber Resource Review (TRR) in 1958 (*Timber Resources for America's Future*). William A. Duerr (1960), who was to become a principal actor in the analysis of the timber situation, noted that the reappraisal report lacked the cautious pessimism of depression time, but contained a new, adventurous optimism tuned to visions of postwar prosperity and abundance. He said the estimated high level of timber requirements suggested that forest depletion was the basic problem, particularly on the small, nonindustrial, privately owned commercial forest land. In the Timber Resource Review the spirit of the reappraisal was continued, but with a call for intensity of forest practices by all ownerships that would startle many people. "Can do management" would replace the concept of timber reservation, and sales from public lands would be allowed to increase to meet the industrial demand.

Relatively candid assessments of the problems created by this new-found optimism and faced by the Forest Service in the early 1960's are found in *Management Practices on the Bitterroot National Forest* (USDA-FS 1970) and *Forest Management in Wyoming* (USDA-FS 1971). The Wyoming study (p. 8) put the problem in a nutshell:

> A primary target of protest, the apparent overharvest of timber, was partly a response to Federal law and USDA regulations that the Forest Service harvest timber to satisfy an obvious public need. It is apparent now that the estimates of allowable cut were partly based on over-optimistic assumptions as to the amount of growth on forested land that was suitable, available, and economically feasible to harvest. Since much of the forested land in certain parts of Wyoming is unloggable under present technology, the cut was concentrated in the area that could be logged.

The inability of extant models to offer planners both spatial and temporal analyses had resulted in a massive public outcry at the management results. Times had changed, and forests were being viewed as important for uses other than solely as a source of wood fiber. People began to question whether or not current timber management practices were consistent with sustaining and increasing the other uses of the forest.

Therefore, the pressure for increased harvests was accompanied by increasing demands for other outputs and resources of the National Forests. Edward C. Crafts (1970, pp. 14-15) argues that these pressures had:

> . . . induced the Forest Service to consider seriously legislation that finally evolved as the Multiple Use-Sustained Yield Act. These included: (1) the drives by various organizations for single use or priority for their special use; (2) increasing conflict between national forest uses and users; (3) growing pressures to overcut national forest timber; (4) unclear legislative directives for recreation and wildlife use, and (5) internal coordination problems within the Service. The timber pressures lead [sic] to the Timber Resource Review (TRR) and grazing pressures to the 1953 Annual Report of the Chief on "Grazing in the National Forests."

Crafts states that the threat to wood sawtimber was obvious and was taken seriously by the Forest Service even when others did not. "It is significant," states Crafts (p. 15) "that the final [Timber Resource Review, 8 years in progress] was completed in 1958, the same year the first Multiple Use - Sustained Yield bill was introduced in the Congress." The combined pressure led, ultimately, to a series of studies on the "timber supply problem." Initially, the focus was on the Douglas-fir region of the Pacific Northwest.

Timber Trends in the Douglas-fir Region

Timber Trends for Western Oregon and Western Washington (USDA-FS 1963), also known as the "Duerr Report," seemed to indicate that then-current practices and harvest levels on private forests could not continue into the future without an eventual decline in available timber, unless supplemented extensively by sales from the National Forests. Duerr's additional analysis (Congressional Record 1966) suggested that changes in public harvest practices could more than make up the projected decline. Johnson (1986, p. 2) states that the analysis "established that timber harvest levels could be set for reasons other than that they satisfied a formula."

However, calculations of sustainable public harvests based on available timber supply models were not sophisticated enough to answer all of the questions surrounding existing timber management and multiple-use policy. Early formula models and area-volume check methods provided solutions for specified conditions but did not assess alternative resource allocations to satisfy a specified objective. Formula models could not recognize differences in stand structure; area-volume check methods could. Neither were capable of handling the multitude of silvicultural treatments available. In spite of their deficiencies, the methods were widely used well into the 1960's (Neff 1973).

As pointed out earlier, classical timber management formulas, such as Hanzlik's, had been designed to determine the harvest rate to bring an old-growth surplus forest into regulation. Considerable improvement in terms of building economic considerations into such calculations was achieved by financial maturity models, which took account of the costs of capital rather than simply calculating biological culmination of mean annual increment. Although such financial models had been discussed in the literature since the nineteenth century, they had not much influenced public policy (such as decisions about investment levels or rotation lengths). But financial maturity models were not scheduling tools. The only scheduling models available up to the 1960's were simple formulas and brain/pencil-operated simulations augmented by map overlays and experience. These approaches and analytical methods proved inadequate for the tasks facing the Forest Service. Nevertheless, timber activity scheduling models developed by the Forest Service in the 1960's and early 1970's continued to be oriented toward ensuring the sustainability of timber harvests, not evaluating the interaction of timber with other resources.

The *Douglas-fir Supply Study* (USDA-FS 1969) added a new twist to the calculation of sustainable harvests by using allowable cut calculation procedures that looked beyond one rotation and by examining several flow patterns for public and private timber harvest. The differences in flow patterns were made possible by the development of computerized models that were the groundbreaking predecessors of those discussed in the next section. ARea VOLume Check Method (ARVOL, Chappelle 1966) was a computerized simulation model that used the area-volume check method. ShOrt Run Allowable Cut (SORAC, Chappelle 1968) was a substantial improvement in that it was specifically designed to look beyond the current rotation toward how intensively managing the regenerated stands might affect current harvest levels. A high degree of complexity in using this approach is represented by Simulating Intensively Managed Allowable Cut (SIMAC). SIMAC was a simulation model that permitted the introduction of a wide range of management practices characteristic of intensive management. It was developed for use by the Bureau of Land Management as well as the Forest Service (Sassaman and others 1972). Also coming on line at this time was a new genre of linear programming models (such as Timber RAM and MUSYC, discussed in the next section) that not only addressed these issues but also opened up avenues of analysis in broader aspects of the evolutionary transition from functional to integrated land management planning.

Multiple Uses Meant Multiple Problems

In the absence of intensive practices, as forests changed from cutting old-growth acres to cutting young-growth acres, the harvest would inevitably and permanently decline. This came to be known as the "falldown." The findings of the Duerr Report, together with those of the *Douglas-fir Supply Study*, held out hope that the "falldown" could be avoided. This hope was based on a widely held feeling that future growth in regenerated stands was a principal determinant of the allowable cut in the current period. It was implicitly assumed that increasing future yields through such practices as precommercial thinning, commercial thinning, fertilization, and improved genetic stock would be translated into higher allowable cuts in the current period. This notion became known as the "allowable cut effect" (ACE) and proved to be a focal point for debate during the early 1970's. (See Schweitzer and others 1972, Teeguarden 1973, Klemperer 1975, Bell and others 1975, and Hyde 1980.) In the mid-1970's yet a different model was developed that would allow the intensity of timber management, by owner class, to be an explicit variable in the projections. This model was named Timber Resource Economic Estimation System (TREES). TREES was used as the primary model in three attempts to analyze the future timber availability in Oregon. (See Beuter and others 1976 and Oregon State Forestry Department 1980.) TREES was also used by the Pacific Northwest Regional Commission's Forest Policy Project in a study of the Pacific Northwest (Oregon, Washington, and Idaho) that looked at forest-related policies and alternatives. (See Johnson and Tedder 1983 for a discussion of TREES and other model types not covered in this paper.)

Despite the notion of an allowable cut effect, the real limits to increased timber supply existed elsewhere. Roger Fight and others (1978, 1979) found that multiple-use management constraints reflecting other demands on the forest resources (such as water quality, recreation, or wildlife habitat) were so severe as to vastly limit the opportunities for narrowly focusing managerial discretion on timber program optimization. As Johnson (1980, p. 5) suggests, subsequent research in the 1970's reflected a different era:

> The Roadless Area-Intensive Management Study [Fight and others 1979] examined this hypothesis [that the non-declining yield constraint was the principal limiting factor on current harvest levels]

> by testing whether intensive management dollars could be substituted for roadless area acres in maintaining the allowable cut on seven national forests. . . . The findings of the study challenged traditional assumptions that long-term growth was the major constraint holding down harvest on land available for timber production. Instead, the researchers found that commitments to forest outputs other than wood fiber were the major constraint holding down timber harvest. . . . As the 70s concluded, it became increasingly clear that the effect of timber harvest on water quality, wildlife, and visual quality would provide the major control on national forest timber harvest levels.

These important policy concerns led to the desire to construct models that not only could look beyond the current rotation, but could also make different assumptions concerning harvest-growth relationships and expected future growth on regenerated stands. More detailed information on the location of resources and activities would be needed. We have identified two interrelated problems: (1) estimating the existing inventory and its potential growth characteristics, and (2) translating that information into allowable cuts. The Forest Service would have to be able to limit timber sale commitments to those that could be met without disrupting other forest objectives. The first problem means that gross overestimates of the allowable cut on a forest would have to be avoided. Spatial relations are typically a second problem that becomes important in ensuring that allowable cuts are feasible, marketable, and compatible with other uses of the forest. Forthcoming models such as FORPLAN would eventually address this dual problem, but adequate analysis of the spatial and multiple-resource problems would have to wait for further model development and improved computers.

A formidable problem was the shortage of personnel adequately trained in the use of computers. Regional staff would have to be used as itinerant consultants to the National Forest Supervisors' Offices. Virtually no one then conceived of the demands for computer facilities that would come from those offices involved in the move from functional to integrated land management planning.

National Level Analysis Models

Before the 1970's were over, the development of computer-based analysis models had proliferated. The Forest Service was faced with a plethora of models developed within the Agency, by university researchers, and by industry. The next section discusses three important forest-level analysis models. Numerous models were developed to handle national and regional level analysis (Field 1973; Bell 1975; USDA-FS 1976; Chappelle 1977; Convery 1977); space allows only a brief discussion of one of these.

Peter Ashton and others (1980) developed an interactive system of four models capable of synthesizing pertinent masses of information into measures of economic, environmental, and social impacts. The National Interregional Multi-Resource Use Model (NIMRUM) used linear programming to allocate national and regional demands for renewable resource uses on the land base. The model was developed in response to the 1974 Forest and Rangeland Renewable Resources Planning Act (RPA) assessment and program analysis needs. RPA was mainly concerned with national level planning, and its primary purpose was to better document the budgetary needs of the Forest Service and to enhance long-term appropriations (Wilkinson and Anderson 1985). NIMRUM was designed to minimize operational costs of alternative national programs (the objective function) while addressing environmental concerns, range production, sustained wood yield, and wilderness.

The first model under the NIMRUM system was developed by the Multiple-Resource Use Interaction group of the RPA staff in cooperation with the Range group and was called a National Interregional Multi-Resource Analytical System (NIMRAS) (Pickens 1980). Although conceptually capable of including analysis of virtually unlimited types of forest resource uses, in practice it was limited to timber harvest practices, domestic grazing and range practices, and wildlife practices. A second model was designed to evaluate regional employment and earnings triggered by alternative national programs. A third model, Futures Foregone, developed by David Freeman, kept count of future options lost in terms of the way it affected citizens groups, the rate of impact, and the length of impact. A fourth model, Social Conflict, also developed by David Freeman, attempted to quantify the amount and direction of conflict patterns resulting from any particular national strategy, program, or alternative (Alston and Freeman 1975). The system of four models was used in the preparation of portions of the 1980 RPA assessment and program analysis. Other users of the NIMRUM system included budget planners and strategists in the Washington Office. However, it was incapable of fulfilling the needs of planners at the National Forest level because (1) it was national in scope and provided little help for forest and regional level planning, and (2) the costs associated with its use were simply prohibitive.

Following publication of the draft RPA assessment and program in August 1975, a national symposium sponsored by the University of California, Berkeley, and the Forest Service was held at Pajaro Dunes, CA, in May 1976. Workshop reports, preparatory studies, and participant discussion focused on what had been learned in that first go-around (Pemberton 1977). The primary conclusion was that the level of aggregation required for national level analysis made it difficult to link, in a site-specific manner, the nationally and regionally determined target level of resource production for specific National Forests. Needed was a local bottom-up approach to data aggregation for the assessment and forest level development of alternative plans. The only feasible approach, if meaningful integrated interdisciplinary planning was to be obtained, would be to turn away from the Forest Service's "product oriented approach." The summary of the symposium proceedings stated that "if it has not already become so, the traditional multiple use approach will soon become obsolete when the multiplicity of new demands becomes apparent" (Pemberton 1977, p. 12). Some of the symposium participants suggested that not only data analysis and planning decisions be kept at the local or regional level but also policy and direction be more decentralized.

These and other concerns lay behind the enactment of the National Forest Management Act (NFMA) in 1976. NFMA, and the regulations promulgated to implement the act, were aimed precisely at improving the forest-level planning process. Wilkinson and Anderson (1985, pp. 76-90) summarize the essential points:

> Uneasiness over the respective roles of local and national planning began with the advent of land use planning in the 1960's.... Modern land use planning did not assume that timber production was an appropriate use of all available commercial forest land.... As a result, national forests began to classify more commercial land as unavailable for full timber production, to reduce their allowable cuts, and to schedule fewer timber sales.... [T]he timber industry began to complain about the loss [and to complain about] allowing local planning officials to sacrifice national lumber and housing priorities in order to placate local concerns. Partly in response to this criticism, the Forest Service instituted the more heirarchical unit planning system [discussed in next subsection] .... The basic local-national planning issue is whether Congress intended local forest plans to meet the resource output goals of the RPA program.... The "top-down" theory maintains that Congress did not intend to allow parochial priorities of local plans to frustrate achievement of national needs. The "bottom-up" theory...argues [for] decentralized control over local land use decisions. A third position [which represents] [t]he Forest Service's current position is essentially an uneasy compromise between the top-down and bottom-up theories... [and] call[s] for an "iterative" exchange of information from local plans and direction from national plans.

The inherent conflict led one critic to call for actual repeal of the RPA/NFMA legislation (Behan 1981). Nevertheless, the national NIMRUM system continued to be used for the 1980 RPA assessment and program. But analysts' interests had shifted to developing models that would be able to generate site-specific multiresource forest plans. For this reason, we now turn our attention to forest level planning and to the linear programming models specifically developed for that purpose.

Forest Level Analysis

The rising demands for timber after World War II resulted in emphasis on improving timber harvest scheduling models. But the Multiple-Use Sustained-Yield Act of 1960 shifted the emphasis to a balanced approach in the use and management of the many resources available from forest and rangelands (Alston 1972).

The first coherent effort to address the multiple-use aspect of public forests came in the form of "multiple-use" plans prepared by each of the National Forests (Schweitzer and Cortner 1984). Although these plans were intended to recognize and balance all forest uses, the absence of adequate data and experience in nontimber-related planning resulted in "multiple-use" plans that were still largely timber oriented. (Even in 1986, in the absence of final Forest Plans, functional timber management plans were still prepared and were still the basis of most day-to-day management activities.) However, the "multiple-use" plans developed during the 1960's did represent a meaningful step toward defining management activities for individual resources.

Rising concerns for all values of the forests may eventually overcome the emphasis on timber. If so, historians may point not to the Multiple-Use Sustained-Yield Act, but rather to the growing recognition of potential environmental consequences of Federal Agency activities and to the passage of the National Environmental Policy Act (NEPA) of 1969.

NEPA required all agencies of the Federal Government to prepare environmental impact statements that identify and evaluate the long-run impacts of projects on the environment. In response to NEPA, the Forest Service in 1973 changed its system of forest planning. In addition to meeting the process requirements spelled out in NEPA and court decisions, a major objective was to ensure greater consistency among national, regional, and local land-use priorities (Wilkinson and Anderson 1985). Each Region prepared Planning Area Guides, which provided general guidelines concerning broad resource capabilities and expectations to be followed by each National Forest in the Region. Each forest prepared plans for subareas of forests called "units." While multiple-use plans were still prepared for entire forests, unit plans were prepared for individual subcomponents of the forest, usually encompassing a large drainage or several watersheds.

Classifying the forest into land-use zones was a basic purpose of the unit plan. Zoning attempted to take into account the unique spatial characteristics of and resource interactions on the forest. Typical zones were general forest zone, watershed zone, streamside zone, recreation zone, critical wildlife habitat zone, and critical soil zone. Management practices were specified or prohibited in certain zones. For instance, buffer zones along streams required special timber harvest practices to limit damage to the watercourse. In scenic or recreation zones, special requirements on size and shape of clearcuts could be imposed to maintain esthetic values. Landscape architects were called on to establish appropriate visual patterns.

