PACIFIC SOUTHWEST Forest and Range Experiment Station

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RANGE RAM ... a long-term planning method for managing grazing lands

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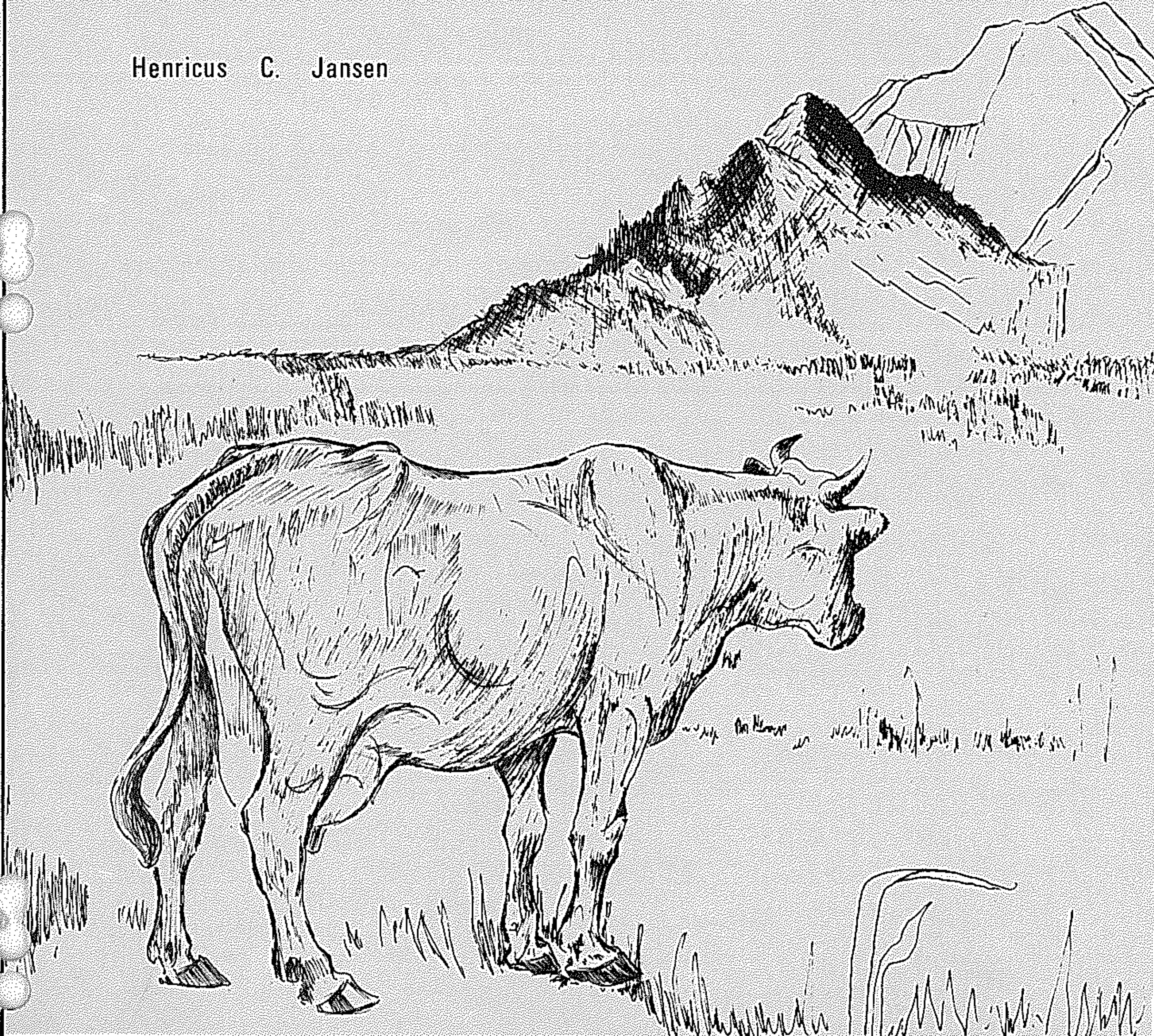

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SUMMARY

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Range RAM (Resource Allocation Method) is a computerized planning method that assists with the development of intermediate and long-term management plans for Federal grazing lands. It is applicable to planning problems concerned with spatial and temporal alternatives in allocating resources at forest, district, or lower levels of decisionmaking.

Within a specified planning period, a number of planning intervals are set forth. At the same time a number of management units (resource classes) is specified. The overall condition or "state" of resource classes serves as the analytical focal point of Range RAM. With a state as the starting point for planning, the management potentials and productive capabilities of the resource classes are determined. The range planner specifies maintenance, improvement, and grazing practices (e.g., grazing at specified intensities, spraying, plowing, seeding, water development). These practices are then linked over consecutive intervals and arranged into "management activities" for each resource class. Resource class states may be designated as management targets. Range RAM will schedule practices so that target states are achieved by a date specified by the planner.

For alternative resource and production constraints and management objectives, Range RAM helps the user select an optimum combination of activities and resource classes. Such combinations or problem solutions can be formulated to maximize production of harvestable forage, Animal Months (AM's) of grazing, gross or net revenue, or to minimize the cost of land maintenance and improvement.

Range RAM includes three computer programs—RANGE/MTX (Range RAM Matrix Generator), a linear programing (lp) code, and RANGE/RPT (Range RAM Report Writer). RANGE/MTX is used to generate management activities, calculate the cost and production coefficients associated with generated activities, and construct a resource allocation matrix. The lp code selects an optimum combination of management activities and resource classes for each management objective and calculates the cost of small deviations from this optimal combination. RANGE/RPT generates reports for alternative lp or planner-designed solutions. Reports describe solutions in terms of economic and resource management criteria and list the selected activities in terms of costs, benefits, practices, and scheduled areas within each resource class.

