SYSTEMS ANALYSIS IN LAND-USE PLANNING... a conceptual development

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USDA FOREST SERVICE
GENERAL TECHNICAL
REPORT PSW- 5 /1973

Oliveira, Ronald A.

1973. **Systems analysis in land-use planning . . . a conceptual development.** Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 8 p., illus. (USDA Forest Serv. Gen. Tech. Rep. PSW-5)

A planning model in which social, economic, and environmental constraints are specified—especially in mathematical form—can be helpful in decisionmaking. The general structure of a land-use decision model approached through systems analysis is described. The proposed procedures emphasize the quantification of interrelationships between uses and the specification of preferences and goals. The complexity of land-use planning is illustrated by an account of how the model might be applied on a Forest Service Ranger District of a National Forest in Colorado.

Oxford: 624:908:907.2.
Retrieval Terms: land-use decisionmaking; resource allocation; planning models; multiple-use management; systems analysis; Dillon Ranger District; Arapaho National Forest.

CONTENTS

As population pressures have increased and national goals changed in past decades, land-use decisions have become increasingly complex and difficult. The reasons are not far to seek. Choices must be made between conflicting uses of resources. Necessary data and analysis of resource relationships are often lacking. Local objectives and problems have regional and national ramifications. As the manager of the National Forests, the Forest Service is confronted with particularly difficult and widely influential decisions, together with the need to make the basis of such decisions clearly evident. As a result, the improvement of planning methods has become an important concern of both the agency and the public.

A planning model in which social, economic, and environmental constraints are specified, especially in mathematical form, can be a valuable guide to decisionmaking. Such a model allows evaluation of the effects of policy alternatives and changing conditions. It can cover either a broad area, such as a region or a National Forest, or can be limited to a particular district or planning unit.

This report describes the general structure of a land-use decision model approached through systems analysis. Actual relationships are not developed in detail. The type of model presented is most suitable for determining the desirable balance of alternative resource uses for a specific area, in the context of the broad goals of Forest Service management. To illustrate the complexity of land planning, some problems facing the Dillon Ranger District, Arapaho National Forest, in Summit County Colorado, are described. Examples of some elements of the planning model are drawn from this area.

LAND-USE PROBLEMS

The multiple-use concept requires that a land unit be managed so as to achieve the best possible balance of resource uses. Such balancing may mean that a land unit is used less than its potential number of uses–if full utilization might impair the use of either that unit or another for a purpose to which it is peculiarly suited. The Forest Service Manual (Title 1, November 1, 1971) defines multiple use as the "management of all the various renewable surface resources of the National Forests so that they are utilized in the combination that will best meet the needs of the American people. . .with consideration being given to the relative values of the various resources, and not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output." Multiple use, then is not necessarily equal use; it means equal consideration for each resource in determining the "best" possible combination of uses. This outcome requires knowledge of how one use affects another, of how to measure present use and predict future demands, and how to weight different uses when conflicts arise.

Evaluation or weighting of the various conflicting uses can be troublesome. Besides the difficulty of collecting and analyzing data for such resources as timber and water there is the problem of quantifying the intangible, or at least unmarketable, products of National Forest use, such as the esthetic quality of a landscape or a wilderness experience. The value of such uses is evident in the costs incurred to experience them. Moreover, in order to experience such uses people often forego the opportunity to engage in other activities that may have a market-determined price or value.

The relationship of National Forest land use to that of surrounding areas is another source of problems. Land managed privately or by local communities, county, State, and other Federal agencies affects and is affected by National Forest management. Such relationships should be considered to achieve the aims of comprehensive multiple-use management. Varying origins of demand for a particular use must also be considered. Local demands may, for example, conflict with national ones. Too superficial an inventory and analysis of the relationships of non-National Forest resources and social and economic conditions will limit the usefulness of unit or District plans.

Thus, National Forest land-use planning must account for a complex system of interrelated elements. It seems reasonable that an empirical decisionmaking procedure for such planning should emphasize the need to explain the workings of the system.

DILLON RANGER DISTRICT

The Dillon Ranger District offers an illustration of the complexity of land-use problems on the National Forests. The District surrounds Dillon Reservoir. Here, most problems of land use arise from high demands for recreation in several competing forms. Dillon Reservoir is a drawing card for water-related recreation activities and is a water supply facility for Denver. In addition, several ski developments are in the area. These two attractions and the general scenic beauty of the area have made it popular for second home and mountain condominium developments as well as for the usual day and weekend recreation uses.