In the early 1970's too little was known about multiresource interactions to attempt much more. As stated in the 1975 RPA Assessment (USDA-FS 1977, p. 228):

> Some research on the joint production of several products from the same land areas has been conducted, the impact of timber harvest upon water yield being the best example. Some other resource interactions have also been studied such as the big game livestock interaction in the West. However, most of the multiresource interactions have received very little study. As the competition for the use of forest and range lands increases, information on these interactions will be increasingly vital and the best hope of attaining efficient use of the land and water resources.

Nevertheless, Schweitzer and Cortner (1984, p. 115) correctly argue that unit plans "were the first truly 'interdisciplinary' or 'integrated' plans on the national forests.... Detailed attention was paid to defining environmental consequences and the social and economic impacts on forest dependent communities of alternative courses of action."

The unit plans, like the multiple-use plans, continued to be supplemented by functional plans for individual resources, and overall decisions concerning forest resource management were based on subjective weightings of the results of the separate analyses. But because timber management plans continued to be the most sophisticated and well-documented in a quantitative sense, they tended to dominate the more qualitative plans for other resources, although this varied significantly from forest to forest. National level analysis was becoming an important part of the overall Forest Service planning effort, but in the early 1970's essentially all decisions for each forest were made locally. During this period the major influence of national level analysis showed up in the form of budget allocations to National Forests and Regions. This period was also marked by a substantial increase in the number of plans called into dispute by various publics, including litigation and an increasing role for the judiciary in settling disputes.

Among the more important of the computerized analysis systems used in forest level and unit planning (other than Timber RAM, which is discussed at length below) was the Resource Capability System (RCS) developed by the Watershed Systems Development Unit at Berkeley, CA (1972). RCS was designed to simulate the response of on-the-ground resource analysis units (land areas with similar soil types or other natural resource characteristics) to alternative management strategies. Resource analysis units thus grouped similar parts of the forest into "zones." The RCS resource analysis areas were often the basis for classifying land use zones for unit planning purposes.

Much like the models discussed in the next section (Timber RAM, MUSYC, and FORPLAN), the RCS model was a linear programming (LP) optimizing technique consisting of a matrix generator that assembled data into a structure suitable for LP analysis, and an output display or report writer. Once assembled by the matrix generator, data would be processed by a commercial LP code. The solution to the LP problem would be interpreted and displayed by the report writer. The LP code evaluated alternative natural resource output and use levels for each resource within management objectives, constraints, and land capability. As with any systems analysis approach, users would interact with the model, making minor adjustments and solving several slightly modified LP problems from each matrix generated by RCS. Because LP problems are abstractions from the realities of on-the-ground management, thoughtful user interaction is an indispensable part of the process.

Used for multiresource planning, RCS scheduled strategies over time, allocated acreage to specific management activities, and identified levels of resource output in response to the allocated acreage. RCS identified the maximum (or minimum) value of an objective function (for example, maximize timber or other resource production, maximize present net worth, minimize specified costs) subject to constraints. The developers of RCS represented the functional area of watershed within the Forest Service, and the model reflected their world view. Thus, RCS paid particular attention to simulating the water quality and water quantity effects of alternative activities (Johnson 1986). Timber was treated as just another output. RCS represented an alternative approach to the timber scheduling models that had been important to the Duerr Report and the Douglas-fir Supply Study and that had dominated much of the multiple-use and unit planning efforts. Within RCS were programs related to (1) onsite watershed analysis, (2) economics, (3) resource allocation and development planning analysis and display, (4) general support programs, (5) statistics and plotting, and (6) editing and general data handling (Hill and others 1974).

A subsequent version of RCS known as the Resource Allocation Analysis system (RAA) eliminated the response simulation models. RAA was used by both the Willamette and Beaverhead National Forests in the formulation of their plans. The Watershed Systems Development Unit at Berkeley, CA, was considered by many to be the effective intellectual center of National Forest Systems modeling in the early 1970's.

RCS might well have been developed into the model specified for use throughout the Forest Service if time had allowed correction of two fatal flaws. It would have to be able to recognize multiple classifications for the same area of land (that is, strata-based analysis areas discussed in the next section). It would also have to diffuse the perception that it was biased toward hydrological concerns. But competition between model developers and between functional staff groups in the Washington Office, the resulting confusion among forest planners, the continued dominance of timber in the ethos of the Agency, and the desire on the part of the Washington Office Land Management Planning staff to have one unified approach for public involvement, led to the decision to designate the FORest PLANning Model (FORPLAN) as the required primary analysis tool for National Forest planning (USDA Forest Service 1979). As Johnson (1986, p. 10) makes clear, however, "The emphasis of RAA on equal treatment of all activities and outputs and their portrayal as 'timestreams' of yields influenced the development of FORPLAN," particularly Version 2.

Summary: Evolution of Planning Led to Systems Approach

Gifford Pinchot's emphasis on wise use and planning as a means to ensure that resources would be used for the benefit of the Nation while at the same time preserving the productivity of the forest reserves has been a thread woven throughout this historical account. His desire for decentralized administration and planning that emphasized local concerns while being responsive to national needs has always been controversial but still guides the Forest Service today. What has changed is the perception of how best to accomplish that noble purpose.

Project planning dominated by independent and functional analyses for each of the separate resources proved unable to meet the needs of decision makers faced with increasing competition between and rising demands for the many resources and products of the forests. Timber and other commodity resource plans gave way in the 1960's to multiple-use plans, but timber plans and harvest scheduling dominated the process. Some sophisticated computer models for timber scheduling could look beyond the current rotation and anticipate the benefits of intensive forestry, but the models did not effectively deal with resource interaction. Various laws, including the Multiple-Use Sustained-Yield Act, NEPA, and NFMA, increasingly required a shift from single resource planning to **multi**disciplinary, and ultimately to **inter**disciplinary planning.

Each step in this evolutionary process required an analytical foundation to support advances in evaluation of all functions and alternative actions in the context of integrated and complex ecosystems. The pace of change is accelerating. As Schweitzer and Cortner (1984, p. 121) argue:

> It took approximately 55 years before planning for public forestry progressed beyond the limited timber plans to encompass planning for a broad array of forest goods and services. Since about 1960, however, far reaching changes have occurred at an accelerating pace. These include changes in the nation's fundamental perceptions of how the national forests should be managed and an increasing insistence that all plans of government be rational and available for inspection. The processes and analyses followed by the agency have changed greatly in response.

We have viewed the changing processes, and we now turn to that part of the story that concerns the analyses.

SECTION II: THE EVOLUTION OF LINEAR PROGRAMMING MODELS AS FOREST SERVICE ANALYSIS TOOLS

The evolution from the functional timber yield estimation-harvest maximization days of Timber RAM to integrated forest planning efforts using FORPLAN reflects the work of many people and spans more than a decade (Iverson 1982). Subsequent parts of this paper focus on the nature of the problem identified by the developers of the models and on the changing technical specification of the models as the analysts attempted to take into account real-world problems and new requirements of planning legislation and policies. For the reader's convenience, terms used throughout the rest of the publication are found in appendixes I and III.

Many of the analytical tools discussed in section I and all of the models discussed in the following pages are linear programming (LP) models. Persons lacking familiarity with LP often believe it capable of doing more than it can. Realistically, LP is a mathematical technique that allows decision makers to compare the ability of alternative management strategies (that is, schedules of specific management activities) to meet stated goals within available resource limitations. An understanding of model specification is important. If managerial decision making is to be modeled, the linkage between the variables internal to the model and the decisions made in the day-to-day management of the land must be explained. A correct specification of the problem requires that management decisions be traceable in terms of modeled decision variables.

For the models discussed here, a decision variable is associated with an activity column representing a prescription for land use on an identifiable area of land. The term "variable" derives from the flexibility under the strategy to manage either no acres or up to some stated number of acres. Once constructed, decision variables are evaluated according to specific criteria stated in terms of a constraint set and an objective function. The LP model selects decision variables that optimize the objective function within the bounds of the constraint set, the residual or unused decision variables being set to zero. Activity columns and constraint rows effectively delimit the range of production options considered. The objective function guides the LP model toward a solution that represents an "efficient" assignment of acreage to land use strategies. An efficient assignment in this limited context is one where the objective function achieves a maximum (or minimum, if desired) subject to fulfilling constraint requirements.

Computerized LP models have thus become popular not because the models make decisions, but because they can facilitate better decisions by evaluating several hundred thousand decision variables in a fraction of the time it would take to locate the best combination of decision variables by hand. The alternative solutions offered by the LP model become important pieces of information to be used in the human decision-making process. Often, the process of using such models, which force careful consideration of assumptions, data, and tradeoffs, is as important as the output of the models themselves.

We now turn our attention to three LP models: Timber RAM, MUSYC, and FORPLAN. Understanding the models and the events that led analysts to abandon Timber RAM and then MUSYC in favor of FORPLAN should help the reader comprehend FORPLAN as an analytical tool useful in developing forest ecosystem management plans.

Timber RAM

The Timber Resource Allocation Method (Timber RAM, Navon 1971) was developed by Daniel I. Navon and others at the Pacific Southwest Forest and Range Experiment Station following several years of experience with computer-oriented models developed in the mid-1960's (Amidon 1964, 1966; Broido and others 1965; Navon 1967; Navon and McConnen 1967; McConnen and others 1967). The model was designed to help formulate "plans which are efficient with respect to stumpage harvested, costs, or revenues, and which are consistent with specific management policies and available resources" (Navon 1971, p. 22). Navon (1971, p. 1) describes the model as follows:

> Given an inventory of forest resources and alternative ways of managing each type of stand, Timber RAM can be used to calculate a schedule which meets a specified objective, such as: maximize revenues, maximize stumpage volume

> harvested, or minimize expenditures. Besides meeting the objective, the Timber RAM schedule can be required to meet constraints on the periodic level of revenues, and expenditures, and on the periodic volume of stumpage harvested. The levels at which revenues, expenditures, and stumpage are constrained can be varied from period to period. Finally the Timber RAM schedule can be required to meet constraints specifying what percentage of each type of stand will become accessible for cutting in successive periods.

Specifically, the model would predict the optimal sustained level of harvest, in a localized area such as a National Forest, given specified assumptions. Use of Timber RAM to answer questions relating to biological sustainability of harvest placed the model in company with ARVOL, SORAC, and SIMAC discussed in section I. Timber RAM, however, used a linear programming approach rather than a binary-search approach to harvest scheduling. Johnson and Tedder (1983) provide a thorough discussion of the two approaches.

Model Specification and Use—Timber RAM was used most frequently to address issues relating to biological sustainability of timber harvests, and to answer the question: What is the maximum sustainable harvest level for a forest? Model specifications included (1) an objective to maximize first period cut, (2) harvest-growth information for the stand classes represented, and (3) a harvest flow restriction. The forestwide decision was how much and where to cut. Decision variables were structured to respond to the question: How many acres should be cut from each stand class in each period? The user would delimit the range of periods (typically decades) over which the stand could be cut and define a variety of silvicultural treatments for a stand class, with some discretion as to when treatments would take place. It is easy to imagine the construction of many decision variables for each stand class.

In the analysis, forest land would be divided into a specified number of timber classes, say *k*, where *k* was typically a number between 15 and 75. A timber class was defined as a collection of acres from across the forest sharing similar silvicultural and economic attributes. Douglas-fir mature sawtimber on high-site-productivity land might comprise a timber class. The number of acres included in any timber class would, of course, vary by forest. Acreage would vary as well by the number of classes so defined. The basic land stratification, homogeneous but noncontiguous, is hereafter referred to as "strata-based." Figure 1 shows that the world view represented in the model is a mosaic of timber stands for forested areas, accompanied by voids in other areas.

A series of timber management prescriptions or strategies would be constructed, each prescription representing an alternative sequence of silvicultural treatments spanning many decades to the planning horizon. In Timber RAM, prescriptions[1] include treatments for both existing timber stands and the managed stands that would replace them in the future. Associated with each prescription are decision variables, which keep track of acreage assigned to particular timing choices for prescriptions in the solution to an LP problem. As such, decision variables become the "choice" variables in the LP problem. Because the focus of the analysis was biological sustainability, the planning horizon was typically 120 to 300 years. The span of time represented in the model was divided into a number of periods, often decades.

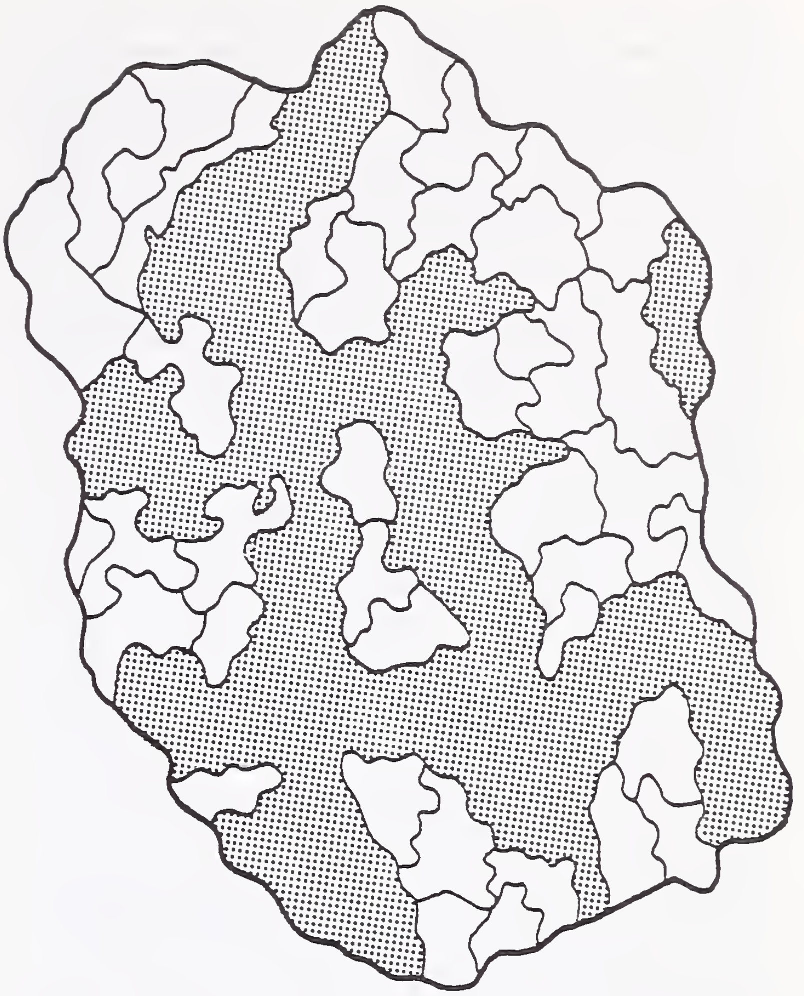

Figure 1—Mosaic of strata-based timber classes as delineated for Timber RAM analysis.

Generally, constraints were added to the model in addition to those needed to track acreage within timber classes. These constraints controlled, for example, the rate of change in timber volume harvested from period to period. Such constraints could be used to simulate the effect of various forest policies.

Given user-defined timber classes and associated prescriptions, Timber RAM would develop a pattern of harvest that would at once satisfy specified constraints while optimizing the chosen objective. The sequence of acres to be cut in each period, coupled with the amount of

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[1] The term "prescription" is introduced here to avoid confusion later on. Navon (1971) used the term "activity" for what we call a prescription, because a prescription was always represented as an activity column in a linear programming problem. Therefore, in our discussion of Timber RAM a prescription refers to a complete sequence of activities or treatments extending from the present to the planning horizon. A prescription is conceptually identified by a particular goal or "management emphasis" and by a particular "management intensity." The timing of treatments with associated outputs, costs, and benefits completes the specification. The term prescription, as shown in subsequent discussion, evolves along with the model development. In Timber RAM, prescriptions were related to timber production only.

timber removed from those acres, is referred to as a "harvest schedule." It is generated as a function not only of the single stand harvest-growth projections but also as a function of the timing of harvest cuts within and across stand classes to meet forestwide goals to the planning horizon. The yield projections would be exogenously developed based on assumptions about silvicultural treatments and their impacts on each stand class.

Prescriptions and associated decision variables were modeled at the stand class level with constraints generally reflecting overall forestwide goals and objectives. Even though stand classes were defined according to components such as working group or species mix, land class, and age class, the user could control harvest only by either individual timber class or forestwide. Harvest control by land classes, for example, was not allowed. As will be seen in subsequent discussion, this meant that managers would not be able to directly control harvest in critical subareas of the forest such as elk winter range or designated visual impact areas. Neither could they control harvest, for example, by species mix or harvest method.