The anticipated application of Range RAM is as a planning tool for resource lands whose primary usage is grazing by either livestock or big game. Other rangeland uses can also be considered, while environmental constraints are recognized explicitly by specifying the type and intensity of range resource development, by reserving forage for other nongrazing purposes, by specifying grazing intensity; and by the temporary or permanent withdrawal of areas from grazing use. In planning for the multiple-use management of the range resource, Range RAM must be used in concert with other appropriate planning techniques.

The U.S. Forest Service manages nearly 106,000,000 acres of rangeland, of which about 58,000,000 acres are classified as suitable for grazing use (U.S. Forest Service 1972). These grazing lands produce an average of 8,000,000 Animal Unit Months (AUM's) per year (U.S. Forest Service 1967-1974). Improved planning techniques to direct management and long-term investment for range rehabilitation could result in an increase in AUM production of more than 80 percent (Forest-Range Task Force 1972, University of Idaho and Pacific Consultants Inc. 1970). Rangelands are characterized by large acreages, diversity in actual and potential production, lack of uniform response to applied management, and slow—often unspectacular—response to improvements.

The development and selection of management plans which show the way to needed increases in AUM production as economically justified expenditures require the efficient allocation of productive resources. Such an allocation process is, however, complicated by conflicting uses of rangeland, by the limited availability of range planning methods, and by the broad spectrum of management options available.

Range Resource Allocation Method (Range RAM) is a computerized method that can help the range planner with the rational allocation of limited resources and with the development of range management and grazing plans. It has been developed for intermediate and long-term planning and decision-making problems typical of Federal grazing lands.

Specific Range RAM objectives are:

- To assist the range planner with the development and evaluation of a wide spectrum of spatial, temporal, and sequential alternatives in the allocation of resources;
- To overcome the computational burden inherent in the formulation of a wide spectrum and large number of such alternatives;
- To assist the range planner with the formulation of "optimum" combinations of management activities;
- To provide for a method of resource allocation that results in the controlled long-term development of the productive capacity of rangelands and the controlled flow of grazing products;
- To assist the range planner with the formulation of alternative management plans for varying management goals, with economic, social, and environmental constraints.

This paper describes Range RAM and outlines the processes of its use. It illustrates the flow of data and information within and between the computer programs, the underlying approach to planning, model assumptions, and the limitations affecting the application of Range RAM. It also provides an explanation of how to use Range RAM, how to formulate a solution, and how to select a management plan from alternative solutions.

Detailed user instructions are beyond the intent and scope of this paper, but may be found in a three-part *Range RAM Users' Manual* which will be available on request from the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, Calif. 94701, Attention: Publications.

Three programs are used in Range RAM: RANGE/MTX (Range RAM Matrix Generator), a linear programing code, and RANGE/RPT (Range RAM Report Writer). To obtain a copy of RANGE/MTX, -/RPT send a 7-track, half-inch tape at least 1200 feet long together with the request to this Station (Attention: Computer Services Librarian).

RANGE RESOURCE ALLOCATION METHOD

The three computer programs that form the basic components of Range RAM provide the range planner with assistance in:

- The development and analysis of a wide spectrum of management activities;
- The formulation and analysis of alternative combinations of management activities, meeting both managerial and resource constraints; and
- The formulation of problem solutions that are optimum in an economic sense and operationally feasible in terms of managerial and other non-economic criteria (e.g. social, political, environmental).

With Range RAM the planner can formulate solutions for the allocation problem that either maximize production, gross revenue, or net revenue, or minimize the cost of resource management and improvement. Types of information needed for using Range RAM are similar to those needed for any planning process. These include: (a) management objectives and production goals; (b) management, production and budget constraints; (c) present and potential production capabilities of the land resource; (d) technological means (management practices) available for land management and improvement; (e) anticipated effects of sequences of management and grazing practices upon land resource productivity; (f) financial returns associated with production; and (g) costs of resources used and costs of management.

Range RAM can also be used to (a) evaluate the impact of alternative budgets or production-level requirements on rangeland use, development, and expenditures; or (b) evaluate the impact of alternative range development and use limitations on budget requirements and production levels.

Program Components

The three Range RAM computer programs are RANGE/MTX, a linear programing (lp) code, and RANGE/RPT. RANGE/MTX and RANGE/RPT are written in Fortran IV language for use on the Univac 1108, EXEC 8 computer. ILONA is the lp code that is used in combination with the RANGE programs; however, other lp programs can equally well be used if a computer programer makes the necessary changes in the RANGE programs. Collectively these programs aid the range planner with three phases of the planning and problem solving procedure: formulation, solution, and interpretation (*Fig. 1*).