These high recreation demands and the expanding activity in building have created an atmosphere of urgency concerning land-use planning in the Dillon area. Some development is occurring on areas with unstable soils, high pollution potential, and high fire hazards. Inadequate sewage facilities may lead to water pollution problems. Many of the new developments may also face water supply problems in the future.

Consequently, the Dillon Ranger District must consider these conditions in its planning. The surge of construction resulting from the impetus of winter sports and reservoir developments is occurring on private land adjacent to the National Forest. Thus, the National Forest serves as a "backyard play area" to these developments, and pressure on the capabilities of the Forest lands continues to rise. The Forest Service needs to know and stipulate the recreation capacity of various land types on the Forest and the capital requirements associated with varying levels of capacity. In addition, its fire prevention capabilities are facing increasing pressure from the higher population densities in subdivisions on private lands as well as from intensified use of the National Forest land.

Campground use on the Dillon Ranger District has been high in past seasons and is expected to grow unless terminated or otherwise controlled. Increasing fire and water pollution hazards of high campground use, as well as financial limitations, have obliged the District to consider the various alternatives; that is, should more campgrounds be built and who should build them, or should all camping be prohibited and public areas limited to day use?

Land exchanges are needed to facilitate judicious and coordinated development of both public and private lands. Developers are seeking more suitable sites along the Blue and Snake Rivers. It is also desirable to leave these areas as open space, however, to reduce flood hazards and maintain esthetic quality. Whether these areas are to become part of private subdivisions, or be left as open space, or become partly open space and partly subdivisions must be determined. These land exchange issues are an essential element in coordination of Forest Service land-use plans with those of the local communities and Summit County.

The variety of land-use problems in the Dillon area has resulted in the expression in multiple-use plans of intention to take specific actions. These actions (e.g., "Convert recreation sites to day use only" or "Retain and obtain in public ownership or open space maximum frontage along the Blue River") may eventually prove to be the "best" ones. But they appear to be preconceived solutions based on conventional wisdom, rather than the outcome of study or analysis, supported by facts, in a form understandable to the public. Perhaps a better planning procedure would be to consider all relevant relationships between land uses, public demands, ecosystems, etc., in the light of the principles of multiple-use management. By so doing it would be possible to set forth the policy actions needed to meet the goals of the Region, Forest, Ranger District, County, and State. The systems analysis approach seems the appropriate one.

SYSTEMS ANALYSIS APPROACH

A systems orientation implies a view of a system of elements as a whole, rather than individually. That is, this perspective emphasizes the interdependencies between the elements of the system and concentrates attention on their relationships (DeLucia *et al.* 1971; Churchman 1968).

Often the systems approach to complex problem solving requires data gathering and analysis by interdisciplinary teams. It is not always obvious in advance which disciplines will make the major contribution to the study. Viewpoints and procedures may be drawn from a variety of disciplines.

In the construction of large systems models, the gap between specialists is often bridged by a mathematical formulation. This formulation provides valuable guidance for research and data collection and allows the engineer, the economist, the biologist, and others to see how small but vitally important pieces of information and theory can merge, and to recognize critical gaps in existing information and knowledge. Mathematical models are tools of the systems approach. Their development and utilization provide a useful framework for integrating the contributions from various disciplines and for incorporating data and the research results from different fields.

Specifying System Boundary

The nature and scope of the particular problem at hand defines the system boundary—the "line" that surrounds those elements considered to be part of the system. In the "art of systems analysis," specifying