"Constraints" in this era were often modeled as reductions in volume available for harvest. This type of constraint became particularly important after 1972 when a change in the Forest Service Manual required categorization of land into standard, special, and marginal components. Only standard lands reflected the full production levels contained in existing yield tables. By 1977, Forest Service planners had classified over a third of all commercial forest land as marginal or special (Wilkinson and Anderson 1985). In Timber RAM the reduced harvest volume implied by such considerations was usually modeled in one of two ways: reduction in harvest-growth volumes accompanying prescriptions or restriction of acres available for treatment in the first five periods. The first approach implies a constraint through yield reduction in the prescription columns. It was generally used for "special" and "marginal" lands. Yields for standard lands reflected full production levels. The second approach controlled access to a timber class through imposition of constraint rows called "accessibility constraints."

In developing harvest schedules, the analyst would typically run the LP model relatively free of constraints other than those needed to keep track of acreage in an accounting sense and to control harvest flow. The solution to this initial run would be subjected to scrutiny by specialists to determine on-the-ground feasibility. If deemed infeasible, additional constraints would be imposed and the model would be rerun until the specialists were satisfied that the selected prescriptions and decision variables represented on-the-ground management possibilities.

Navon (1971, p. 7) suggested that the above procedure could "be extended to include review of Timber RAM plans or revisions of Timber RAM problems by fire, recreation, range, and wildlife management planners." Ostensibly, functional timber management planning in the Forest Service would be sensitive to other resource demands.

Critical Evaluation—Timber RAM was billed as a tool for use in development of harvest schedules compatible with multiple-use management objectives. But could it live up to the billing? Timber RAM was, after all, a timber management planning model. Therefore, information from other resource specialists was interpreted and filtered by timber specialists resulting in an alleged bias that plagued Timber RAM and the models that evolved from it. Model developers, analysts, and planners who used the models were challenged by both internal and external critics to show that the models were not unduly biased toward timber. (The developers of RCS, as discussed in section I, were similarly accused of being biased toward hydrological and watershed concerns.)

But a potential timber bias was not the only issue. In studying wildlife management, Thompson and others (1973) identified modeling needs pertaining to the size, spacing, and distribution of clearcuts—considerations important in evaluating the intertemporal impacts of timber harvests. In addition, Walker (1971) looked at the economic implications of modeling situations where stumpage prices varied with harvest volume. Timber RAM could accommodate the latter problem (Hrubes and Navon 1976), but explicit demand curves were often absent or based on questionable assumptions. In practice, however, those and many other issues could not be easily represented in the model structures.

The use of intertemporal harvest flow constraints to simulate sustained yield in model specification was one approach to dealing with the charges of bias. Such controls represented flow constraints useful in forest regulation. But, in the eyes of other forest users, controls could also be used to restrict overcutting. In practice, harvest flow constraints were being used as surrogates for restrictions on harvest for economic, social, political, or environmental reasons. The policy of sustained timber yield could be, and almost invariably was, internalized in the form of a nondeclining yield (NDY) constraint. This constraint requires that the cut not fall from period to period within the planning horizon. Nondeclining yield became Forest Service policy in 1973 with the release of Emergency Directive 16 (USDA-FS 1973). However, the NDY constraint was often the sole mechanism, beyond the individual stand class harvest-growth projections, used to distribute the cuts through time.

Timber RAM was widely used to develop timber management plans for National Forests in the Western United States in the 1970's. The plans themselves were developed to address the questions of biological sustainability of the cut on a forestwide basis. The model served that need rather well. But the questions Timber RAM was designed to address were relatively unsophisticated, and as attention began to shift from growth maximizing formulas to site-specific environmental questions, more sophisticated model structures were required. The MUSYC model was developed as a first-stage response.

MUSYC

<u>M</u>ultiple <u>U</u>se-<u>S</u>ustained <u>Y</u>ield <u>C</u>alculation Technique (MUSYC, Johnson and Jones 1979) evolved from an attempt by K. Norman Johnson and others to improve the user orientation of Timber RAM. Desired constraints on timber harvest volume and silvicultural practices at or below the forest level dictated, it seemed, a complete overhaul of the Timber RAM computer code. The decision was made in the mid-1970's to revamp the system.

But a complete revamping did not occur. The end product maintained the older Timber RAM structure while adding a new one to it. MUSYC emerged with two mathematical structures designed for timber activity scheduling problems. Johnson and Scheurman (1977) outline these generic structures, labeling them "Model I" and "Model II." The key to understanding the distinction between them is found in the definition of decision variables.

In Model I, decision variables trace prescriptive managerial activities to the planning horizon, from the existing stand through, perhaps, several harvests on future regenerated stands. Johnson and Scheurman (1977) classify Timber RAM among models where decision variables are structured in a Model I format. In contrast, Model II is typified by a separation of decision variables. One set of decision variables traces actions on the existing stand. A separate set of decision variables traces actions on the land during the establishment and regeneration harvest of the subsequent stand. Each time a stand is reestablished, it is tracked with a new set of decision variables. Constraint rows link the two sets of decision variables and ensure that acres are properly tracked in an accounting sense.

The name MUSYC was acquired toward the end of developmental work on the system. Early on, it had been nicknamed "Model II" because the decision variables were so structured. Although it was conceptually appealing, Johnson and his coworkers soon found that some Model II formulations could create LP problems too large to solve efficiently. Johnson and Scheurman (1977) thought the Model II form produced more attractive LP problems with regard to computational efficiency than did the Model I formulation in Timber RAM. Forest Service administrators in Timber Management apparently also thought this because they chose Johnson rather than Navon to overhaul the Timber RAM computer code.

As Johnson (1977, p. 446) reveals, however, it quickly became apparent that computational efficiency is situational:

> Problem size for Model I is especially sensitive to minimum rotation age and problem size for Model II is especially sensitive to the number of acreage groupings at each age that must be maintained for future stands within each type-site. Which model is more computationally efficient in a given problem depends, among other things, on the users' preferences relative to these two key parameters.

This meant that instead of overhauling the Timber RAM computer code, Johnson would have to develop a completely new model and incorporate characteristics from both Model I and Model II. The Model I formulation was subsequently retrieved and the name changed to MUSYC. However, the "Multiple Use" in MUSYC was a misnomer because the model could handle multiple-use considerations, such as nontimber uses of the forest, only in the form of constraints on the timber harvest obtainable from various site classes. The prescriptions, in other words, were all timber oriented.

Enhanced Constraint Capability—In the tradition of Timber RAM, the MUSYC system was developed to address questions about general forest harvest and growth patterns. As suggested in Johnson's own account (1986, p. 7), timber planners using Timber RAM were demanding increased "ability to portray constraints that would reflect [the] emerging [social and environmental] restrictions on timber harvest" discussed earlier. They sought model enhancements that would help categorize information and develop constraints needed to control harvest with regard to area as well as volume. Johnson, in response, added the desired element of control to MUSYC, at least as it applied to timber class identifiers. In Timber RAM the timber class identifiers (working group, land class, and condition class) were used only to cluster information useful in specifying prescriptions. In both Timber RAM and MUSYC, an additional component, the "regeneration class" was used to allow for simulation of a variety of possible management regimes for future stand classes. Note that a timber stand would be identified by either a condition class (existing stands) or a regeneration class (future stands), but not both.

As discussed earlier, explicit constraint rows could not be developed by timber class component in Timber RAM. In the MUSYC system, however, users could aggregate information within and across these timber class components in developing constraints. Also, each possible treatment, such as a commercial thinning or a shelterwood regeneration harvest, could be named by treatment type. Users were allowed to develop constraints with regard to acres or volume treated forestwide by treatment type per period, and by groups of inventory categories formed by some combination of the identifiers. These constraints would allow control on, for example, the maximum number of acres clearcut in a given period for Douglas-fir mature sawtimber on sensitive soils. This was a substantial improvement on Timber RAM. In addition, reports summarized the results of the solution to an LP problem in terms of acres and volumes according to identifiers, treatment types, and time periods.

No doubt, improved constraint specification was helpful in projecting more realistic harvest schedules. In fact, the model gained acceptance in private forest land planning (Boise Cascade Corp. 1980) largely due to added flexibility in model definition and constraint capability.

Critical Evaluation—The problem with MUSYC relative to multiple-use planning was that it was just a more sophisticated timber management model. Enhanced subforest constraint capability was realized by further defining the strata-based timber classes seen in Timber RAM. This approach failed to give explicit recognition to the geographic areas important to specialists from wildlife, recreation, watershed, and so forth. (Some uses of RCS had focused on just such resource-specific analysis areas.) The problem with strata-based analysis areas versus geographically defined analysis areas is not just a timber versus nontimber problem. Strata-based analysis areas presented problems even when timber alone was being modeled. Consider one common conflict: strata-based analysis areas can provide greater precision in estimating timber yields, but geographically defined analysis areas can provide greater precision in estimating timber costs wherever road costs are important. The latter information was critical if sensible economic analysis was to be possible.

Analysis of location-specific issues such as transportation analysis could not be easily accomplished in MUSYC. In the early 1970's simulation models for transportation system planning were capable of dealing with recreation travel, one-lane road simulation, and network analysis. Weintraub and Navon (1976) attempted to integrate silvicultural and transportation activities. Such models, while significant improvements over older methods of analysis, were still inadequate for complex planning issues. Not until the end of the decade did Malcolm Kirby and others at the Forest Service Management Sciences Staff, Berkeley, CA, develop Integrated Resource Planning Model (IRPM) to deal with the spatial aspects of transportation plans (Kirby and others 1980).

Both the temporal and the spatial dimensions of the timber management problem are crucial to development of acceptable management plans. Timber RAM and MUSYC were designed to address the temporal dimensions of the problem, and IRPM was designed to address the spatial dimension. The challenge would be to bridge the gap.

Furthermore, as discussed in section I, by 1976 RPA and NFMA laws had changed the nature of Forest Service planning. A step in the direction of interdisciplinary planning had been taken by the adoption of unit planning, but the need for spatial and temporal integration across the whole forest could not be met by that approach. Thus, in 1976 development of the MUSYC system and its required documentation stalled. Documentation was completed in 1979 (Johnson and Jones 1979). But long before that Johnson had begun work on a model to address the issues of integrated planning.

The need was for more locational specificity than is provided by strata-based forestwide decision variables. This was available in RCS. However, the wording of NFMA regarding timber management actions suggested a need to retain the harvest-growth information packed into the decision variables of Timber RAM and MUSYC. These were absent in RCS. The dilemma is evident. To at once retain information on timber yields, yet address nontimber issues such as cover-forage relationship on elk calving grounds, presented a formidable challenge. In addition to detailed timber yield information, information on roads and openings created by timber harvests needed to be considered in a manner consistent with the desired cover-forage relationships. Prescriptions defined only in terms of timber classes would no longer suffice.

FORPLAN

FORPLAN was developed by K. Norman Johnson and others to bridge the gap between functional resource planning and integrated land-use planning (Kelly and others 1986; Kent and others 1985; Johnson 1986). Whereas Timber RAM and MUSYC only analyzed commercial timberland, FORPLAN could accommodate all lands and water in the forest. The basic structure existed in MUSYC or Timber RAM. However, the role of the decision variable would need to be enlarged. Whereas previous decision variables traced activities needed to produce timber through time, FORPLAN decision variables would trace multiple resource activities through time. These activities are packaged in prescriptions associated with the decision variables.

A prescription in FORPLAN represents an integrated set of activities, outputs, costs, and benefits. As it applies to FORPLAN, a prescription is broader than the timber activities in Timber RAM. The activities may be accomplished within one period (generally one decade) or may span many periods. Prescriptions, however, trace the consequences of the activities to the planning horizon.

The coming of NFMA meant that truly integrated multiple-use planning was no longer just an idea—the law mandated its immediate implementation. "Lead" National Forests had been identified in Forest Service Regions, representing a set of forests that, through trial and error, would set the much-needed precedents for planning. On December 3, 1979, the Forest Service (USDA-FS 1979) designated FORPLAN as "the required analysis tool" for forest planning. The stage was set and the players identified.

Unfortunately, the rules of the game, if identifiable, were not easily followed (Field 1984). If timber and range classes (henceforth termed "analysis areas") could be defined on the basis of homogeneity of site and vegetative characteristics, recreation and wildlife analysis areas could not. Production of either recreation or wildlife requires diversity of site and vegetative characteristics. Analyzing these relationships would require models with a high degree of spatial orientation. Typically, for instance, a wildlife biologist would choose a contiguous area such as an elk "home range" as the relevant analysis area. Generally, FORPLAN would need to reflect the world view of each specialist separately and allow for cases where two or more specialists would write prescriptions for joint resource outputs from the same tract of land. That is, prescriptions for managing the land would need to be written for the separate production of timber or wildlife and for the joint production of timber and wildlife. Linkage was maintained in FORPLAN by creating a new class of prescriptions called "aggregate emphases."

Aggregate Emphases—This concept, developed in FORPLAN, represented for the first time a separation of decision variables for land allocation from decision variables for activity scheduling. The Forest Service planning process focuses on "analysis areas," which, when defined by strata, are homogeneous but not necessarily contiguous parcels of land. An aggregate emphasis prescription in FORPLAN packages broad management direction (typically a specific land-use directive) over a composite of analysis areas in a user-defined zone (Crim and Johnson 1981; Johnson and Crim 1986). Selection of a specific aggregate emphasis delimits the set of prescription choices for the strata-based analysis areas covered by the aggregate emphasis zone. That is, an aggregate emphasis associates a single management emphasis or a user-defined set of emphases to the analysis areas defined within an identified zone. Whereas FORPLAN without aggregate emphases provides decision variable choices for treatment of individual analysis areas, the inclusion of aggregate emphases provides choices both in the broader allocation of land and in the narrower assignment of prescription treatments to the land. Effectively, the model structure is one of choice within choice. Individual prescription assignment is made under the umbrella of an aggregate emphasis.

Figures 2A and B highlight the separate world views captured by the model. Figure 2A depicts an aggregate emphasis prescription displaying a roading proposal. Figure 2B depicts a mosaic of analysis areas.

Chappelle and others (1976, p. 291) pinpoint the significance of the role of aggregate emphases in providing a solution to the problem plagueing Timber RAM:

> Non-timber uses of the forest are handled indirectly in Timber RAM and essentially form constraints on timber production. Insofar as they are effective at all, they merely limit land available for timber activities and limit the range of treatments that may be applied in timber production. . . . [T]empering Timber RAM solutions with adjustments for "multiple-use considerations". . . does not necessarily provide an optimal solution appropriate for forestry planning. [What is required is that] all goods and services of the forest [be] quantified within the objective function.

Chappelle and others, along with Navon and Lundeen (1974), felt that the problem could be eliminated if Timber RAM could be linked with another model, such as RCS, capable of allocating the total resource pool to a complete range of alternative forestry products. Aggregate emphases accomplished just this linkage in FORPLAN, at least in concept.

In FORPLAN, output yield and economic information may be associated with the aggregate emphasis directly or can be associated with prescriptions as before. For example, assume that an aggregate emphasis defined the roading of an important anadromous fish drainage, with the roading system designed primarily to access the available timber. The cost of the roading system is likely a shared cost for all the analysis areas within the aggregate emphasis zone. Either the road is built or it is not.[2] The cost is, therefore, associated with the aggregate emphasis prescription directly rather than trying to associate it with accompanying prescriptions for strata-based analysis areas separately. Similarly, output yields for recreation, sediment delivered to the fishery, and so forth, that accrue primarily due to the implementation of this aggregate emphasis, would also be assigned directly. Output yields such as timber harvest volume would be packaged in the individual prescriptions as before.