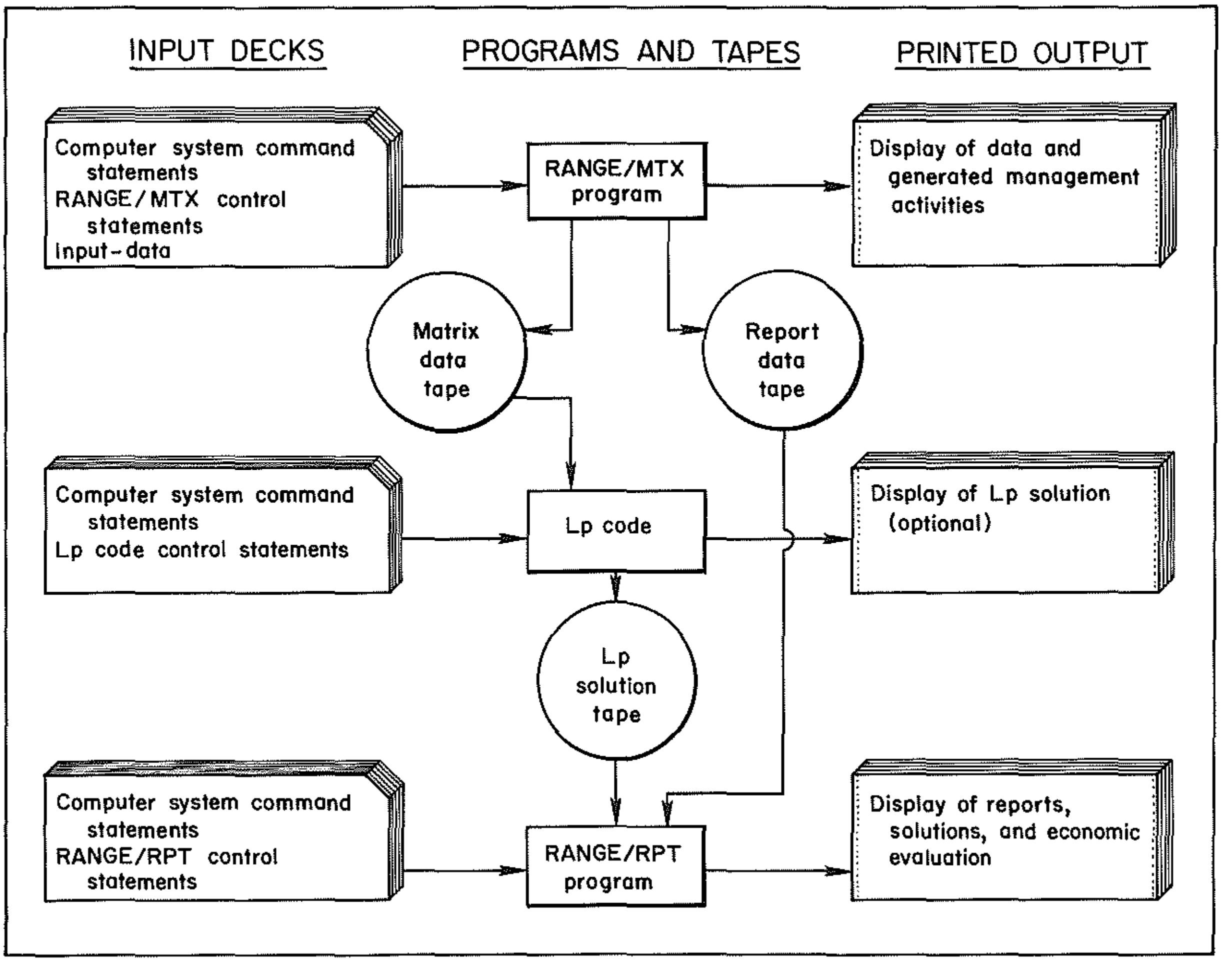

Figure 1—The three input decks activate the RANGE/MTX, the lp, and the RANGE/RPT programs and thereby cause the storage of matrix data, report data, and lp solution data on tape. In addition, these programs cause the display of problem data, lp solutions, and solution reports on computer print-out. Arrows indicate the flow of control information and data.

RANGE/MTX assists in structuring the resource allocation problem into a matrix format that is suitable for subsequent analysis and solution with the lp code. Constituent parts of a problem matrix are: the management activities which allocate the resources used (land and capital) and products obtained, one or more management objectives, and the resource and production constraints.

Principal RANGE/MTX functions are:

1. The input and storage of user-provided data, such as range production characteristics and development potential, improvement and use alternatives, management objectives, and resource and production constraints.
2. The formulation of management activities for range use and development alternatives.
3. The calculation of the cost and production coefficients associated with the formulated activities.
4. The structuring of the problem data into a matrix format.

RANGE/MTX has a number of user-options which generally deal with the specification and manipulation of data, the specification of type and number of alternative objectives of management, and the specification of budget and production constraints. For example, the planner can request for the temporary or permanent storage of his data, control the nature and number of management activities that the program will formulate, and then direct the extent to which computer-calculation of selected production coefficients occurs.

The lp code is a general purpose linear programing optimization routine. Its function is to analyze the resource allocation problem and to obtain possible solutions. Solutions are those combinations of management activities and corresponding acreages which satisfy the constraints of the allocation problem and yield an optimum result.

The RANGE/RPT interprets the lp problem solution and prepares a report. RANGE/RPT output (report) is given in sufficient detail to be understandable to the range planner who is unfamiliar with print-out produced by lp codes.

Two types of reports can be prepared: (a) reports for problem solutions formulated by the lp code, and (b) reports for solutions formulated by the planner. A report describes each activity in the lp solution (or in the planner's solution) in terms of the individual practices (e.g. grazing, improvement, maintenance), the scheduled acreages, the associated costs, and the production levels. The report also gives an economic evaluation of a solution. This includes a description of the plan's gross and net revenues, costs, production levels and benefit/cost ratios.

Approach to Planning

Long-term planning for range resource use and development must be a well defined and logical process if it is to lead consistently to useful results. Principal steps in long-term planning are:

1. Inventory of the land resource and evaluation of its productive potential.
2. Development of projections for range product demand.
3. Determination of objectives, production goals, and constraining factors.
4. Formulation and evaluation of management activities.
5. Generation of alternative combinations of management activities and their evaluation in terms of management objectives, production goals, and constraining factors.
6. Selection of that combination which best meets most resource and production constraints, which provides for the highest possible value combination, and which is operationally feasible.