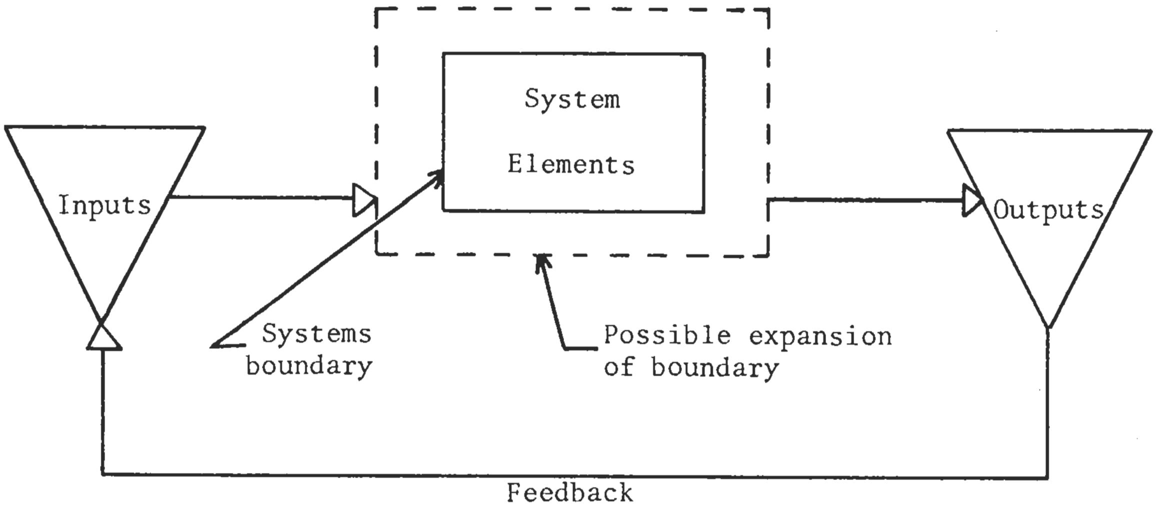

Figure 1—A basic system model consists of inputs, elements of the system, and the outputs. The boundary of the system can be expanded to cover problems whose scope widens during the systems analysis.

this boundary enables the user to choose the appropriate model to define the system. Land-use planning models are subjective in that the system boundary is not an objective datum perceivable through direct observation, but is largely a choice of the analyst, who arbitrarily classifies some borderline interactions as exogenous (outside the system).

The system boundary is specified to include those elements that are interrelated and pertinent to the set of decisions to be made. The boundary usually encloses those parts of the system that are subject to some degree of control. For example, if in planning for campground units it is assumed that the demand functions for campgrounds are known but that pricing policy is beyond the planner's control, then demands are noncontrolled. If, however, the planner can charge camping fees or establish quotas, demands are now at least partially controllable, and are considered endogenous to the system. In effect, the scope of the problem can expand or contract the system boundary definition. In addition, it can influence the degree of aggregation and approximation with which pertinent interacting elements are considered.

A system in simple terms is charted in *figure 1.* The system receives inputs–some controlled, others not–that affect the interaction of system elements. Outputs are produced which in dynamic systems may affect the inputs (feedback). The control decisions seek to achieve some objective or set of objectives. A simplified example of such a system could be a National Forest campground area. The inputs would be demand for the campground, fees, and other campground regulations, type of sites, soil types and slopes, vegetation, etc. The system would be the interaction of these inputs, and the outputs would be environmental quality of the area, fire hazard, actual campground use, etc. These outputs in turn would have feedback effects on future inputs. Forest Service decisionmakers, recognizing the interactions within the system, would manipulate the controllable inputs, such as length-of-stay or limit, to achieve the outputs desired.

Evaluating Resource Uses

A systems analysis approach to the integrated control and use of National Forest resources provides for the examination and evaluation of a large number of possible resource uses. It does not necessarily, however, require the inclusion of all uses in the resource development plan. Inclusion or exclusion depends on the degree to which a particular use contributes to the broad objectives of land use, and on the extent to which the use is complementary to other desired uses. The danger exists that the attempt to be comprehensive may be used to guarantee the inclusion of certain preselected uses. A systems planning effort that is well designed and executed avoids this hazard.

In contrast to the traditional analysis of a particular function, a well-defined systems model allows decisionmakers to assess the degree of complementarity between purposes. Complementarity may be considered a measure of the efficiency with which a land resource system can serve several purposes—sites for outdoor recreation, timber production, and wildlife habitat, for example. Complementarity exists when a stand of timber that is thinned to control disease and insect damage yields usable wood. Similarly, the thinning may improve stand growth and wildlife habitat. Different purposes are usually not perfectly compatible; for instance, timber harvesting and recreation seasons may coincide, and the removal of trees may temporarily reduce the esthetic quality of the landscape. If a system is developed and operated to obtain maximum efficiency for one resource use, then in general, less than full efficiency is achieved in other uses.