To fully comprehend the aggregate emphases scheme, the yield production process must be dichotomized. Some yield information (also cost and benefit information) is predicted at the analysis area level in development of prescriptions. Other yield information (also cost and

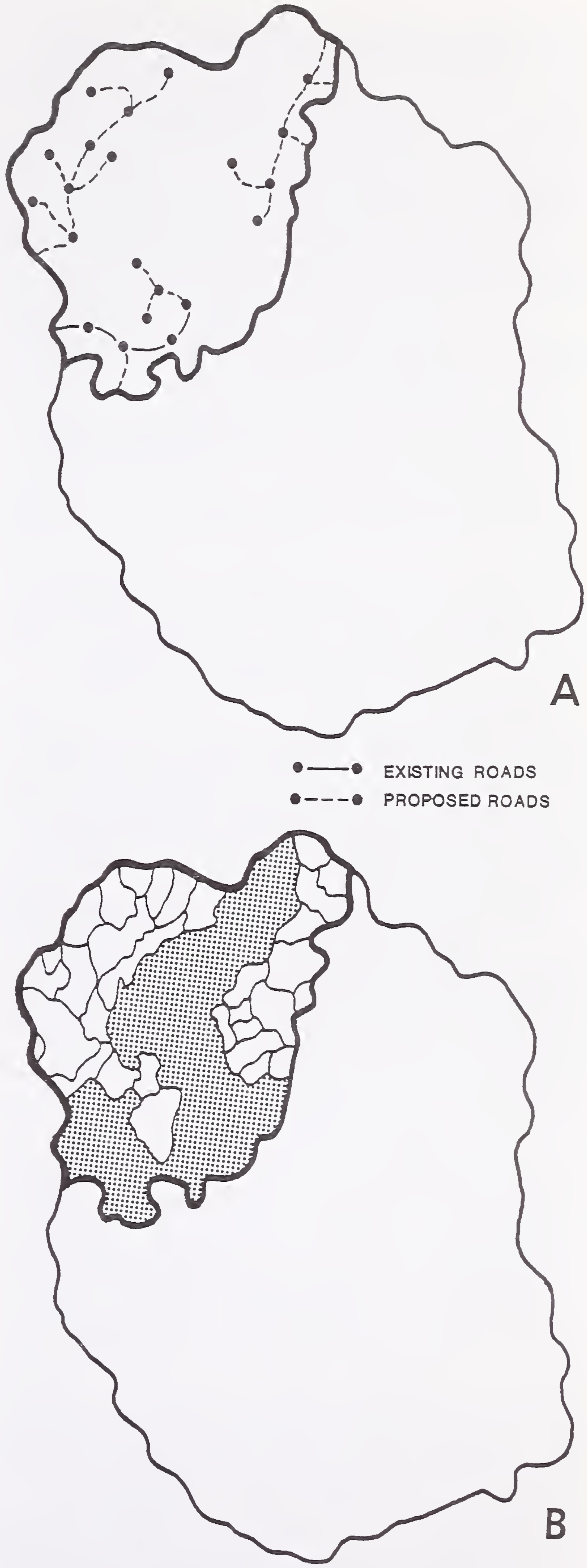

Figure 2 A)—Aggregate emphasis prescription for a roading proposal (B)—Aggregate emphasis prescription for a mosaic of analysis areas.

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[2] Note that when dealing with roads or other activities with a high degree of spatial content, the decision variable no longer represents a choice along a continuum. The choice is binary; either you make the choice or you do not. Therefore, linear programming cannot be used in its classical optimization mode, but rather it is often used to develop efficient prescription assignment for continuous variables given specified states for the binary variables. Johnson and Stuart (1986) give a detailed explanation of this problem and provide insight into several methods to resolve it.

benefit information) is predicted at the aggregate emphasis area level in development of activity schedules associated with it. A further refinement allows for timing options. That is, the user may structure several aggregate emphasis decision variables that are similar, yet differ with respect to period of implementation. For the roading example, this would expand the decision by adding a timing choice to the choice of whether or not to build.

The notion of activity scheduling for multiple resource production, and the notion of land allocation decisions being somewhat separate yet intertwined with the activity scheduling decisions, are significant milestones that set the stage for future development. In terms of analysis, they represent the major accomplishments derived during the initial development stages of FORPLAN.

Minor accomplishments included expansion of the ability to user-constrain output flows. With FORPLAN, users could constrain across subsets of lands, activities, and periods. Perhaps equally important was the movement away from timber supply estimates based solely on strata-based analysis that historically had resulted in relatively high estimates of the timber available for potential harvest. Each round of planning with FORPLAN results in better estimates of what would be available where and when. Reduction in the estimated potential harvest of timber is the case even when constraints for other resources are held constant.

Critical Evaluation—Although it was enhanced by the ability to track multiple resource outputs and consider land allocation decisions, FORPLAN was besieged with problems. Technical problems are covered in detail by Stuart and Kent (1982). Problems include (1) model size and (2) difficulty in generating spatially reasonable land allocations and activity schedules.

The first problem is one of model size. Stratifying a land base in the Timber RAM and MUSYC tradition typically resulted in 15 to 75 timber classes. FORPLAN stratifications for multiple-resource problems typically resulted in 250 to 800 analysis areas, with resource specialists begging for more. Further, use of the aggregate emphases notion often greatly expanded the size of the underlying LP. Each allocation decision variable is linked to a separate set of scheduling decision variables. Therefore, each newly considered allocation choice may have a multiplicative impact on model size. The twin factors of multiple-resource considerations and broad land allocation considerations treated independently would each have a significant impact on model size. Considered jointly, the potential impact on model size was staggering.

The second problem deals with the difficulty of generating spatially reasonable allocation/scheduling packages. Consider a currently unroaded 30,000-acre drainage with, say, only two aggregate emphasis prescriptions. The first leaves the area unroaded and does not consider any activity scheduling. The second prescription simulates development of roads for the area in the first period of the planning horizon. Further, this prescription is linked to prescriptions allowing for scheduling activities on the analysis areas within the drainage. Without the imposition of further constraints linking the timing of activities on adjacent and nonadjacent analysis areas in the aggregate emphasis zone, the model structure allows for many sequences of actions that might be undertaken in the drainage.

Ofttimes an assignment of prescriptions deemed efficient in an LP run will not be spatially reasonable in the eyes of at least one resource specialist. Determining cases where a model "run" simulates unreasonable timing choices and subsequently constraining away from these choices has proven to be time consuming and expensive. Such technical problems were troublesome but not insurmountable when the model was put into the hands of sophisticated and imaginative users. One ought not discount the creativity of forest analysts. Indeed, FORPLAN and its predecessors proved in the long run to be much more flexible than might otherwise be suggested by our treatment. The users proved to be adept, for example, at squeezing enhanced geographical specificity and spatial realism out of otherwise restrictive model structures.

The major problem with FORPLAN was not a technical one. Rather, it was a problem of perceived bias—a problem inherited from predecessor models. FORPLAN, itself a sophisticated timber scheduling model, proved cumbersome at best, and inappropriate at worst, to some integrated forest planning needs. Johnson and others (1986, p. 2) provide insight into two forms of criticism:

> [First], that FORPLAN was inherently incapable of modeling forest planning because it was a barely camouflaged enhancement of a functional model representing the views of Timber Management; and [second], that the specific capability of the model was inadequate to address forest planning problems. Many people saw a causal relationship between the two criticisms: that being a functional model (FORPLAN) would inevitably prove to be inadequate for the multifunctional, integrated planning required under the National Forest Management Act.

This criticism did not fall on deaf ears. Once again events would intervene, model development focus would shift, and a new model would emerge.

FORPLAN Version 2

In 1981 the Regional Forester in the Southwestern Region of the National Forest System (New Mexico and Arizona) received permission to use ADVENT (Kirby and others 1978) for National Forest planning. Because the focus of ADVENT was multiyear budgeting and program planning, and because it was not linked to a particular functional area, it was deemed acceptable to the planners in that Region.

Many people had long been uneasy about FORPLAN. Among them was Bill Russell, then Assistant Director of Land Management Planning and head of the Systems Application Group in Fort Collins, CO. He came from a range management background, making his approach to land management planning less likely to be served by the apparent timber bias in FORPLAN. But the support base for FORPLAN was not easily eroded. More than one debate took place in the Agency about which model would be appropriate. However, in the end Johnson became convinced that Russell, his supporters in the Southwestern Region, and the less outspoken opponents to the continued use of FORPLAN were right after all. "As much as [Johnson] and his colleagues had tried to broaden the timber management planning perspective of FORPLAN, its terminology and orientation would always be foreign to many planning and resource specialists" (Johnson and others 1986, p. 3).

Johnson came to realize that FORPLAN's primary usefulness was for the heavily timbered forests in the Pacific Northwest and the Southeast. It had limited appeal to planners on other forests. As Johnson later put it:

> FORPLAN was bound to fail (as a universally applicable model) because it simply was incapable of answering the questions that some planners deemed most important. These planners (and the Forest Supervisors they worked for) were less interested in long term scheduling models than they were in being able to provide meaningful answers to their clientele relative to what would happen and where it would occur as a result of the Forest Plan in the next 10 years (personal communication 1985).

Under Russell's guidance, Johnson constructed a model dramatically different from FORPLAN (hereafter referred to as FORPLAN Version 1). Rather than exploiting yields from tables assumed to be widely applicable and associated with prescriptions for strata-based analysis areas, the user could define activities and resource products uniquely associated with the area in question. That is, the user would package into an activity column all the activities and outputs associated with an entire set of management prescriptions (including timing choices) for, say, a watershed or other user-defined zone to be managed holistically with a specific goal in mind. The new model was originally called Direct Entry (DE) FORPLAN, precisely because of the uniqueness of the data associated with each decision variable specified (Johnson and others 1982). Eventually the title DE-FORPLAN was abandoned and the model was, and is, called FORPLAN Version 2 (Gilbert and others 1985; Johnson and Stuart 1986; Johnson and others 1986).

At first, and from an accounting standpoint, the model presented to satisfy the desires of the Southwestern Region personnel was surprisingly similar to ADVENT. However, FORPLAN Version 2 did not resemble ADVENT for long because its capabilities were soon expanded. Johnson and his coworkers, especially Tom Stuart and Sarah Crim, worked diligently to create a new model that could overcome the criticisms leveled at FORPLAN Version 1, but without the need to jettison any of its capabilities. As Johnson and others (1986, p. 3) put it:

> In this [new] construction, a number of principles were followed: 1) the model would be compatible with the Forest Service Accounting System, 2) the different kinds of land organization—especially the strata-based and area-based approaches—would be equally possible, 3) the different kinds of data entry, especially unique data and shared data approaches, would be equally possible, 4) the data input conventions would be organized to avoid the need for the user to repeat data, 5) the ingredients of each management choice would be visible to the user, 6) the model structure would not favor any particular functional branch, 7) no particular problem formulation would be required, but rather the model would adapt to the user's perspective.

From an analysis perspective the real milestone embodied in FORPLAN Version 2 went beyond even the initial ideas that guided its developers. The key attraction to the analyst would prove to be the flexibility in specifying activity columns, decision variables, and constraints. In previous modeling efforts, a decision variable represented either a pure scheduling decision (for example, how many acres to assign to a particular prescription) or a pure allocation decision (for example, how many acres to assign to particular management emphasis). FORPLAN Version 2 allows the user to choose from along a continuum with traditional scheduling choices in the Timber RAM tradition at the one end and packaged land allocation - output scheduling choices in the ADVENT tradition at the other end.[3] That is, the user can package activities and outputs across space and time according to the dictates of the analysis at hand.

For example, if an inquiry into the biological sustainability of harvest were desired, the user could create a model structure similar to Timber RAM. Alternatively, if the inquiry was whether or not to enter into a previously unroaded drainage for timber harvest, the user might adopt an entirely different strategy and develop a simple exposition of, say, three scenarios. The first might involve no action and simply project outputs and effects through time. The second scenario might consider a roading activity, with outputs and effects, assuming helicopter logging. The third scenario might consider a different roading scheme derived from a cable logging system. Conceptually, three activity columns would have been developed. The activity columns formed could be called coordinated allocation schedules or simply "coordinated schedules."

Coordinated Schedules—A coordinated schedule defines the sequence of activities to take place on a user-defined area or zone to the planning horizon. That is, a sequence of activities, their costs, benefits, and environmental effects for, say, a 30,000-acre drainage in each period of the planning horizon would be totally user defined. Each package of activities (or activity column) would be associated with a separate decision variable. Alternative packages compete to see which one could most efficiently meet areawide or forestwide objectives and constraints. Each package would be constructed by an interdisciplinary team in an attempt to ensure that it is spatially reasonable. Figure 3 portrays a coordinated schedule wherein several roads are proposed along with a series of clearcuts.

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[3] ADVENT was designed to evaluate competing projects. That is, each modeled activity column represents a separate project. To depict land allocation - output scheduling choices in what we term the "ADVENT tradition" requires, first, that a land-use zone must be identified, and second, that a sequence of activities, outputs, costs, and benefits must be identified that defines a management strategy for the zone from the present to the planning horizon. The "ADVENT tradition" represents a penchant for choosing between predefined projects or programs defined holistically. Use of ADVENT for broad land allocation decisions was infrequent, however, relative to use of the system in project planning and program budgeting (Kirby 1978).

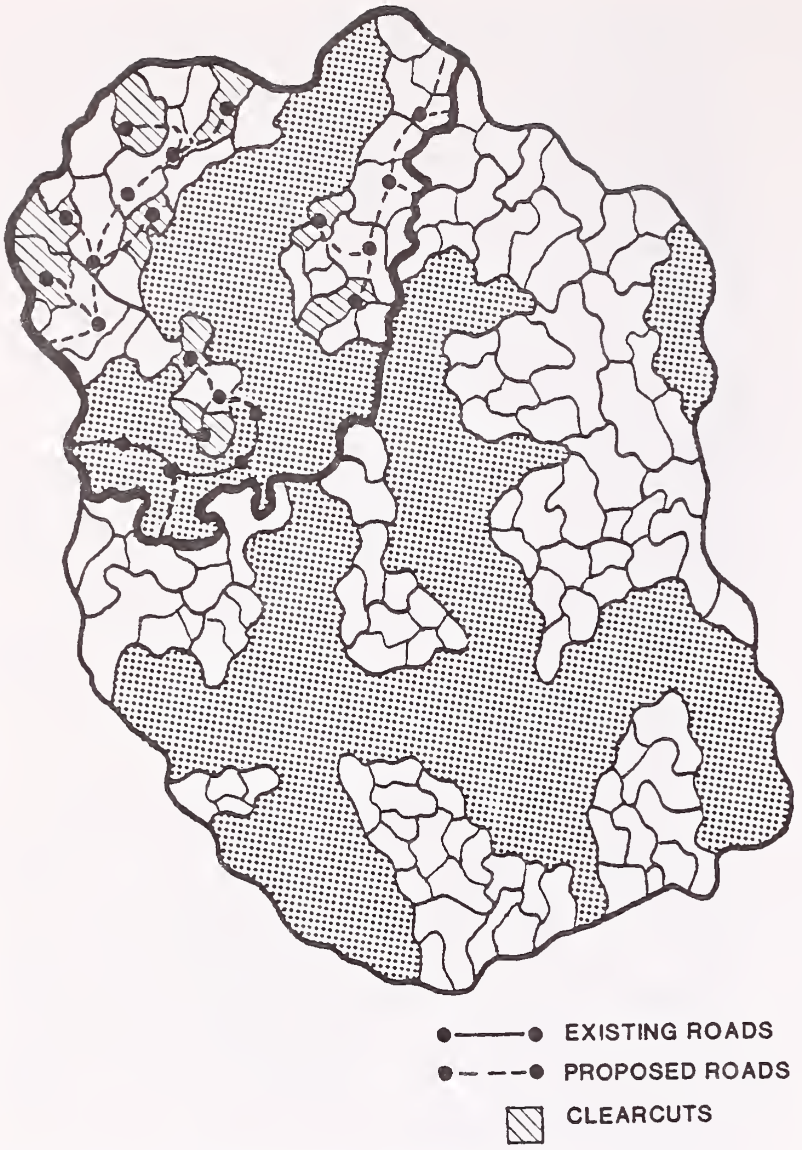

Figure 3—A coordinated schedule depicting several clearcuts and associated access roads.

Because a coordinated schedule spans all periods to the planning horizon, it is not easily represented in a figure. Therefore, a snapshot view at the end of period 2 is depicted in the figure.

Coordinated schedules can be developed in FORPLAN Version 2 in two ways: Unique yields can be input directly, or unique yields can be packaged from yield tables associated with prescriptions for strata-based analysis areas. In either case, the coordinated schedule is developed by an interdisciplinary team and is associated with a single decision variable in the model. (In recent documentation of FORPLAN Version 2 there is no reference to "coordinated schedules" [Johnson and others 1986; Johnson and Stuart 1986]. The terminology, however, still resides in the User's Guide [Gilbert and others 1985]. The terminology was not used in later documentation due to the possible negative connotation for output schedules developed in a different manner that might therefore be construed to be "uncoordinated." To this date no one has conceived of a thoughtful substitute for the term "coordinated schedule," and for this reason we use it here.)

Johnson (1982, pp. 9-10) emphasized the pros and cons in moving to coordinated schedules:

> Developing scheduling choices for areas instead of stands could, in theory, greatly assist in ensuring that environmentally feasible schedules be developed for the forest. Model size could significantly decline. A problem with one hundred areas each having the choice of 10 coordinated schedules would result in 1000 choices in total.
>
> The reduction in model size gives some clue as to a disadvantage in representing scheduling choices on an area basis. These choices are time-consuming to construct and require considerable imagination. Probably not all those that might be developed will be represented in the problem. Therefore, achievement of the objective specified for the problem may be reduced not only because of the constraints implied by the standards that must be met, but also because important choices were left out.