While the Range RAM approach considers all of these six steps, the following discussion focuses on the fourth and fifth steps for which the Range RAM programs were specifically designed.

Formulation and Evaluation of Management Activities

We define a management activity as a scheduled sequence of management practices, such as maintenance, development, and grazing practices, extending from the present to the end of the planning horizon. Formulating any number of management activities for a planning unit poses a number of problems which must be resolved. Thus the planner must decide which practices are required to meet management objectives and production goals. He must decide where, when, and in what sequence and combination to apply the selected practices, and determine the extent (area) and the intensity of practice application. Lastly, he must determine the costs, benefits, and effects on the range resource of the practices.

Numerous management activities can generally be formulated for a range resource. The range planner might, for example, plan to graze, control noxious vegetation, and fertilize on one portion of the range resource, while he plans different activities on the remainder. Determining the nature and type, costs and benefits, and intensity and sequencing of the planned practices in each activity depends on local criteria, conditions, and objectives. Range RAM assists the planner with these tasks.

The range planner starts the process of formulating management activities by selecting a planning horizon for the allocation problem. This planning horizon determines the length of the planning period which the planner must divide into a number (1 to 20) of equal-length planning intervals. An interval may be from 1 to 20 years long.

The rangeland resource determines the dominant characteristics, boundaries, and size of the allocation problem. The planner must divide this range land into a number (1 to 200) of resource classes. Each resource class should, as near as possible, be homogeneous in biological, physical, economic, and management characteristics, and should respond uniformly to management practices.

Next, the planner determines a set of "resource states" and sets of management practices for each of the resource classes. Resource states are descriptions of the resource classes at discrete points in time. Range RAM limits the planner to three characteristics for describing the states of each resource class. With the sets of management practices which have been selected for the resource classes, changes in state must be feasible (e.g., it must be feasible to transform the states of a resource class with the management practices). The planner should specify as many pairs of related states as possible (i.e., related by a set of practices), including pairs of identical states.

The specific points in time at which resource states must be determined are the beginnings (or ends) of the planning intervals. Any changes in state must, therefore, be accomplished with the specified practices within the length of the interval. The determination of the interval length, the resource states, and the sets of practices to be implemented during the intervals is an iterative process. First, the planner must determine what practices are available. Second, he must determine the length of time needed to complete practice implementation. Third, he must determine the effect of the practices on the characteristics of the range resource.

For each resource class the "initial" state (i.e., the state at the beginning of the planning period or first interval) must also be determined. Naturally, there can be only one initial state per resource class. On the other hand, several states can be designated as the targets for resource class development. Such "target" states can be specified for any one of the intervals in the planning period.

Finally, given all pairs of states and connecting practices for a resource class, a network can be constructed (*Fig. 2*). A network shows for all intervals in the planning period the specified states and

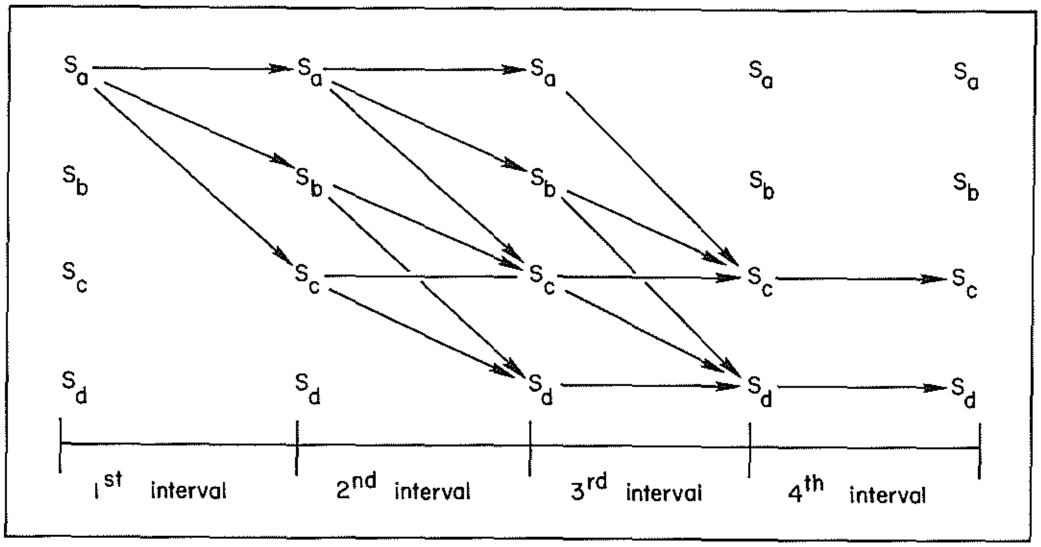

Figure 2—The nodes S_a, S_b, S_c, and S_d in the network represent resource states, the arrows (arcs) connecting the nodes represent sets of management practices (e.g. structural, non-structural, grazing, and maintenance practices). Shown only, are the complete pathways, or Range RAM management activities, which lead from the initial state S_a at the beginning of the first interval, to the target states S_c, and S_d at the end of the third interval, to the final states S_c and S_d at the end of the fourth and last interval.

sets of practices. Each complete pathway through the network, leading from the initial state to a target state, to the end of the last interval is by definition a Range RAM management activity and is formulated with RANGE/MTX.

The use of states to monitor and describe the effects of practices on a resource class lends itself to two shorthand notations for describing management activities.

Let a sequence of practices affect a resource class in such a manner as to cause changes in its initial state, say State S_a, leading through intermediate states S_b, S_c, ... S_m to a final state S_n. Then the shorthand or "state" notation for any management activity can be given as:

$$S_a \rightarrow S_b \rightarrow S_c \ldots S_m \rightarrow S_n$$

The state notation is used in RANGE/MTX to identify all possible management activities for each of the resource classes.