DEVELOPMENT OF A SYSTEMS MODEL

In general, the most appropriate situation for the application of systems analysis is one in which conditions are changing too rapidly for experience to be assimilated by informal, unsystematic methods, but slowly enough to permit the formulation of a model applicable to both the recent past and relevant future, and to permit the accumulation of the data needed (DeLucia, *et al.* 1971). Such a situation apparently exists in land-use planning, especially on the National Forests. The applicability of systems analysis to National Forest land-use planning has been broadly outlined earlier in this report. How a model can be developed is illustrated by using the Dillon Ranger District as an example.

The first step in analysis is to specify objectives *(fig. 2).* They constitute the framework in which choices between resource uses and alternative plans will be made. The general goals of management in the Dillon Ranger District are those of the Forest Service as a whole. The Forest Service has outlined its objectives and guides to policy in its *Framework for the Future* (USDA Forest Service 1970). One objective, for example, is to "protect and improve the quality of air, water, soil, and natural beauty." Another is to "promote and achieve a pattern of natural resource uses that will best meet the needs of people now and in the future." All 11 objectives listed presumably have equal priority, but in the decisionmaking process, some choice must be made to resolve potential or actual conflicts.

The aim should be to find a satisfactory compromise (possibly eliminating some uses), based on

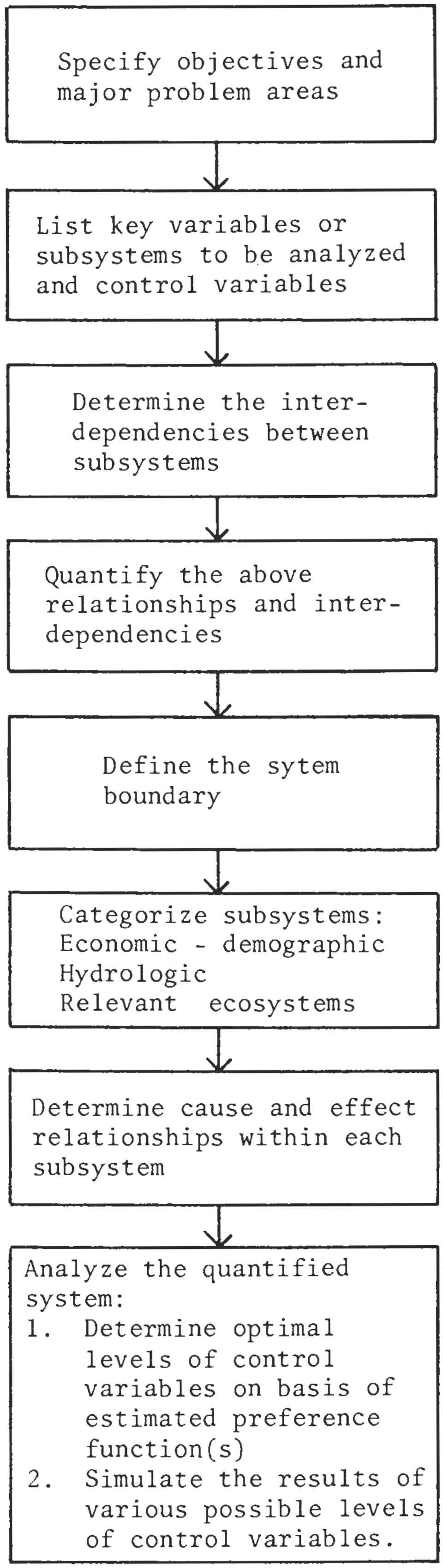

Figure 2—The systems analysis process may be viewed in terms of a flow chart.

analysis of the relative "costs" and "benefits," both economic and environmental, of each use. Often, however, a measurement for uses other than the primary one, especially the "use" represented by maintenance of environmental quality, is difficult. In such instances, the cost-effectiveness approach may be employed to compare the net dollar benefits of the use foregone to preserve, for example, a certain number of undeveloped acres. If appropriate information is available, the number of undeveloped acres might possibly be related to numbers of certain specific species saved or protected. It should be noted, however, that this particular example is a problem of nonmarketability in the benefit estimate, not intangibility.