Flexibility in Problem Specification—FORPLAN Version 2 allows the user to analyze problems in several ways. Consider an "Allocation choice - traditional scheduling" formulation. Allocation choices (the Version 2 analogue of aggregate emphases) are developed for each zone represented in the problem. In addition, output scheduling prescriptions are developed for analysis areas defined according to strata represented in the problem. Decision variables for the two classes of prescriptions are mathematically linked. The linkage is a user option.

Analysis areas can be defined in a variety of ways in relationship to allocation zones. First, strata-based analysis areas may be specified within each allocation zone (fig. 4). In this case, activity and output schedules would be reported by zone as a part of the solution to a linear programming problem. The underlying model structure is identical to that developed for a similar aggregate emphases formulation in Version 1.

In a second case, strata-based analysis areas may be specified independently from allocation zones (fig. 5). The schedules reported by the model would not be directly traceable to the allocation zones. However, scrutiny of each allocation choice would determine whether or not (and when) acres would be available for activity scheduling. Once determined available, acres from one zone would be pooled with like acres from other zones for scheduling. The resultant activity and output schedules would be reported forestwide.

A third approach would allow definition of strata-based analysis areas according to user-specified combinations of allocation zones (fig. 6), with coincident schedules reported for the zone combinations.

In those cases where the user chooses to develop schedules at a level of aggregation higher than the allocation zone (cases 2 and 3 above), both problems and opportunities are encountered. Problems arise because users must prorate activity and output schedules back into the allocation zones. This process is cumbersome, but the solution to the LP problem offers some information useful in the proration. First, users know the allocation choice(s) selected for each zone. They also know whether or not (and when) analysis area acres are available for scheduling. It is left as a management decision, then, to reconcile the schedule into the zones. This brief introduction to the problem may hint at the opportunities.

Perhaps the most obvious result in cases 2 and 3 is that model size is reduced. There are also other opportunities.

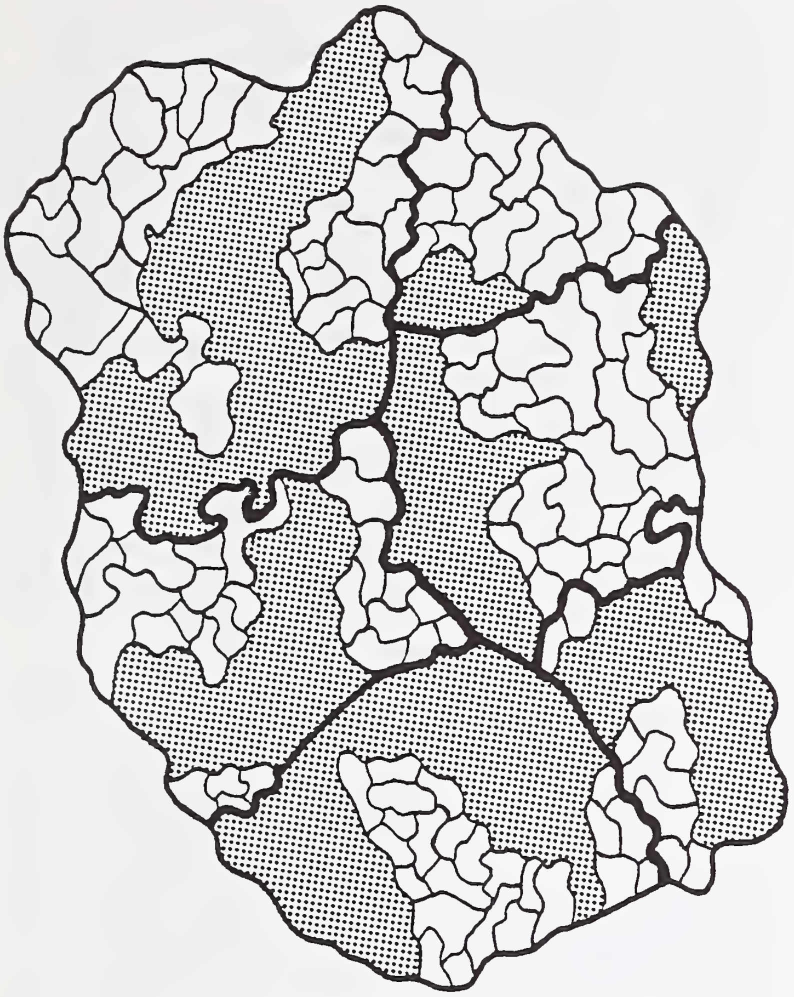

Figure 4—Strata-based analysis areas specified within each allocation zone.

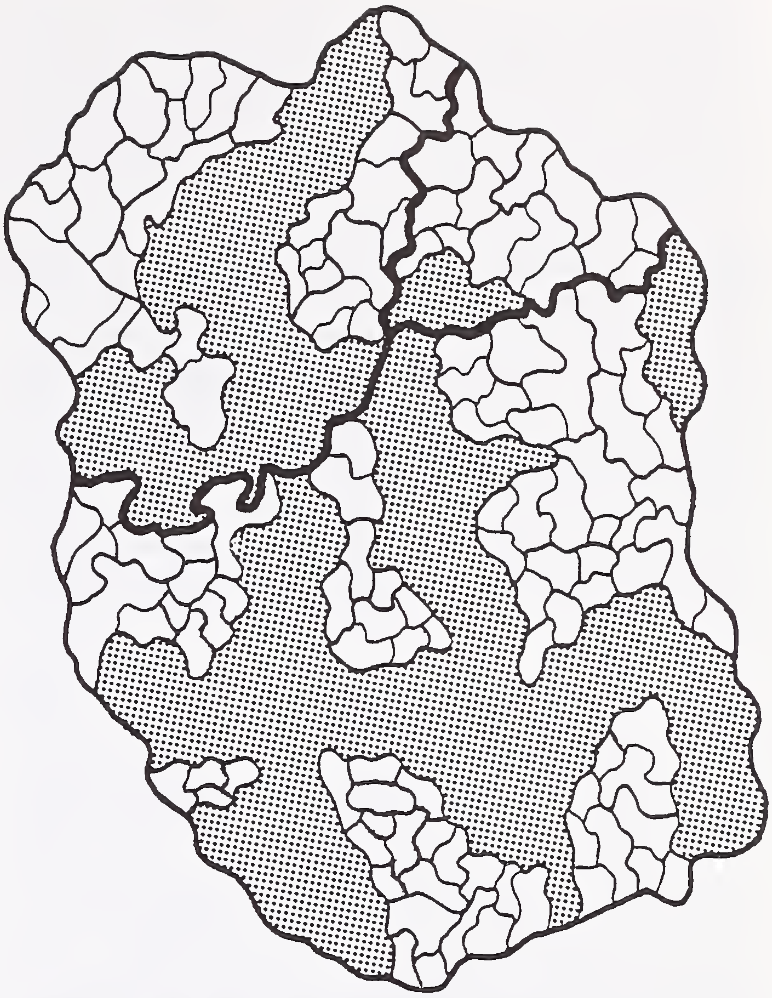

Figure 6—Strata-based analysis areas delineated according to user-specified combinations of allocation zones.

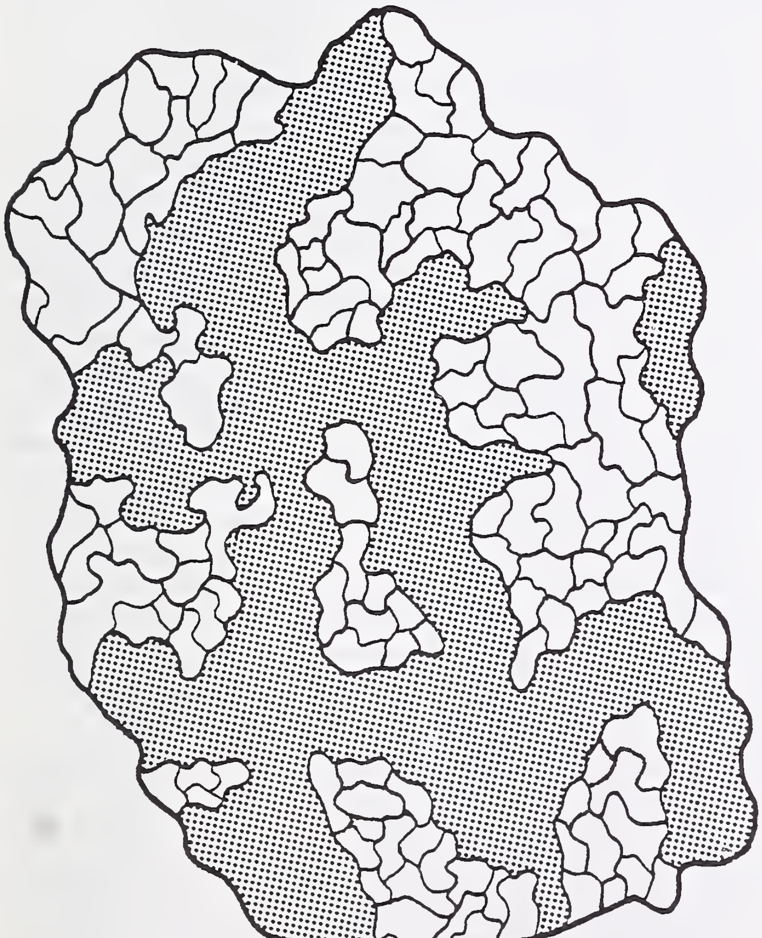

Figure 5—Strata-based analysis areas specified independent from allocation zones.

When using "traditional scheduling" formulations, site-specific information is not provided for prescriptions associated with strata-based analysis areas. As previously mentioned, the solution to an LP problem so structured would not be expected to be spatially correct when identified to the allocation zone level. Structuring the model such that activity and output schedules are not automatically developed for the allocation zones forces user interaction with the models in positioning the schedules on the ground. Similarly, the user interacts with the model in making allocation decisions. Human insight and intuition allow for a nonmechanical and reasoned apportionment of activity and output schedules within and across allocation zones.

The intertemporal aspects of the user options have not yet received as much attention as the spatial aspects. This class of options can be described from the "allocation choice - traditional scheduling" model framework. Consider a case where the user desires to specify the allocation for an area and dictate the scheduling for, say, the first two time periods. Beyond those first two periods, scheduling is not felt to be as critical, yet there is a need to monitor the flow of outputs and effects to the planning horizon. FORPLAN Version 2 allows the user to package information for an allocation choice and associated scheduling prescriptions for the first two periods into a single activity column for each zone. The process can be conceptualized as embedding the scheduling of activities and outputs for periods 1 and 2 into each allocation choice.

Traditional scheduling prescriptions for periods 1 and 2 would not be developed. However, prescriptions and decision variables representing scheduling choices for the remaining periods would be developed in exactly the same manner as in other "allocation choice - traditional scheduling" formulations.

In addition, FORPLAN Version 2 allows the user to define the point in time when acreage will be transferred from one prescription to another. This capability is a generalization of the Model II capability (Johnson and Stuart 1986). In Model II (Johnson and Scheurman 1977), a stand class (analysis area) transfers acreage between prescriptions at time of regeneration—that is, two or more sets of decision variables track analysis area acreage. The first set of decision variables tracks acreage through prescriptions defined for existing timber stands. The second set tracks acreage through prescriptions defined for the regenerated stands that replace existing stands once harvested, and so on.

FORPLAN Version 2 generalizes this concept and allows the user to define interrelated sets of decision variables for use in a variety of applications. For example, a user may wish to transfer acreage between decision variables as a function of the age of the overstory. In this fashion, analysis regarding the intertemporal dimension of catastrophic fire or insect infestations may be simulated.

In generalizing the available model structures, FORPLAN Version 2 allows users to specify differing parts of a problem with different model structures. This effectively allows the user to mix and match model structures situationally to better analyze problems.

Generalized Constraint Capability—In FORPLAN Version 2, constraint capability was generalized to include three broad categories of constraints: absolute constraints, flow constraints, and general relational constraints.

Absolute constraints are similar to the subforest constraints outlined for MUSYC. Except for the ability to aggregate activities or outputs or both, these constraints are largely similar to those in FORPLAN Version 1. Flow constraints generalize the idea behind "harvest flow" to any user-specified activity, output, or activity/output aggregate. General relational constraints allow the user to specify relationships between activities, outputs, or aggregates thereof. For example, a user might separately package costs and benefits deriving from the timber program. General relational constraints could be used to specify that the benefits exceed the costs in each period or that the benefits must cover a specified proportion of the costs.

Additional constraint capability allows the user the opportunity to link prescriptions and associated decision variables not easily connected through one of the general constraint categories. If we were to expand the previously mentioned roading example to include links in a road network that might or might not be developed contingent on prior construction of other links, we can readily visualize the need to consider other user-defined links between activity columns. FORPLAN Version 2 accommodates this use through a process referred to as "linked selection of coordinated allocation choices."

The capability to consider networking ties FORPLAN Version 2 with Integrated Resource Planning Model (IRPM) developed by Malcolm W. Kirby and others at the Forest Service Management Sciences Staff, Berkeley, CA (Kirby and others 1980). The method discussed here is a simple network structure. Sophisticated networks including "traffic flow" decision variables can be easily specified in FORPLAN Version 2. Johnson and Stuart (1986) point out that FORPLAN Version 2 can be used to analyze a variety of problems encountered in traditional "transportation planning" situations.

Critical Evaluation—Some may consider it premature to critically evaluate this version of FORPLAN. We share that concern. Nevertheless, some general remarks concerning linear programming as it is applied in forest ecosystem planning are appropriate. FORPLAN Version 2 represents the latest and a substantially different model in a series of models developed for this purpose.

Given the generic nature of FORPLAN Version 2, we argue that many criticisms leveled at earlier models have been overcome. Any computer model focuses all disciplines' attention on the same mechanism of analysis. FORPLAN Version 1 and its predecessors put timber at the focal point, with other forest resources, goals, and outputs on the periphery. FORPLAN Version 2, however, permits each discipline to redefine the point of focus—all forest resources have the opportunity to get into the middle. In this sense FORPLAN Version 2 is a positive force.

But criticism will not disappear. Rather, it will be focused on particular applications of the model. We are cautiously optimistic that such criticism will provide for better decisions on those projects and programs involved in such analysis.

Criticism regarding the use of mathematical programming techniques in forest management planning will no doubt continue. First, FORPLAN Version 2 is, after all, still a linear model and consequently doesn't handle nonlinear problems very well. Many thoughtful analysts see this as the major drawback of all models discussed in this section. Second, it is possible to build a model that is so complicated that even the analyst no longer understands why certain outcomes are identified as optimal. It is at least debatable whether such a model would add insight into the planning process. Users should also be cautioned that this model, like other models in the series, was not intended to provide answers to general equilibrium economic questions. Rather, the model is designed to simulate some of the consequences of alternative courses of action. Mathematical programming in general, and linear programming in particular, is most useful in understanding the nature of the problem, not in providing numbers representing the "answer" to a problem. Geoffrion (1976, p. 81) instructs that the true purpose of mathematical programming is

> . . . to help develop insights into system behavior which in turn can be used to guide the development of effective plans and decisions. Such insights are seldom evident from the output of an optimization run. One must know not only **what** the optimal

solution is for a given set of input data, but also **why**. The desired insights usually have more to do with the "why" than the "what."

In summary, then, we note that FORPLAN Version 2 is unique among the models we have discussed because it can handle a wider variety of problems that arise in forest management. It can simulate outcomes of forestwide allocation and scheduling problems, or it can be used to evaluate different projects. In the middle ground, the system can be used to evaluate groups of projects connected in time and space. It is also unique as a forest planning tool because it offers the opportunity to shift the focus of criticism away from functional concerns and toward the integrated planning process itself.

SECTION III: SUMMARY AND CONCLUSIONS

The evolution of Forest Service planning models has taken us a long way toward improving our ability to formulate problems in a manner that allows for sophisticated analysis and design. Millions of dollars and countless hours have gone into their development and implementation. This monograph has traced the development in forest planning thought, emphasizing the role played by harvest scheduling. Particular attention focused on the development of FORPLAN, which represents the work of many people scattered throughout the country. Just where have we arrived?

Randall O'Toole (1983) argues that with the emergence of FORPLAN Version 2 the Forest Service has reached the level of "total unintelligibility" and that people working with forests using the model will find that runs produced by it are far longer and more complicated than those of earlier models. From the perspective of citizens who desire to influence public forest policy, he could be right. The level of sophistication, and the concurrent ability to hide assumptions and manipulate data, have risen to the point that even trained users are not always aware of the ties that bind.