The lp code uses an alternative notation. This lp code or "coefficient" notation characterizes the management activities in terms of their costs and benefits on a per unit area per interval basis.

Let the sequence P_a, P_b, ... P_m represent a scheduled sequence of sets of practices. Let the sequence C_a, C_b, ... C_m and the sequence B_a, B_b, ... B_m represent the corresponding sequences of scheduled management costs and benefits. Then in coefficient notation any management activity can be given as:

$$C_a, B_a; C_b, B_b; \ldots C_m, B_m.$$

Further detail on the formulation of management activities and on the calculation of benefit coefficients is provided in the Appendix.

Solving the Allocation Problem

Linear programing as a tool for solving resource allocation problems has been applied only to a limited degree in range management. Brown (1961) reported one of the first applications and described a model that uses linear programing as an aid in the valuation of range improvement practices on ranches typical of the Western Range. Nielsen (1964) worked with Brown on the problem of estimating the economic value of the range resource as measured through livestock production. Navon (1969) described a lp model for wildland planning, and Navon (1971) formulated Timber RAM, for commercial timber lands. Kaiser and others (1972) developed the linear decision model FREPAS (Forest Range Environmental Production Analytical System) which was used by a U.S. Forest Service Forest-Range Task Force for a one-time analysis of selected management alternatives on the nation's forest-range lands. FREPAS was limited to the consideration of only six management alternatives in the formulation of management plans. D'Aquino (1974) and Bartlett and others (1974) described linear models for short-term ranch management activities (resource allocation alternatives). The developed models differ from one another in purpose and in method of formulating the activities.

Range RAM uses linear programing to solve the resource allocation problem. The problem is to find that combination of management activities and acreages that optimizes the management objective function and simultaneously stays within all resource and production constraints. For example, what combination of activities and acreages provides for a least-cost maintenance and improvement program while staying within specified AM-production levels for each planning interval?

The linear programing method used in Range RAM is the revised simplex method. This method has been adequately described in several textbooks dealing with linear programing (Dantzig 1963, Heady and Candler 1958, Spivey 1963) and will therefore not be discussed here.

The resource allocation matrix (*Fig. 3*) that RANGE/MTX generates for subsequent analysis and possible solution by the lp code, contains three types of information: (a) the management activities in coefficient notation; (b) the constraint levels for costs, products, and land; and (c) one or more alternative management objective functions. For a given allocation problem, as defined by the matrix, alternative management options can be analyzed. Each combination of one management objective function and one set of constraints defines an option for which an lp solution may be found. Changes in the matrix (e.g. deletion or addition of management activities or resource classes) define new allocation problems for which again alternative management options may exist.

An lp solution may be "feasible" or "infeasible." It is feasible if a combination of management activities is found that meets all constraints on cost, production, and land. It is infeasible if no combination satisfying all stated constraints can be found. By adjusting one or more of the contraints (i.e. introducing a new management option) the planner may resolve the infeasibility of a solution.

row \ column	one column for each management activity for each of the resource classes		right hand side(s)
input commodity	one row for the management input per unit of area during each planning interval	$<$ or $>$	input constraints for each interval (minimum and maximum)
output commodities	one row for each output commodity generated from a unit of area during each planning interval	$<$ or $>$	output production requirements for each commodity for each interval (minimum and maximum)
land	one row for each resource class in the planning unit	$\leqslant$	total area of land available in each resource class
objectives	alternative management objective(s) considered for optimization	$=$	final value of objective function(s)

Figure 3—A resource allocation matrix and constraint column (right hand side) for a management problem.

Once a feasible lp solution has been found, a report can be formulated with RANGE/RPT. A report consists of a bundle of activities and their assigned areas (acres, hectares) for all of the resource classes in the allocation problem.

Assumptions and Limitations

The deterministic nature of Range RAM assumes that all management costs, benefits, and commodity prices are fixed and known. Range resource potential, quantitative management goals, and other objectives are assumed to be known with certainty. Also assumed to be known are the range resource production characteristics, expected budgets, state of the art, supplies of fixed resources, and the social, political, and environmental realities.

Because of the limitations of a deterministic model, the planner should judge all results with reservation and update his data and management assumptions frequently when more reliable information becomes available. The planner should regard the quality of Range RAM output as directly related to the quality of the input provided. The reliability and adequacy of data, the degree to which formulated activities reflect the full spectrum of management opportunities, and the optimality of the formulated solution, are of critical importance in deciding if a proposed solution merits translation into a management plan.

Another set of assumptions and limitations pertains more specifically to the method of formulating management activities. The use of the state approach as an activity-generating method requires that three assumptions are met:

1. The resource classes into which the range resource is divided have uniformity in their physical, biological, and economic characteristics, and in addition each resource class responds uniformly to applied management.

2. The states of all resource classes are known for discrete points in time. Changes in resource states can be accomplished through the application of maintenance, improvement, and grazing practices and occur in a known manner.

3. Unit requirements and unit returns of all prac-

tices or practice combinations are known and can be described in terms of costs and benefits per unit area per unit time.

The use of linear programing as the solution technique requires two additional assumptions: (a) costs and benefits of management activities (as well as their component parts—the practices) are directly proportional to area managed; (b) when several activities are combined to form an "optimum" combination, output per unit of input for each activity remains unchanged, regardless of which other activities are operated within the same or other resource classes.

In order for points (a) and (b) to hold, the standard lp assumptions of linearity, divisibility, and independence of management activities must be made. Point (a) reflects the assumptions of linearity of the production function and divisibility of goods and factors of production. Point (b) involves the assumption of independence among management activities.