The next step in the analysis is for each member of the interdisciplinary team to list those variables in his areas that should be explained by the system and to specify the structural form of the subsystems with which he will be concerned. For example, an economist might specify employment, production, and income as some of the relevant variables of an economic-demographic subsystem *(fig. 3)*. The presumed causal relationships within each subsystem need to be formulated; in other words, each endogenous variable (e.g., employment in lumber manufacturing) will be expressed in a mathematical relationship as a function of various explanatory variables. The nature of these relationships must be specified, on a basis of available theory and empirical findings, either mathematically or verbally.

In addition to those functions making up the various subsystems, an account of other relationships central to specific problems or issues may be desirable in the over-all system. Some of these relationships may have already been specified in the subsystems. Examples of such relationships, in the form of questions applying to the Dillon area, are the following:

1. What is the effect of more recreation activity on water quality in the area?

   a. How does this vary with the type of activity and the type of soil on which the activity takes place?

   b. What is the limit of recreation capacity for Dillon Reservoir to preserve its water quality?

2. What is the effect of various forest land activi-

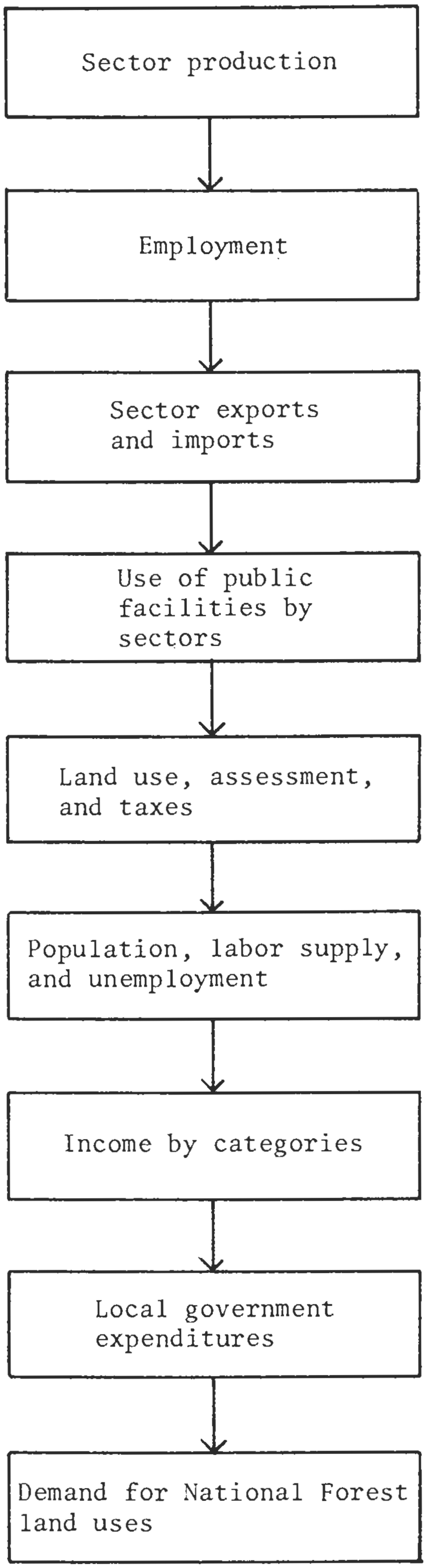

Figure 3—A simplified example of a hypothetical economic-demographic subsystem of this type may be formulated from theory and altered to fit the specific application. The arrows represent a possible causal relationship that would need to be verified empirically.

ties (timber harvesting, recreation, wildlife management, fire, etc.) on the environmental factors in the area (soil erosion, water quality, noise level, wildlife, scenic quality, etc.)?

3. How are different land uses interrelated or what are the trade-offs between uses?

4. What land areas are best suited for construction and which areas are not suitable?

5. What is the expected demand for ski areas in the Dillon area? Does this demand need to be met? If so, what are the suitable sites?

6. What will be the influence of the new I-70 tunnel on the area?

7. How will increasing urbanization or semi-urbanization affect the environmental quality of National Forest land?

Whenever feasible, demand relationships should be introduced into the land-use system. Traditionally, land-use plans have usually treated demand, which is different from use or participation, as an exogenous factor beyond the control of the local planning unit. Demand is influenced by local conditions, however, such as land taxes, zoning, fees, and building regulations. An understanding of the causal nature behind certain demands will enable the Forest Service to anticipate changes in demand and decide whether changes in supply are necessary.