However, we reach a different conclusion. The authors share a desire to improve current land management planning. As economists, we are particularly concerned that whoever manages the land and plans its future uses be as aware as possible of the complex tradeoffs involved in multiple-purpose management. As we have reviewed the three-decade evolution of the planning models discussed herein, we conclude that in spite of the limitations inherent in any attempt to abstract from holistic reality through modeling the complex ecosystems that constitute our National Forests, the benefits may yet exceed the costs.

The shift in emphasis from a single-resource orientation to a multiple-resource orientation involved legislation on a national scale and Forest Service interdisciplinary team involvement on many units of the National Forest System. The models have evolved from Timber RAM to FORPLAN Version 1 and beyond in the form of the metamorphosed FORPLAN Version 2. Modeling emphasis has shifted.

Timber RAM and MUSYC were structured to answer questions relating to the physical-biological sustainability of timber harvest levels. FORPLAN Version 1, and more effectively, FORPLAN Version 2 attempt to respond to questions relating to financial consequences and environmental effects of any of a variety of actions undertaken in the course of managing a forest.

The application of FORPLAN to National Forest planning has surfaced problems relating to: (1) large linear programming models that proved to be costly (in some cases, prohibitively costly) to solve and (2) LP models that did not address well the spatial considerations of National Forest planning. These problems have been recognized, and their joint resolution is suggested in model structures available in FORPLAN Version 2. Clearly, the efforts through the past several years have not only helped better identify the problem but have also given insight into the modeling dilemma of problem size versus spatial reality. The key lies in problem identification and specification to simultaneously reflect land use and activity scheduling. The task of intelligently structuring the choices modeled is paramount.

FORPLAN Version 2, like its predecessors and other models being developed in the Forest Service to complement it, is merely a tool. As such it is capable of providing a reasonable approximation of the most efficient mix of management options consistent with the objective functions and constraints specified and the input data. If problems exist in the latter, they must be altered and improved.

Any tool that allows public land managers to ask "what if" questions has the potential of being useful. The more focused the questions, and the more accurate the input data, the more likely will answers be useful to thoughtful foresters. As William A. Atkinson (1986, p. 28) has argued: "Foresters must be able to interact with the model and interject opinions and 'common sense.' The thinking forester needs to be actively involved in management decisions; nature is far too complex to be reduced to pure numbers."

We believe that the evolution of models will continue and that we must move beyond what has been termed the "hacker" stage. "Realists" will recognize both the limitations and the prospects for use of complex models to aid decision making. The FORPLAN models are powerful analytical tools, but they must be used and interpreted with care.

REFERENCES

Alston, Richard M. FOREST: goals and decisionmaking in the Forest Service. Research Paper INT-128. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 84 p.

Alston, Richard M. [Memorandum to Director, Intermountain Forest and Range Experiment Station, Ogden, UT]. 1974 December 18. [A critical technical report on a symposium held at University of Washington, 1974 November 23, on "The Economics of Sustained Yield Forestry"]. 23 p.

Alston, Richard M. The individual vs. the public interest: political ideology and national forest planning. Boulder, CO: Westview Press; 1983. 250 p.

Alston, Richard M.; Freeman, David M. The natural resources decisionmaker as political and economic man: toward a synthesis. Journal of Environmental Management. 3: 167-183; 1975.

Amidon, Elliot L. A computer-oriented system for assembling and displaying land management information. Research Paper PSW-17. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1964. 34 p.

Amidon, Elliot L. MAIDS2 - an alphanumeric map information assembly and display system for a large computer. Research Paper PSW-38. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1966. 12 p.

Ashton, Peter G.; Pickens, James B.; Ohlander, Coryell; Benninghoff, Bruce. Many resources, many uses: a system analysis approach to renewable resource development. Water Resources Bulletin. 16(4): 738-744; 1980.

Atkinson, William A. Zeroing in on zoned management. Journal of Forestry. 84(1): 27-28; 1986.

Baumol, William J. Economic theory and operations analysis. 4th ed. Englewood Cliffs, NJ: Prentice Hall; 1977. 695 p.

Behan, R. W. The succotash syndrome, or multiple use: a heartfelt approach to forest land management. Natural Resources Journal. 7: 473-484; 1967.

Behan, R. W. Political popularity and conceptual nonsense: the strange case of sustained yield forestry. Environmental Law. 8(2): 309-342; 1978.

Behan, R. W. RPA/NFMA - time to punt. Journal of Forestry. 79(12): 802-805; 1981.

Bell, Enoch; Fight, Roger; Randall, Robert. ACE: the two edged sword. Journal of Forestry. 73(10): 642-644; 1975.

Bell, Enoch F. Problems with goal programming on a National Forest planning unit. In: Proceedings of systems analysis and forest resource management workshop; Athens, GA. Bethesda, MD: Society of American Foresters; 1975: 119-126.

Bennett, John D. Economics and the folklore of forestry. Syracuse, NY: Syracuse University; 1968. Ph.D. dissertation. 246 p.

Beuter, John H.; Johnson, K. Norman; Scheurman, H. Lynn. Timber for Oregon's tomorrow: an analysis of reasonably possible outcomes. Research Bulletin 19. Corvallis, OR: Oregon State University, School of Forestry, Forest Research Laboratory; 1976. 111 p.

Boise Cascade Corporation. Computer technology at work in the woods. Boise Cascade Quarterly Report. Boise, ID; 1980. 4 p. [Mimeo].

Broido, A.; O'Regan, W. G.; McConnen, R. J. Some operations research applications in the conservation of wildland resources. Management Sciences Ser. A 11(9): 802-814; 1965.

Cameron, Jenks. The development of governmental forest control in the United States. Baltimore, MD: Johns Hopkins Press; 1928. 471 p.

Chappelle, D. E.; Mang, M.; Miley, R. C. Evaluation of Timber RAM as a forest management planning model. Journal of Forestry. 74(5): 288-293; 1976.

Chappelle, Daniel E. A computer program for calculating allowable cut using the area-volume check method. Research Note PNW-44. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1966. 4 p.

Chappelle, Daniel E. A computer program for scheduling allowable cut using either area or volume regulation during sequential planning periods. Research Note PNW-93. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1968. 9 p.

Chappelle, Daniel E. Linear programming for forestry planning. In: Convery, F. J.; Ralston, C. W., eds. Forestry and long range planning. Durham, NC: Duke University, School of Forestry and Environmental Studies; 1977: 129-163.

Clawson, Marion. The federal lands revisited. Washington, DC: Resources for the Future; 1983. 302 p.

Clawson, Marion; Held, R. Burnell. The federal lands: their use and management. Baltimore, MD: Johns Hopkins Press for Resources for the Future; 1957. 501 p.

Congressional Record. Allowable timber cuts on federal land in Oregon—a tempest in a teapot. Unpublished excerpts from a preliminary review draft of a manuscript entitled "Timber trends in western Oregon and western Washington" dated August 1960, prepared by Division of Forest Economics, Pacific Northwest Forest and Range Experiment Station, Portland, OR. Testimony by Sen. Morse and others. January 17, 1966: 374-383.

Convery, Frank J. Land and multiple use. In: Clawson, M., ed. Research in forest economics and policy. Washington, DC: Resources for the Future; 1977: 249-326.

Crafts, Edward C. Saga of a law: Part I. American Forests. 76(6): 13-19, 52-54; 1970.

Crim, Sarah A.; Johnson, K. Norman. Allowing choices on a per acre and per area basis in forest planning. 1981. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Fort Collins, CO. 45 p.

Dana, Samuel T. Forest and range policy - its development in the United States. New York: McGraw-Hill; 1956. 455 p.

Dana, Samuel T.; Fairfax, Sally K. Forest and range policy. 2d ed. New York: McGraw-Hill; 1980. 458 p.

Dantzig, George B. Linear programming and extensions. Princeton, NJ: Princeton University Press; 1963. 627 p.

Davis, Kenneth. Forest management: regulation and valuation. 2d ed. New York: McGraw-Hill; 1966. 519 p.

Doig, Ivan. When the Doug-firs were counted. Journal of Forest History. 20(1): 20-27; 1976.

Dorfman, Robert. Mathematical, or "linear," programming: a non-mathematical exposition. In: Mansfield, Edwin, ed. Managerial economics and operations research: techniques, applications, cases. 4th ed. New York: Norton and Co.; 1953: 319-353.

Duerr, William A. Fundamentals of forestry economics. New York: McGraw-Hill; 1960. 579 p.

Duerr, William A.; Teeguarden, Dennis E.; Guttenberg, Sam; Christiansen, Neils, eds. Forest resource management. Philadelphia, PA: W. B. Saunders Co.; 1979. 612 p.

Dykstra, Dennis P. Mathematical programming for natural resources management. New York: McGraw-Hill; 1984. 318 p.

Field, D. B. Goal programming for forest management. Forest Science. 19(2): 125-135; 1973.

Field, Richard C. National Forest planning is promoting US Forest Service acceptance of operations research. Interfaces. 14(5): 67-76; 1984.

Fight, Roger D.; Johnson, K. Norman; Connaughton, Kent P.; Sassaman, Robert. Roadless area-intensive management tradeoffs on western National Forests. Revised. Washington, DC: U.S. Department of Agriculture, Forest Service; 1978. 57 p.

Fight, Roger D.; Johnson, K. Norman; Connaughton, Kent P.; Sassaman, Robert W. Can intensive management make up the harvest lost when roadless areas are left undeveloped? Journal of Forestry. 77(3): 148-151; 1979.

Gaffney, Mason. Concepts of financial maturity of timber and other assets. A.E. Information Series No. 62. Raleigh, NC: North Carolina State College, Department of Agricultural Economics; 1960. 105 p.

Geoffrion, Arthur M. The purpose of mathematical programming is insight, not numbers. Interfaces. 7(1): 81-92; 1976.

Gilbert, Bradley; Johnson, K. Norman; Crim, Sarah; Marose, Robin; Armel, Bryan. FORPLAN Version 2 user's guide [computer printout]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1985. Various pages.

Gross, L. A. Timber management plans on the National Forests. Washington, DC: U.S. Department of Agriculture, Forest Service, Division of Timber Management; 1950. 59 p.

Hill, M.; Kirsh, E.; Kirby, M.; Schwarzbart, G.; Valfer, E.; Wagner, D. Analysis of computer support systems for multifunctional planning: Report I. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Management Sciences Staff; 1974. 119 p.

Hrubes, Robert J.; Navon, Daniel I. Application of linear programming to downward sloping demand problems in timber production. Research Note PSW-315. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1976. 6 p.

Hyde, William F. Timber supply, land allocation, and economic efficiency. Baltimore, MD: Johns Hopkins Press for Resources for the Future, Inc.; 1980. 224 p.

Iverson, David C. The genesis of FORPLAN: an historical sketch of U.S. Forest Service resource management decision analysis. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1982. 27 p.

Johnson, K. Norman. A comment on "techniques for prescribing optimal timber harvest and investment under different objectives - discussion and synthesis." Forest Science. 23(4): 444-446; 1977.

Johnson, K. Norman. Timber activity on the National Forests: the second revolution; 1980. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Fort Collins, CO. 8 p. [Mimeo].

Johnson, K. Norman. Assessing the environmental feasibility of proposed timber schedules for the National Forests; recent developments and future needs. 1982. Unpublished paper prepared for Forest Planning Symposium sponsored by the University of California, Berkeley, on file at: U.S. Department of Agriculture, Forestry Service, Fort Collins, CO. 13 p.

Johnson, K. Norman. Personal communication, 1985.

Johnson, K. Norman. FORPLAN Version 1: an overview. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1986. 85 p.

Johnson, K. Norman; Crim, Sarah A. FORPLAN Version 1; structures and options guide. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1986. 214 p., var. numbered plus 8 appendixes.

Johnson, K. Norman; Jones, Daniel B. A user's guide to multiple use sustained yield resource scheduling calculation (MUSYC). Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Timber Management; 1979. 242 p.

Johnson, K. Norman; Scheurman, H. Lynn. Techniques prescribing optimal timber harvest and investment under different objectives—discussion and synthesis. Forest Science Monograph. 18. Washington, DC: Society of American Foresters; 1977. 31 p.

Johnson, K. Norman; Stuart, Thomas W. FORPLAN Version 2: mathematical programmer's guide. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1986. 156 p. plus appendix.

Johnson, K. Norman; Stuart, Thomas W.; Crim, Sarah A. FORPLAN Version 2 - an overview. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1986. 85 p.

Johnson, K. Norman; Stuart, Thomas W.; Russell, William. DE-FORPLAN—an overview. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1982. 80 p. [Draft].

Johnson, K. Norman; Tedder, Phillip L. Linear programming vs. binary search in periodic harvest level calculation. Forest Science. 29: 569-581; 1983.

Kaufman, H. The forest ranger: a study in administrative behavior. Baltimore, MD: Johns Hopkins Press; 1960. 259 p.

Kelly, James W.; Kent, Brian M.; Johnson, K. Norman; Jones, Daniel B. FORPLAN Version 1: user's guide. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1986. 171 p., var. numbered plus 10 appendixes.

Kent, Brian M. The Forest Service land management planner's introduction to linear programming. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1980. 63 p.

Kent, Brian M.; Kelly, James E.; King, John J. FORPLAN Version 1: mathematical programmers guide. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning Systems Section; 1985. 327 p., var. numbered plus 8 appendixes.

Kirby, Malcolm W. Large-scale budget applications of mathematical programming in the Forest Service. In:

Navon, Dan, compiler. Operational forest management planning methods: proceedings, meeting of steering systems project group, International Union of Forestry Research Organizations; 1978 June 18-24; Bucharest, Romania. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station; 1978: 60-67.

Kirby, Malcolm W.; Wegner, Dwain C.; Visser, Louis. ADVENT: a model for program budgeting, user's guide. 4th ed. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1978. Various pages [looseleaf].

Kirby, Malcolm W.; Wong, Peter; Hager, William A.; Huddleston, Mary E. Guide to the integrated resources planning model. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Management Sciences Staff; 1980. 212 p.

Klemperer, David W. The parable of the allowable pump effect. Journal of Forestry. 73(10): 640-641; 1975.

Koopmans, T. C., ed. Activity analysis of production and allocation: Proceedings of a conference. [Cowles Commission for Research in Economics Monograph No. 13.] New York: Wiley; 1951. 404 p.

Marsh, R. E.; Gibbons, W. H. Forest-resource conservation. In: Farmers in a changing world: the yearbook of agriculture. Washington, DC: U.S. Department of Agriculture; 1940: 458-488.

McArdle, Richard E. An interview [by Elwood Maunder] with the former Chief, U.S. Forest Service, 1952-1962. Santa Cruz, CA: Forest History Society; 1973. 262 p.

McCloskey, J. Michael. Note and comment: natural resources - National Forests - the Multiple Use-Sustained Yield Act of 1960. Oregon Law Review. 41: 49-77; 1961.

McConnen, R. J.; Amidon, E. L.; Navon, D. I. The use of operations research techniques in determining allowable cut. In: Annual meeting, Society of American Foresters: Proceedings; 1967: 109-115.

Navon, Daniel I. Computer-oriented systems for wildland management. Journal of Forestry. 65(7): 473-479; 1967.

Navon, Daniel I. Timber RAM. . .a long-range planning method for commercial timber lands under multiple-use management. Research Paper PSW-70. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1971. 22 p.

Navon, Daniel I.; Lundeen, Dean. A proposal for combined use of RAM and RCS as analytical tools for land use planning: Report I. In: Hill, M.; Hirsh, E.; Kirby, M.; Schwarzbart, G.; Valfer, E.; Wagner, D. Analysis of computer support systems for multifunctional planning. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Management Sciences Staff; 1974: 116-119.

Navon, Daniel I.; McConnen, Richard J. Evaluating forest management policies by parametric linear programming. Research Paper PSW-42. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1967. 13 p.

Neff, Paul E. Calculation of allowable harvest for the National Forests. Journal of Forestry. 71(2): 86-89; 1973.

Oregon State Forestry Department. 1980 Oregon timber supply assessment: projections of future available harvests. Salem, OR; 1980. 165 p.

O'Toole, Randall. The citizens' guide to FORPLAN. Eugene, OR: Cascade Holistic Economic Consultants; 1983. 51 p.

Pack, Arthur Newton. Forestry: an economic challenge. New York: Macmillan; 1933. 161 p.

Pemberton, Billy G. 1976 inter-university symposium on renewable resource assessment and programming: executive summary. General Technical Report PSW-21. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1977. 21 p.