The significance of the linearity assumption is that the relationship between costs, benefits, and area is continuous linear, for example, fertilizing 10 acres increases cost and production tenfold as compared to fertilizing 1 acre. The linear relation of cost and benefit to the area treated reflects both uniformity of treatment and homogeneity of response of the treated area.

The assumption of divisibility implies that all factors used in the production process are considered continuous variables. For example, the practice of constructing livestock watering facilities can in reality only be carried out at discrete unitary levels, but the divisibility assumption includes the construction of, for example, 3.5 water-developments as a possibility.

The assumption of independence of activities may sometimes be unrealistic. Many practices interact and their effect on the final outcome is frequently a function of the other practices carried out on the range resource, simultaneously or at different times. It may, for example, be difficult to formulate an independent management activity containing the practice of fencing. If such an activity were selected in an lp solution for a particular area then the area outside of the fence will generally be affected as well.

Through the careful selection of resource states and practices, the limitations imposed by the assumptions of linearity, divisibility, and independence can be partly overcome. These limitations can be further ameliorated by the procedures discussed below.

APPLICATION

Planning for Range Resource Management

Range RAM serves as a planning technique for lands used mainly for grazing by either livestock or big game. For this reason Range RAM emphasizes and assists with the calculation of the following management costs and benefits:

1. Dollar cost of range maintenance, improvement and utilization (discounted or undiscounted).
2. Harvested forage.
3. Animal months of grazing.
4. Rental fee income derived from livestock grazing (discounted or undiscounted).
5. Net revenue representing the difference between items 4 and 1, above (discounted or undiscounted).

Other concurrent uses of the range can also be analyzed, while constraints on grazing-use of a social, political, or environmental nature are recognized explicitly through the judicious selection of intermediate and target states, the selection of type and intensity of maintenance, improvement and grazing practices, the reservation of forage for other nongrazing uses, and the withdrawal of areas from grazing-use.

Several computer runs need generally be made to encompass the array of management options available in most situations. For example, the analysis of two options, one with and one without "intensively developed" resource states, must be conducted in separate computer runs. Uncertainty about future levels of product demand, budgets, and prices necessitates the examination of alternative solutions for the same and for different planning problems. Even so, it is extremely unlikely that a globally "optimal" plan will be found.

To a limited extent, Range RAM can assist the planner in developing management plans for range resource uses other than grazing (e.g. timber, water production, recreation). For each alternative use the planner must redefine the resource classes and resource states, since different classification and management criteria will apply. Benefits (e.g., board-feet of timber, acre-feet of water, recreation days) must be calculated by the planner and be entered into the resource allocation matrix. This is unlike the case for grazing products, where RANGE/MTX calculates output levels and enters these into the allocation matrix.

In planning for the multiple-use management of the range resource, Range RAM must be used in concert with other appropriate planning techniques. Since each Range RAM management objective function can only be defined in terms of a single commodity (e.g. pounds harvested forage, AM's) the optimization of a bundle of commodities is not possible.

Formulating a Management Plan

The complete process of formulating a solution with Range RAM is a three-step procedure (*Fig. 1*). Each step consists of preparing problem specifications, developing a Fortran card deck, and making a computer run.

Step 1: Formulation of the management problem with RANGE/MTX. At this initial step the planner defines his management problem, determines his management data and planning options, and manipulates and stores his data with RANGE/MTX for subsequent analysis. Specific data requirements are the length and number of planning intervals; the resource and production constraints; alternative management objective functions; resource classes; resource states; maintenance, improvement, grazing practices; and cost and benefit coefficients necessary for the valuation of the management activities. All data are then processed with RANGE/MTX and a matrix is prepared. This resource allocation matrix is stored on the "Matrix Data" tape for analysis in Step 2. Problem specifications and the generated management activities are stored on the "Report Data" tape for analysis in Step 3.

Step 2: Solving the resource allocation problem. Information needed for this step comes from the "Matrix Data" tape. The lp code develops solutions for one or more planning options and writes these on the "Lp Solution" tape. Solutions for all alternative planning options form the basis for the reports which are generated next.

Step 3: Formulation of reports with RANGE/RPT. Reports can be prepared for lp, and for user-produced solutions to allocation problems. For the first type of solution, the "Lp Solution" tape and "Report Data" tape provide the necessary data. For the second type, the planner himself must submit part of the required information on Fortran data cards. Additional information is obtained by RANGE/RPT from the "Report Data" tape directly.

The solution and the economic evaluation that are prepared as part of each report consist of a set of tables, schedules, and summaries of the costs and benefits of the selected activities. Costs and benefits are given on a per unit area and on a total area per interval basis. Summaries of costs, benefits and their ratios are given over all intervals and over all activities. Finally, the report gives the value of the optimized objective function and various indices of management performance.

With the three Range RAM programs the planner can process and analyze alternative planning options for the same problem and report on each solution. The three programs can be processed separately, and results can be stored on tape, or the three programs can be processed in one computer job.

Selecting a Management Plan

The process of selecting a solution for implementation as the management plan must be conducted with strict regard to the local situation and competing range resource uses. Ranking of alternative solutions in terms of economic criteria of performance, where possible, is only one of several evaluation and selection procedures. Before considering a solution as a potential management plan, the solution's acceptability must be determined. To be acceptable, a solution must be: feasible, accurate, robust, and practical.