Once the team has specified the structural form of the system, the mathematical or reduced form of each relationship must be specified. Statistical procedures for estimating the parameters of each relationship need to be selected. These procedures will often be limited by the availability of data. In fact, many of the functions or relationships may have to be approximated because data are limited. Often *a priori* parameter estimates may be obtained from previous studies or other analysts.

Once the above relationships have been quantified (that is, their parameters have been satisfactorily estimated), the land-use systems model is ready for analysis. For such a model two types of analytical technique are feasible: an optimization system and a simulation system.

Optimization Procedure

An optimization procedure would prove useful for decisionmakers in a policymaking framework. Often policy makers dislike the use of words (or procedures) such as "optimize" or "maximize." Such terminology is used in government planning guides, however, and specifically in the multiple-use directives of the Forest Service Manual (Title 2100, November 1971): "Public goals established by people through political processes for the management of National Forest System and related lands require that their protection, development and use provide optimum public benefits."

As noted above, Forest Service decisions regarding land use must serve broad economic, social, and environmental objectives. When these goals are competitive, a higher level of attainment of one goal can be reached only by reducing the level of attainment of another goal. Thus, an implicit preference or objective function exists by which land planning decisionmakers weight the relative importance of the various goals when making choices. That is, they consider and weigh the trade-offs between actions. Obviously, such evaluation should be evident, if possible, in the planning system.

Procedures for estimating the parameters or weights of a preference function for policy analysis have been discussed by others[1] and are beyond the scope of this report. One approach is worth mentioning, however. The system team or analyst chooses several land-use planning objectives. (This procedure is similar to that proposed by Van Eijk and Sandee (1959).) They then attempt to obtain the ratios or trade-offs between the various variables entering the preference function. These ratios or "barter terms" indicate the willingness of policymakers to sacrifice one variable for a certain amount of another variable without changing the value of the preference function. That is, the analyst attempts to ascertain points of indifference. "The coefficient of each target is then obtained as the (geometric) average of the barter terms of that target against all other targets (and against itself, which terms are obviously unity)" (Van Eijk and Sandee 1959, p. 4). Thus, the preference function might be formulated for a group of individuals who shape government policy on a committee and consulting type basis. In reality, such a situation is highly probable since policy actions may be decided by government officials, but influenced by many others such as advisors, pressure groups, labor leaders, and various technical experts. To estimate the

[1] For examples, see the paper *A conceptual regional econometric model incorporating policy considerations,* by R. A. Oliveira and G. C. Rauser, presented at the Western Economic Association annual meeting, Davis, Calif., Aug. 27-28, 1970; and the paper *Estimation of social preference functions for the analysis of economic policy problems,* by G. C. Rauser and J. W. Freebairn, presented at the American Agricultural Economics Association annual meeting, Gainesville, Florida, Aug. 20-23, 1972 (copy on file at Dep. Agric. Economics, Univ. Calif., Davis, Calif.).

subjective barter terms underlying the preference function of such a group, Van Eijk and Sandee (1959, p. 4) propose a method which they refer to as imaginary interviewing. In other words, they feel that an actual interviewing of policy makers to ascertain their preferences would not be possible. They suggest a type of imaginary interviewing or actually a reviewing of written and spoken policy statements.

The objectives of Forest Service management are clearly stated and communications between staff and line decisionmakers are fairly open. Therefore either the imaginary or straightforward interviewing procedure may prove feasible. In addition, this method could easily be used to construct several possible preference functions rather than a single one. These could reflect the extreme viewpoints and preferences of different central decisionmakers (or different citizens' groups) involved in the planning process, as well as viewpoints lying between these extremes. Thus, the analysis team could present the policy decisionmaking group with a series of assessments based on a variety of objective functions, leaving the policy group to make its own choice as to which one best reflects (or is closest to) their preferences or objectives.

Where objectives are not complementary, but where they can be ranked in order of preference or priority, the analyst could specify a ranking or ordering of objectives where the last objective consists of a few variables that could be combined in a preference function. That is, satisfactory levels (e.g., satisfactory water quality standard) would be specified for all variables except those in the last objective, and preference weights would need to be determined for these few variables only. The weighted combination of these variables would then be maximized subject to satisfactory levels of all prior objectives or goals.