Pickens, James B. NIMRAS system documentation. [Prepared for Peter G. Ashton, 1980 June 30.] Washington, DC: U.S Department of Agriculture, Forest Service; 1980. 45 p. plus 2 appendixes [mimeo].

Robinson, Glen O. The Forest Service: a study in public land management. Baltimore, MD: Johns Hopkins University Press for Resources for the Future; 1975. 337 p.

Sassaman, Robert W.; Holt, Ed.; Bergsvik, Karl. User's manual for a computer program for simulating intensively managed allowable cut. General Technical Report PNW-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1972. 50 p.

Samuelson, Paul. Economics of forestry in an evolving society. Economic Inquiry. 14: 466-491; 1976.

Schweitzer, Dennis L. Analysis to support planning for the National Forests in the United States. In: Kaiser, Fred; Schweitzer, Dennis; Brown, Perry, compilers. Proceedings for economic value analysis of multiple use forestry, International Union of Forest Research Organizations meeting; 1984; Denmark. Corvallis, OR: Oregon State University, Department of Resource Recreation Management; 1984: 123-132.

Schweitzer, Dennis L.; Cortner, Hanna J. Evolution of planning requirements for national public forestry in the United States. In: Kaiser, Fred; Schweitzer, Dennis; Brown, Perry, compilers. Proceedings for economic value analysis of multiple use forestry, International Union of Forestry Research Organizations meeting; 1984; Denmark. Corvallis, OR: Oregon State University, Department of Resource Recreation Management; 1984: 112-122.

Schweitzer, Dennis L.; Sassaman, Robert W.; Schallau, Con H. Allowable cut effect: some physical and economic implications. Journal of Forestry. 70(7): 415-418; 1972.

Shands, William E.; Healy, Robert G. The lands nobody wanted: policy for National Forests in the eastern United States. Washington, DC: Conservation Foundation; 1977. 282 p.

Steen, Harold K. The U.S. Forest Service: a history. 2d printing, with corrections. Seattle: University of Washington Press; 1977. 356 p.

Stuart, Thomas W.; Kent, Brian. Forest planning models in the USDA Forest Service: Where are we now? How did we get there? Where might we go from here? Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Land Management Planning; 1982. 24 p. [Draft unpublished paper.]

Teeguarden, Dennis E. The allowable cut effect: a comment. Journal of Forestry. 71(6): 357-369; 1973.

Thompson, Emmett F.; Halterman, Bernard G.; Lyon, Tunis J.; Miller, Robert L. Integrating timber and wildlife management planning. The Forestry Chronicle. 49(6): 247-250; 1973.

Towle, Everett L. A brief history of forest policy and the Forest Service in the United States. In: Actes du symposium international d'histoire forestiere, Vol. II, pp. 284-304. 1982. [Nancy, France: Ecole National du genie rural des eaux et des forets.]

Twight, Ben W. Organizational values and political power: the Forest Service versus the Olympic National Park. University Park, PA: The Pennsylvania State University Press; 1983. 139 p.

U.S. Congress, Senate. A national plan for American forestry. Senate Document No. 12, 73d Congress, First Session, 2 vols.; 1933. 1677 p.

U.S. Department of Agriculture, Forest Service. The use of the National Forests. Washington, DC; 1907. 42 p.

U.S. Department of Agriculture, Forest Service. The National Forest manual. Washington, DC; 1911. 45 p.

U.S. Department of Agriculture, Forest Service. Forests and national prosperity. Miscellaneous Publication 668. Washington, DC; 1948. 99 p.

U.S. Department of Agriculture, Forest Service. Forest land resources, requirements, problems, and policy. Part 8 of the supplementary report of the Land Planning Committee to the National Resources Board. Washington, DC; 1935. 114 p.

U.S. Department of Agriculture, Forest Service. Price trends and relationships for forest products. Washington, DC; 1957. 58 p.

U.S. Department of Agriculture, Forest Service. Timber resources for America's future. Forest Resource Report 14. Washington, DC; 1958. 713 p.

U.S. Department of Agriculture, Forest Service. Timber trends in western Oregon and western Washington. Research Paper PNW-5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Division of Forest Economics and Research; 1963. 154 p.

U.S. Department of Agriculture, Forest Service. Douglas-fir supply study: alternative programs for increasing timber supplies from National Forest lands. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1969. 53 p.

U.S. Department of Agriculture, Forest Service. Management practices on the Bitterroot National Forest. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1970. 100 p.

U.S. Department of Agriculture, Forest Service. Forest management in Wyoming - timber harvest and the environment on the Teton, Bridger, Shoshone, and Bighorn National Forests. Ogden, UT: Intermountain Region; and Denver, CO: Rocky Mountain Region; 1971. 80 p.

U.S. Department of Agriculture, Forest Service. Emergency Directive No. 16 [to FSM 2410.3]. Washington, DC; [issued May 1] 1973. 2 p.

U.S. Department of Agriculture, Forest Service. Socioeconomic overview for unified planning, Beaverhead National Forest. Publication No. R1-74-005. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1974. 96 p.

U.S. Department of Agriculture, Forest Service. Timber harvest scheduling issues study. Washington, DC; 1976. 292 p. plus 105 p.

U.S. Department of Agriculture, Forest Service. The nation's renewable resources—an assessment, 1975. Forest Resource Report 21. Washington, DC; 1977. 243 p.

U.S. Department of Agriculture, Forest Service. Letter from Douglas R. Leisz, Associate Chief, to Regional Foresters and National Forest Systems Staff Directors; File 1920; Subject: Development and use of forest planning model. 1979 December 3.

Walker, John L. An economic model for optimizing the rate of timber harvesting. Seattle: University of Washington; 1971. 117 p. Ph.D. dissertation. [Diss. Abstr. 32(5): 2276-A] [Microfilm No. 71-28489].

Watershed Systems Development Unit. The resource capability system: user's guide. Part I: an overview. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1972. 51 p.

Weintraub, Andres; Navon, Daniel. A forest management planning model integrating silvicultural and transportation activities. Management Science. 22(12): 1299-1309; 1976.

Wikstrom, John H.; Hutchison, S. Blair. Stratification of forest land for timber management planning on the western National Forests. Research Paper INT-108. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 38 p.

Wilkinson, Charles F.; Anderson, H. Michael. Land and resource planning in the National Forests. Oregon Law Review. 64(1 and 2): 1-373; 1985.

APPENDIX I: LINEAR PROGRAMMING IN BRIEF

The essence of linear programming (LP) can be conveyed by means of a relatively simple but concrete example. We present one illustration in a production context. Our purpose is only to introduce the basic concepts of linear programming. The reader who would learn to solve an LP problem, even the simplest, will have to look elsewhere. The standard references include Dantzig (1963) and Koopmans (1951). A nonmathematical, graphical approach may be found in Dorfman (1953). For the person who seriously wants to learn how to apply LP, see Baumol (1977), which includes an extensive treatment of the theory, sample applications in a variety of contexts including production, and simple problems to be worked out by the reader (with answers conveniently provided in the back of the text). For mathematical programming examples specific to natural resources management, see Dykstra (1984). Kent (1980) provides an introduction focusing on forest management. Of course, the short cut is to turn to widely available LP software compatible with personal computers. We do not recommend this approach except to those who have spent at least some time familiarizing themselves with the assumptions and limitations of the approach.

Forests are capable of producing multiple products, or outputs. For simplicity, assume that a 1,000-acre forest can produce varying amounts of timber, water, range forage, and primitive recreation depending on the number of acres allocated to each use. Forested land occupies 600 acres and rangeland covers the remaining 400 acres. For simplicity we assume two management strategies represented by decision variables for each type. Forested acres may be managed emphasizing either (1) timber or (2) primitive recreation, but not both. Rangeland, it is assumed, may be managed emphasizing (1) grazing and primitive recreation or (2) no grazing and primitive recreation. For this example we assume that timber management precludes primitive recreation and lowers water quality, and that grazing lowers quality, therefore value, of both water and recreation. Inputs will be limited to (1) the acres assigned to each use category and (2) the management activities (expenditures) undertaken for each output. We'll assume that the output per acre per year for timber is 15 M bd ft, for water is 0.1 acre-foot, for range is 0.5 animal unit months (AUM), and for recreation is 2 recreational visitor days (RVD). The management cost of an incremental unit of timber output (M bd ft) will be constant across all forested acres and equals, say, $10 per unit of output. Costs associated with a unit of water are $1.20 per acre-foot, range forage costs are $7 per AUM, and recreation costs are $4 per RVD. Stumpage values are $15 per unit, water $3 or $5 per unit (depending on quality), range forage $9 per unit, and recreation $5 or $7 a unit (depending on quality). Two final assumptions are that acres allocated to any management strategy are not available for other purposes, and the budget available for land management purposes is $8,000.

We may formulate this relatively simple (and simplistic) problem and display the output information and summarized cost and benefit data as shown in the following tabulation. The problem is to determine which use should be chosen in order to maximize the objective function—that is, the total (gross) value attainable in this example.

	Timber	Water	Range	Primitive recreation	Available
	Input required to produce one unit of output per year[1]				
Acres	0.067				600
		10		0.5	1,000
			2		400
$ management	10	1.2	7	4	8,000
	Dollar value per unit				
Forested land	15	3	—	—	Timber emphasis
	—	5	—	7	Primitive recreation emphasis
Rangeland	—	3	9	5	Grazing emphasis
	—	5	—	7	No grazing/ recreation emphasis

[1] Outputs per acre have been transformed into the acres required to produce one unit of output (for example, 15 M bd ft per acre for timber implies it requires 1/15 = 0.067 acre to produce 1 M bd ft).

To find the answers we may translate the problem into the following linear program in the four continuous decision variables (Timber emphasis = x_1, Primitive recreation emphasis = x_2, Grazing/Recreation emphasis = x_3, No grazing/Recreation emphasis = x_4). In this formulation each decision variable is associated with an activity column specifying the physical production relationships associated with each strategy. Also associated with each decision variable are coefficients that show the benefits (in the objective function) or costs (in the budget constraint) that are relevant to that decision variable. Note, however, that the objective function values are derived by multiplying the dollar value ($) per unit by the output per acre and summing across outputs produced under the management strategy. Thus, in the case of the timber emphasis, for example, the coefficient 225.3 for x_1 is obtained by multiplying the value of $15 per M bd ft times the output per acre of 15 M bd ft and then adding the $3 water value per acre-foot times the output per acre of 0.1 acre-foot: ($15 × 15) + ($3 × 0.1) = 225.3. Other coefficients, including those in the budget constraint, are similarly derived. Note also that water values are lower when timber harvesting is present ($3) in comparison to water values in the absence of timber harvesting ($5), reflecting our assumption of changes in water quality. In a similar fashion, the value of recreation is negatively impacted by the grazing activity, when present ($5 with grazing vs. $7 without). Inspection will show that grazing also negatively affects water quality and value, as was the case with timber harvest.

Mathematically, the model specification is:

Maximize value:

$$V = 225.3x_1 + 14.5x_2 + 14.8x_3 + 14.5x_4$$

Subject to:

acreage constraints

$$\begin{array}{llllll} 1x_1 + & 1x_2 & & & \leqslant & 600 \\ & & 1x_3 + & 1x_4 & \leqslant & 400 \end{array}$$

budget constraint

$$150.12x_1 + 8.12x_2 + 11.62x_3 + 8.12x_4 \leqslant 8{,}000$$

To rule out absurd results we must also impose nonnegativity requirements: $x_1 \geqslant 0$, $x_2 \geqslant 0$, $x_3 \geqslant 0$, $x_4 \geqslant 0$.

This is the standard form for an LP problem. It consists of four parts: (1) the function (V) (such as profits, costs, present net value) whose value is to be maximized or minimized, which is called the objective function; (2) the prescriptions or activity columns $\{a\}_j$'s represent the potential strategies for land use and are associated with decision variables (x_j's); (3) the constraint rows, such as capacity, budget, or minimum output, and (4) the nonnegativity conditions on the variables. The above example contains the case of four decision variables and three constraints.

We state the generalized n-variable, m-constraint linear program in two ways: in longhand and in summation (Σ) notation. (A third approach, matrix notation, is not presented here.)

When completely written out, a maximization program in n variables and subject to m constraints will appear as follows:

$$\begin{array}{lcl} \text{Maximize: } V = & c_1 x_1 + c_2 x_2 + \ldots + c_n x_n & \\ \text{Subject to:} & a_{11} x_1 + a_{12} x_2 + \ldots + a_{1n} x_n \leqslant r_1 & \\ & a_{21} x_1 + a_{22} x_2 + \ldots + a_{2n} x_n \leqslant r_2 & \\ & \cdot \quad \cdot \quad \cdot \quad \cdot & \\ & \cdot \quad \cdot \quad \cdot \quad \cdot & \\ & a_{m1} x_1 + a_{m2} x_2 + \ldots + a_{mn} x_n \leqslant r_m & \\ \text{and} & x_j \geqslant 0 \ (j = 1, 2, \ldots, n) & \end{array}$$

The value of the objective function (V) is to be maximized. The decision (choice) variables are denoted by x_j ($j = 1, 2, \ldots, n$). The coefficients in the objective function are designated by c_j (with $j = 1, 2, \ldots, n$) and are a set of given constants. The r_i symbols ($i = 1, 2, \ldots, m$) are another set of constants and represent restrictions (or requirements, in which case the inequality would be reversed, $\geqslant$). Of course, each of the constraints (restrictions or requirements) could be written as strict equalities ($=$). The coefficients for the decision variables in the constraints represented by a_{ij} ($i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$) are also a set of given constants.

A substantial savings in space can be achieved by expressing the linear programs in summation (Σ) notation:

$$\text{Maximize: } V = \sum_{j=1}^{n} c_j x_j$$

$$\text{Subject to: } \sum_{j=1}^{n} a_{ij} x_j \leqslant r_i \quad (i = 1, 2, \ldots, m)$$

$$\text{and} \quad x_j \geqslant 0 \qquad (j = 1, 2, \ldots, n)$$

We use this concise summation notation in appendix II. The notation contains all elements (objective function, constraint set, and nonnegativity requirements) in the standardized version.

Our simple example points up the problems that ultimately faced analysts. Their task was to find a way to formulate the questions faced by decision makers, taking into account the realities of the systems within which forest land management would take place. In our example, acres assigned to timber are assumed unavailable for other uses. In practice, of course, acreage available for timber production may be simultaneously used for domestic livestock forage. Our example only generates a total output level for each decision variable, but it does not tell us where to locate the activities that generate those output levels. This is the spatial problem. Closely related to the spatial question of where to obtain desired outputs is the transportation problem. What about roading costs? When and where will transportation networks need to be developed if the desired levels of output are in fact to be achievable?

Furthermore, our example did not illustrate the fact that certain minimal levels of output for each decision variable may be required if multiple-use mandates (and public demands) are to be met. This is the problem of predetermined minimum (or maximum) levels of output within which the objective function is to be maximized. Such constraints may show up in the form of sustained yield or nondeclining yield requirements, minimum levels of water (quality or quantity), formalized rights to minimum grazing established by permit systems, or acreage that is not available due to administrative assignment (such as research natural areas, wilderness, or visual impact areas).

Our sample problem assumed that there was only one production process or management activity by which to obtain outputs. In the real world, of course, a complex spectrum of options exists. Thus, a particular harvest level in the future may be achieved by increasing acres assigned to harvest, through silvicultural practices such as precommercial thinning and fertilization, or with genetic selection in reforestation practices, to mention only a few options.

Complexities abound. And it was precisely such complexities that led to the model development, refinement, and evolution described in the main body of this paper.

APPENDIX II: MATHEMATICAL STRUCTURE OF VARIOUS FOREST PLANNING MODELS

In this appendix five mathematical structures are presented and related to the various models discussed in the body of the report. The intent is modest and limited to illustrating land use and harvest scheduling in terms of decision variables and rows used to account for acres represented in the problem. A complete description of model structures including discussion of control rows can be found in the mathematical programmer's guides that accompany each of the models (see especially Johnson and Stuart 1986). Given our modest goal, we restrict attention to timber outputs. Extrapolation to other resource products is relatively straightforward. In the following discussion, each relation (objective function or constraint equation) is identified by reference to the model (such as Form A, B, C, D, or E) where it first appears and is defined. Certain relations appear in more than one structure and are numbered to help readers identify those that are repeated and those that are new or unique to a particular model form. For example, the number "B 3" refers to a relation that first appears in Model Form B, and is the third new relation added in the appendix by Model Form B.

FORM A: Timber Harvest Scheduling Model I

The following structure is indicative of timber scheduling problems formulated in Timber RAM, MUSYC, and FORPLAN Version 1 or Version 2. In Model I, a prescription describes the sequence of activities on a user-defined analysis area for each period to the planning horizon.