Feasibility of the solution refers to the constraints of the problem. If the lp problem analysis results in an infeasible solution because of limiting constraints, then no acceptable management plan can be formulated from the solution. In this situation the problem must be reformulated until a feasible solution is found. Constraints on cost, production, and acreage need to be reexamined even if a feasible solution is obtained. Uncertainty of budgets, product requirements, and competing resource uses necessitate the analysis of alternative constraint levels. A plan's feasibility must therefore be judged in a context that gives due regard to the local situation and realities.

The accuracy of the solution refers to the costs and benefits of the management activities and to the degree with which the assumptions of the activity formulation process and lp solution procedure are met. The assumption was made that resource classes are homogeneous and react uniformly to management. In assigning the management activities in the solution to the actual "on-the-ground" resource classes, the planner must check carefully if his assumptions live up to reality.

The assumptions of linearity, divisibility, and independence of the management activities must also be carefully examined. For example, the per unit area cost of management might decrease when larger areas are treated. Since the planner assumed that unit costs and unit benefits are constant and that total costs and total benefits are linearly related to area managed, the linearity assumption may introduce some bias. The costs and benefits of each management activity in a solution must, therefore, be examined for this bias and offending activities should either be adjusted or removed.

"Significant" deviations from the assumptions of divisibility and independence also bias the accuracy of a solution. Depending on the situation, such deviations may increase or decrease the costs and benefits of a plan. Significant deviations include costs or benefits of the management activities that are either too low or too high; the area assigned to certain activities is either too small or too large for effective activity implementation; and activities in one area or resource class affect the costs and benefits of activities scheduled in different areas or resource classes. When deviations from the assumptions of the model are "significant," the planner can take two alternative courses of action.

One alternative for the planner is to redesign the entire management problem and reprocess all three programs. Another is to delete the unacceptable management activities from the lp solution and reprocess only the RANGE/RPT program with acceptable activities. The first course of action enables the planner to alter the resource classes and their boundaries, to change the resource states and management practices, and to recalculate costs and benefits. The second course of action enables the planner to keep the acceptable management activities and their assigned acres (hectares) in the solution, and to replace the unacceptable part of the solution by a set of activities and allotted areas formulated by the planner himself.

The lp solution for a management problem is called robust when small changes in cost or benefit coefficients, or small changes in the levels of the resource and production constraints, cause only small changes in the solution and the final value of the objective function. When changes of 5 to 10 percent (depending on the local situation) in cost and benefit coefficients or constraints cause large changes in the lp solution or final objective value, then the solution is not sufficiently robust for translation into a management plan.

The translation of a solution that lacks in robustness involves the risk of misallocating resources. This possibility of resource misallocation provides yet another reason for considering alternative solutions.

A solution's practicality must be viewed in terms of its on-the-ground implementation. When the ranger cannot implement the management activities of a solution, or when their implementation leads to unsurmountable obstacles, the solution is not practical and must be revised.

The examination of a solution's practicality must include an examination of its component parts. Therefore, the planner must check the practicality of timing, location, intensity, and extent of the management practices that are scheduled in the activities. The ranger must be able to carry out proposed grazing practices and grazing systems. Similarly, he must be able to carry out the maintenance and improvement practices for the effective management of vegetation and structural range improvements.

When the planner has determined that a solution is feasible, accurate, robust, and practical, its acceptability should be co-judged by the ranger, grazer, and other range resource users. Judgment should consider and evaluate the possible impact on other resource uses and products, environmental conditions, and other parameters of political and social concern. Much effort can be saved in the formulation and selection of a management plan if all concerned parties partake in the planning process from the start.

CONCLUSIONS

The need for improved planning procedures was documented by the Forest and Rangeland Renewable Resources Planning Act of 1974. By rehabilitating deteriorated land and by adopting improved management practices, range managers have made considerable gains in the past. Shortages and misallocation of capital, time, manpower, and data continue to deter optimum range resource use and improvement programs. Therefore, careful planning procedures and efficient allocation methods are necessary to ensure wise use of these limited resources.

Range RAM serves the function of assisting the planner with the formulation of management activities and plans. Efficient use of Range RAM facilitates the task of deciding on: the kind of maintenance, improvement, and grazing practices required; where to apply these practices; when best to apply such practices and in what sequence; what level of practice intensity to employ; to what extent (acres, hectares) practices should be applied; how best to combine practices; and what the associated costs and benefits are.

The quality of Range RAM based plans is directly related to the quality of data and data estimates. The translation of a Range RAM solution into a management plan, therefore, requires much caution. When imprecision of the solution makes its translation into a plan poorly advised, the solution may still be useful as a guideline for choosing alternative management options or for drawing attention to research needs.

In selecting a Range RAM solution as the management plan, the planner must take into account the financial, legal, social, political, and environmental constraints. The selected management plan is, therefore, not necessarily the economic optimum solution for a resource allocation problem. Instead, it is by necessity a compromise of combining management activities and areas of application so that the result is consistent with all constraints.

APPENDIX

A—Activity Formulation With The State Approach

Each Range RAM management activity is a sequence of practices extending from the present to the planning horizon. The range resource planner selects the horizon and divides the planning period into intervals. Range RAM allows up to 20 intervals of equal length, ranging from 1 to 20 years.

To improve accuracy in activity development, the planner must subdivide and classify the range resource area into resource classes, which should be uniform in biological, physical, economic, and management characteristics. Up to 200 resource classes can be specified per planning problem. Selected classification characteristics may reflect various range features, for example, vegetation type, range condition, productive potential for livestock grazing, or other dominant ecological-environmental features. Given a description of each resource class, the planner must describe the initial states (i.e. the initial set of characteristics) and select and describe sets of intermediate and target states. These states of the resource classes serve as the explicit linkage points in formulating the management activities.