Simulation Procedures

If it is not possible to specify an objective function, then the land-use systems model may be analyzed by simulation procedures. In other words, the analyst could vary the magnitude of certain variables and/or parameters and simulate the effects on the system. Experiments could be performed on the model to see how sensitive the outputs were to various assumptions, variables, parameters, or forecasts. In addition, certain policy actions could be tested and their results observed. If several such tests were made, policymakers could observe the results of their actions and thus make better decisions.

A hypothetical simple simulation model for camp-

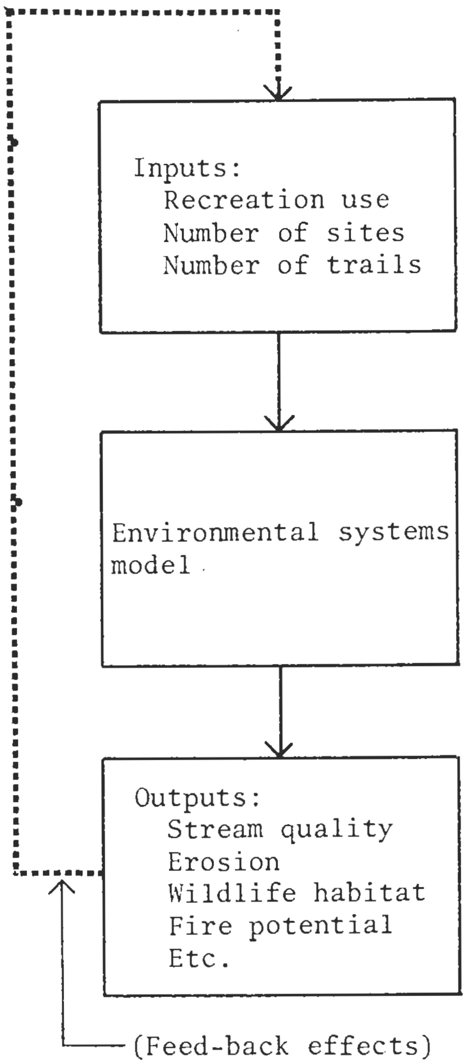

Figure 4—Hypothetical simulation model of campground use.

ground management is given in *figure 4*. The inputs would be recreation use in camper days and land management decisions, such as the number of camping sites and trails. The model would show how these inputs interact with the local environment (or ecosystem). Plausible outputs could be various environmental measures. The effects of various inputs (such as different use rates) could be simulated with the model. A more sophisticated approach would treat recreation use as an endogenous output which would be a result of the interactions within the system.

CONCLUSION

The land-use systems model and the analysis methods I have described are in accord with the Forest Service's multiple-use planning unit concept.

Planning units could easily serve as boundaries for land use systems. The Forest Service Manual (Title 2100, Directive 1, Section 2126, Nov. 1971) describes such units as "specific, identified and delineated land areas. Smaller than Planning Areas, they are large enough to encompass most of the meaningful or significant relationships within a drainage or series of drainages. The purpose of Planning Units is to provide a focus for planning activities in a small enough area to be workable and large enough to enable the planning team to envision or predict the cause and effect relationships of management alternatives...."

The proposed land-use planning systems analysis could easily meet the analysis requirements as specified in the Forest Service Manual. The use of an objective function would indicate how alternative plans contribute to goals and would indicate the trade-offs between alternatives. In addition, the construction phase of the model would point out any data or inventory limitations which may exist.

The systems analysis approach seems well suited to Forest Service land use planning. It allows for analysis, experience, judgments, and revisions to enter the decisionmaking process. Proposed programs can be examined in relation to various objectives, both economic and social, of local and regional programs. This type of multidiscipline approach is needed to solve problems having a wide range of alternative solutions. The effects of such alternatives can be displayed in multiobjective accounts framework that can then be used in policy discussion and in other studies and programs. In addition, the systems planning approach has cumulative value in that information and operation costs incurred in one area may be applicable to National Forest planning problems in other areas.

Obviously implementing the systems approach to National Forest land use planning would not be easy; investments would be required in system analysis, computer time, and supporting facilities. The investments in time and money would be small, however, minuscule compared with the total costs of managing the National Forests. Complex and sophisticated procedures are now in use in such areas as timber management, watershed management, and forest engineering. The land use decision process could profitably be analyzed with the same rigor.

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