Maximize: $$\sum_{s=1}^{F} \sum_{i=1}^{P_s} \sum_{k=1}^{T_i} A_{sik} x_{sik} \qquad \text{(A 1)}$$

Subject to: area constraints

$$\sum_{i=1}^{P_s} \sum_{k=1}^{T_i} x_{sik} = \text{Area}_s \quad s = 1 \ldots F \qquad \text{(A 2)}$$

and nonnegativity requirements

$$x_{sik} \geqslant 0 \quad \text{for all } s, i, k \qquad \text{(A 3)}$$

where:

x_{sik} = acres assigned to timing choice k of prescription i of analysis area s

A_{sik} = contribution to the objective function per acre from timing choice k of prescription i of analysis area s

F = number of analysis areas

P_s = number of prescriptions for analysis area s

T_i = number of timing choices for prescription i (of analysis area s)

Area_s = size of analysis area s in acres.

FORM B: Timber Harvest Scheduling Model II

The following structure is indicative of timber scheduling problems formulated using MUSYC, FORPLAN Version 1 or Version 2 when Model II is desired (Johnson and Scheurman 1977). In Model II, a prescription describes the sequence of activities on a user-defined analysis area for each period until the area is harvested. Another prescription will then track activities on regenerated acres.

Maximize: $$\sum_{s=1}^{F} \sum_{i=1}^{P_s} \sum_{k=1}^{T_i} A_{sik} x_{sik} + \sum_{r=1}^{R} \sum_{z=1}^{P_r} \sum_{k=1}^{T_z} B_{rjzk} y_{rjzk} \qquad \text{(B 1)}$$

Subject to: area constraints

$$\sum_{i=1}^{P_s} \sum_{k=1}^{T_i} x_{sik} = \text{Area}_s \quad s = 1 \ldots F \qquad \text{(A 2)}$$

regeneration area constraints

$$\sum_{z=1}^{P_r} \sum_{k=1}^{T_z} y_{rjzk} - \sum_{s=1}^{F} \sum_{i=1}^{P_s} \sum_{k=1}^{T_i} x_{sik} = 0 \qquad \text{(B 2)}$$

$$j = 1 \ldots J$$
$$r = 1 \ldots R$$

and nonnegativity requirements

$$x_{sik} \geqslant \text{ for all } s, i, k \qquad \text{(A 3)}$$

$$y_{rjzk} \geqslant 0 \text{ for all } r, j, z, k \qquad \text{(B 3)}$$

where:

x_{sik}, A_{sik}, F, P_s, T_i, and Area_s are defined in Form A

y_{rjzk} = acres established (recognized) in period j that are assigned to timing choice k for prescription z of regeneration class r

B_{rjzk} = contribution to the objective function from an acre established (recognized) in period j that is assigned to timing choice k for prescription z of regeneration class r

J = number of time periods

P_r = number of prescriptions for regeneration class r

R = number of regeneration classes

T_z = number of timing choices for prescription z (of regeneration class r).

FORM C: Timber Harvest Scheduling Generalized Model II

The following structure is indicative of timber scheduling problems formulated with FORPLAN Version 2 (Johnson and Stuart 1986). This structure broadens the Model II structure of Johnson and Scheurman (1977) in three ways: (1) acres can be passed to multiple regeneration classes at regeneration harvest (instead of only one regeneration class), (2) acres can be passed to regeneration classes at all stand ages up to regeneration harvest, and (3) acres passed to a regeneration class can contain stands with an age greater than zero.

Maximize: $$\sum_{s=1}^{F} \sum_{i=1}^{P_s} \sum_{k=1}^{T_i} A_{sik} x_{sik} + \sum_{r=1}^{R} \sum_{z=1}^{P_r} \sum_{k=1}^{T_z} B_{rjzk} y_{rjzk} \qquad \text{(B 1)}$$

Subject to: area constraints

$$\sum_{i=1}^{P_s} \sum_{k=1}^{T_i} x_{sik} = \text{Area}_s \quad s = 1 \ldots F \qquad \text{(A 2)}$$

regeneration area constraints

$$\sum_{z=1}^{P_r} \sum_{k=1}^{T_z} y_{rjzk} - \sum_{s=1}^{F} \sum_{i=1}^{P_s} \sum_{k=1}^{T_i} G_{rjsik} x_{sik} -$$
$$\sum_{r'=1}^{R} \sum_{j'=1}^{j-1} \sum_{z=1}^{P_r} \sum_{k=1}^{T_z} H_{rjr'j'zk} y_{r'j'zk} = 0 \qquad \text{(C 1)}$$

$$j = 1 \ldots J$$
$$r = 1 \ldots R$$

and nonnegativity requirements

$$x_{sik} \geqslant 0 \text{ for all } s, i, k \qquad \text{(A 3)}$$

$$y_{rjzk} \geqslant 0 \text{ for all } r, j, z, k \qquad \text{(B 3)}$$

$$y_{r'j'zk} \geqslant 0 \text{ for all } r', j', z, k \qquad \text{(C 2)}$$

where:

x_{sik}, A_{sik}, F, P_s, T_i, and Area_s are defined in Form A

y_{rjzk}, B_{rjzk}, J, P_r, R, and T_z are defined in Form B

$y_{r'j'zk}$ = acres established (recognized) in period j' that are assigned to timing choice k for prescription z of regeneration class r'

G_{rjsik} = a factor that gives the proportion of the acres assigned to timing choice k for prescription i of analysis area s that transfers to regeneration class r in period j

$H_{rjr'j'zk}$ = a factor that gives the proportion of the acres assigned to timing choice k

for prescription z of regeneration class r' established (recognized) in period j' that transfers to regeneration class r in period j.

FORM D: Timber Harvest Scheduling Recognizing Contiguous Land Use Zones

The following structure is indicative of timber harvest scheduling formulated, for convenience purposes, in Model I. Model II scheduling is also possible but is not presented here. Activity Columns labeled "allocation choices" are specified for activities, such as roadbuilding, that do not lend themselves to prescription activity columns specified in Forms A, B, or C. Allocation choices are linked to the previously defined prescriptions. Note that scheduling is depicted to be forestwide. In FORPLAN Version 2, the user may choose to impose control on harvest schedules forestwide or at some other level of aggregation defined by the user, including the option to develop schedules by allocation zone. In FORPLAN Version 1, aggregate emphases formulations always scheduled within each allocation zone (or emphasis area). That is, instead of x_{sik} the aggregate emphases formulation developed x_{tsik}. The aggregate emphases formulation, therefore, constitutes a special case of models taking Form D.

Maximize: $\sum_{t=1}^{E}\sum_{m=1}^{CH_t}\sum_{n=1}^{T_m} C_{tmn} w_{tmn} + \sum_{s=1}^{F}\sum_{i=1}^{P_{sp}}\sum_{k=1}^{T_i} A_{sik} x_{sik}$ (D 1)

Subject to: area constraints[4]

$$\sum_{m=1}^{CH_t}\sum_{n=1}^{T_m} w_{tmn} = 1 \qquad t = 1\ldots E \qquad \text{(D 2)}$$

$$\sum_{t=1}^{E}\sum_{m=1}^{CH_t}\sum_{n=1}^{T_m} \text{Area}_{tmnspj}\, w_{tmn} - \sum_{i=1}^{P_{sp}}\sum_{k=1}^{T_i} x_{sik} + u_{spj} - v_{spj} = 0 \qquad \begin{array}{l} j = 1\ldots J_{sp} \\ s = 1\ldots F \\ p = 1\ldots PG \end{array} \qquad \text{(D 3)}$$

and nonnegativity requirements

$w_{tmn} \geqslant 0$ for all t, m, n (D 4)

$x_{sik} \geqslant 0$ for all s, i, k (A 3)

$u_{spj} \geqslant 0$ for all s, p, j (D 5)

$v_{spj} \geqslant 0$ for all s, p, j (D 6)

where:

x_{sik}, A_{sik}, F, and T_i are defined in Form A

C_{tmn} = contribution to the objective function per area from timing choice n of allocation choice m on allocation zone t

w_{tmn} = proportion of allocation zone t assigned to timing choice n of allocation choice m

CH_t = number of allocation choices (for allocation zone t)

E = number of allocation zones

T_m = number of timing choices for allocation choice m (of allocation zone t)

$Area_{tmnspj}$ = acres of analysis area s located in allocation zone t (and managed under timing choice n of allocation choice m) which are made available for use by prescription group p in period j

P_{sp} = number of prescriptions from analysis area s that are in prescription group p

T_i' = limited number of timing choices for prescription i. Model reflects a full range of choices, but only a limited number are explicitly represented when used with acreage transfer variables u_{spj} and v_{spj}

u_{spj} = acres from analysis area s made available in periods prior to period j for use by prescription group p that were not used, therefore are available for use in period j by prescription group p

v_{spj} = acres from analysis area s made available in period j for use by prescription group p that are not used in period j, therefore are available for use by prescription group p in subsequent periods

J_{sp} = number of periods in which acres from analysis area s are made available for use by prescription group p

PG = number of prescription groups.

FORM E: Timber Harvest Scheduling Packaged Within Land Use Zones

The following structure is indicative of timber scheduling problems formulated in FORPLAN Version 2 where all activities, outputs, costs, and benefits are uniquely specified by land use zone. With minor modifications, this formulation is also available in ADVENT and IRPM. (In IRPM, "traffic flow" variables are structured as continuous decision variables that are mathematically linked to packaged "project" decision variables. IRPM, therefore, can be viewed as a modified Form E model.) In this formulation, schedules are packaged and embedded into allocation choices. That is, no separate scheduling prescriptions are developed.

Maximize: $\sum_{t=1}^{E}\sum_{m=1}^{CH_t}\sum_{n=1}^{T_m} D_{tmn} z_{tmn}$ (E 1)

Subject to: area constraints

$$\sum_{m=1}^{CH_t}\sum_{n=1}^{T_m} z_{tmn} = 1 \qquad t = 1\ldots E \qquad \text{(E 2)}$$

and nonnegativity requirement

$z_{tmn} \geqslant 0$ for all t, m, n (E 3)

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[4] The "proportional approach" outlined by Johnson and Stuart (1986, Chapter 5) specifies area constraints as depicted here and in Form E. Earlier specifications of area constraints (Forms A, B, C) follow what is referred to as the "acreage approach." FORPLAN Version 2 allows for specification of area constraints either way as a user option.

where:

CH_t, E, and T_m are defined in Form D

D_{tmn} = the contribution to the objective function of a particular strategy, mn, practiced on zone t

z_{tmn} = proportion of zone t managed under strategy m with timing choice n.

Summary

Whereas most models are somewhat restricted regarding the type problem to be analyzed, FORPLAN Version 2 can be used to analyze problems using any of the forms discussed. Further, the user may mix and match forms within any problem definition. All other models discussed are largely form dependent. That is, without a great deal of alteration and adjustment, the mathematical form underlying analysis performed with the models is itself dictated by the model. Timber RAM typically analyzed problems represented by Form A. MUSYC analyzed problems represented by either Form A or Form B. FORPLAN Version 1 analyzed problems represented by Form A, B, or D. ADVENT uses Form E. IRPM includes roading and timber project activity columns characteristic of Form E. In addition, "traffic flow" decision variables not characteristic of Form E are specified and linked mathematically to the decision variables associated with projects.

APPENDIX III: GLOSSARY

Many terms familiar to land management planners, resource specialists, and mathematical programmers are given particular meaning in this monograph. Some of the terms have been defined for official Forest Service use. See the Forest Service Manual (FSM 1970.5) and 36 CFR 219.3.

Activity. Any action or treatment defined as an input in a prescription.

Activity column. Aspects of a production relationship specified as a column vector in a linear programming (LP) problem.

Activity schedule. The sequence of activities prescribed in the production of the output(s) under consideration. The activities span many periods from the present to the planning horizon.

Aggregate emphasis. A prescription specifying part of a production relationship for an identified zone of land. The aggregate emphasis packages those aspects of production unique to the zone defined on a "per area" basis. It is represented as an "activity column" with an accompanying decision variable in LP problems. An aggregate emphasis is always used in conjunction with other prescriptions defined for strata-based analysis areas within the zone. It is unique to FORPLAN Version 1.

Allocation choice. A prescription unique to FORPLAN Version 2. It is similar to an aggregate emphasis in Version 1, but allows somewhat more generally defined output scheduling. Specifically, it is used in conjunction with other prescriptions defined for strata-based analysis areas either within the zone or defined such that a portion of the analysis areas is located within the zone and portions located elsewhere on the forest. In the first case an allocation choice is equivalent to an aggregate emphasis. In the second case, output scheduling decisions are modeled forestwide or at a level of aggregation higher than the associated allocation zone.

Allocation zone. A contiguous area of land identified for purposes of analysis. It may be denoted by ecological characteristics such as watershed, by economic characteristics such as haul zone, or by other characteristics suited to the purpose of the analysis.

Analysis area. Area of focus in defining response to prescriptions. Analysis areas represent either contiguous or noncontiguous areas of land. Contiguous analysis areas represent logical management units such as "wilderness areas" or "transportation access areas." Because prescriptions for these areas represent treatment for all lands within the zone, contiguous analysis areas are often referred to as an "area-based" stratification. Noncontiguous analysis areas generally represent scattered areas of land possessing similar characteristics such as site productivity, cover type, degree of access, or some combination thereof. An analysis area so defined is referred to as "strata-based" because all acres included in the analysis area are assumed to respond similarly to a prescription.

Coordinated schedule. An activity column specifying all the production relationships for a zone of land. The activity column specifies both location and timing for all activities, outputs, costs, and benefits from the present to the planning horizon.

Constraint. Restriction or requirement on the quantity of an input used or output produced. Constraints may be defined as "control rows" or defined as restrictions embedded in "activity columns" in LP problems. Additionally, constraints may be defined as control rows to "link" prescriptions together to specify production relationships in some model formulations.

Decision variables. The choices available in optimizing an objective function, subject to a specified set of constraints. In LP problems discussed here, these variables typically reflect the number of acres assigned to a prescription and an associated timing choice.

Linear programming. A special class of mathematical programming problems that requires all relations among decision variables to be linear. Mathematical programming, in turn, deals with determining the optimal allocations of limited resources to meet stated objectives.

Management emphasis. An aspect of a prescription that characterizes the overall goals and objectives for an analysis area managed under that prescription.

Management intensity. An aspect of a prescription that characterizes an investment level or other indicator of the degree to which treatments are prescribed.

Objective function. A mathematical relation stating the set of goals to be optimized when solving a mathematical programming problem. Common objective functions discussed here include "maximize first period timber harvest" and "maximize present net value."

Output. A product, service, or use that results from the application of a prescription to an analysis area.

Output schedule. The sequence of output yields predicted in each period to the planning horizon. An output schedule is often derived as a solution to an LP problem. As such, it is tied to the associated activity schedule.

Period. A time interval, usually a decade, defined for purposes of analysis. Analysts typically define between 15 and 30 such periods in evaluating forest management options.

Planning horizon. The last period for which inputs or outputs are to be explicitly represented, especially in defining constraints.

Prescription. A set of management practices or activities with associated standards and guidelines. Each prescription is a point from a production function, projecting activities, outputs, costs, and benefits through time. A prescription may be defined by a single activity column or by several columns that are linked mathematically for analysis. Decision variables are associated with prescriptions and reflect the number of acres assigned to a prescription for a particular timing choice in the solution to an LP problem.

Timber activity schedule. The sequence of activities or silvicultural treatments prescribed for lands suited for timber production.

Timber harvest schedule. The sequence of timber volumes to be cut in each period to the planning horizon. A harvest schedule is often derived as a solution to an LP problem. As such, it is tied to the associated timber activity schedule.

Timing choice. An aspect of a prescription and its associated decision variable indicating the period of implementation for a set of activities

Treatment. Any action or activity related to the production of outputs. Treatments are defined as activities in a prescription and span many periods from the present to the planning horizon.

Iverson, David C.; Alston, Richard M. The genesis of FORPLAN: a historical and analytical review of Forest Service planning models. General Technical Report INT-214. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1986. 31 p.

Historical review of Forest Service resource planning shows a steady movement away from timber harvest scheduling toward interdisciplinary, integrated planning. Three linear programming models—Timber Resource Allocation Method (Timber RAM), Multiple Use-Sustained Yield Calculation Technique (MUSYC), and Forest Planning Model (FORPLAN)—are evaluated in terms of basic structure and role in the evolutionary process.

KEYWORDS: forest management planning, harvest scheduling, linear programming, multiple use, natural resource management, FORPLAN, MUSYC, Timber RAM

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