The state of a resource class at the beginning of any interval is a function of: (1) the practices which were implemented during the previous interval, and (2) the previous state. Furthermore, the specific nature of each state delimits the set of maintenance, structural, non-structural, and grazing practices that can be implemented on the resource class during a subsequent interval. Using Range RAM, the planner may describe states with up to three "state parameters." Herbage production, forage production, basal area of merchantable timber, and soil stability are some examples. The planner should exercise managerial judgment, consider concurrent resource uses, and express planning directives in defining the state parameters most appropriate to each management situation.

Up to nine levels can be specified for each state parameter. For example, the levels for a forage production parameter could be specified as 50, 200 . . ., 1250 lbs/acre/year; for a timber basal area parameter as 500,1000, . . ., 2000 cft/acre; and for a soil stability parameter as 5 (very poor), 4 (poor), . . . , 1 (excellent). From the set of 9 x 9 x 9 combinations of parameter levels that is theoretically possible for each resource class (each combination represents a resource state), the planner may select a maximum of 15 combinations per resource class. Resource states not included in a given problem because of the specified limit on the number of states may be included and considered for analysis in a subsequent reformulation of the management problem.

As in the selection of the state parameters, the planner should exercise managerial judgment, and express management directives and multiple use criteria in the selection of the parameter levels and resource states. Only those states should be considered which can be achieved with available technology and are acceptable from social, political, and ecological decision criteria. When alternative sets of resource states are analyzed in successive problems, the planner gains the opportunity to determine the relative costs of benefits associated with restrictions on the resource states. For example, the analysis of two alternative management problems—one with and one without "intensively managed" resource states—can be conducted in two different computer runs.

A "state transformation" is the change from one state into another. State transformations may result from natural or man-caused actions. While specifying the resource states, the planner must specify how (i.e. with what grazing, maintenance, structural, and non-structural improvement practices) the states can be transformed. Furthermore, the planner must determine the costs and benefits of these practices, and must express these on the basis of a unit area and interval.

The range resource manager can use grazing, structural, and non-structural improvement practices for two purposes: first, to increase the production of certain desired benefits; and second, to transform (or maintain, as the case may be) resource states. In situations where dissimilar practices (or combinations of practices) exist which cause identical state transformations, the planner must apply managerial judgment in the selection of one set of practices over the other. For example, under one set of management criteria the use of herbicides might be an acceptable means of transforming a state whereas under another set of criteria these practices must be rejected in favor of prescribed burning.

Control over rate, type and direction of resource class development is generally of great interest to the planner. With the state approach the planner can exercise such control. For each resource class, the planner may specify one or more target states as well as the last planning interval in which these states must be achieved. When no development is planned for a given resource class, the target state should be similar to the initial state. When range resource utilization has a regressive impact, the planner can specify a target state which is less "developed" than the initial state. Rate, type and direction of range resource development can be specified separately for each resource class.

A management activity which has been described in terms of states and practices is best illustrated with a range management example.[1] The general notation is shown here.

Let $\{S_{ijk}\}$ $\quad i = 1, 2, \ldots, 9$
$\quad j = 1, 2, \ldots, 9$
$\quad k = 1, 2, \ldots, 9$

identify the set of resource states for a resource class, where i, j, and k identify the state parameters, each having nine levels.

$$\text{Let } \{P_n\} = (P_1, P_2, P_3, \ldots, P_N)$$

identify the set of maintenance, structural, non-structural, and grazing practices applicable to that resource class. Then in general there exist sub-sets of practices

$$\{P_{n_i}\} = (P_{n_1}, P_{n_2}, \ldots, P_{n_I});$$

which when applied to the resource class during an interval transform the states of the set $[S_{ijk}]$ into other states of that set, for example:

$$S_{ijk} \xrightarrow[(P_{n_1}, P_{n_2}, \ldots)]{} S_{ijk'}$$

For a sequence of consecutive intervals leading from the present to the planning horizon, a management activity can then be written as follows:

$$S_{ijk} \xrightarrow[P_{n_i}]{} S_{ijk'} \xrightarrow[P_{n_j}]{} S_{ij'k'} \text{ - - - - - - } S_{i'j'k'}$$

| 1st interval | 2nd interval | nth interval |

To use RANGE/MTX for activity formulation, the planner must specify the planning horizon, the number of planning intervals within the planning period, one or more resource classes and the area of each. For each resource class he must specify:

1. The resource states (up to fifteen per resource class);
2. The initial state;
3. One or more target states;
4. The state transformations;
5. The sets of management practices with which state transformations are accomplished;
6. The interval in which target states must be achieved; and
7. The inputs required and benefits produced during the state transformations.

Following their formulation, all management activities are entered into the resource allocation matrix. The planner provides the cost and production constraint levels, the discount rates, and objective functions which complete the matrix for subsequent lp analysis and solution.

[1] See Range RAM Users' Manual Part II: Using Range RAM.

B—Calculation of Output Coefficients

The required inputs and generated outputs corresponding to the per unit area per interval costs and benefits of the state transformations are known as the input and output coefficients. These coefficients must be defined and determined by the Range RAM user. However, in order to improve the precision and speed with which the calculations of output coefficients can be performed, the RANGE/MTX program contains certain options which free the user from these tasks. The coefficients for three types of output can be calculated with the computer: harvested forage, animal months of grazing, and rental fee income.

The precise definition of these outputs must be left to the planner, but their general interpretation should be as follows: harvested forage—the actual amount of vegetable matter harvested (or planned to be harvested) by grazing animals; animal months (AM's) of grazing—the number of animal months of grazing provided by the amount of harvested forage; rental fee income—the revenue derived from leasing out range land for grazing use.

For each resource class for which the planner decides to rely on computer calculations of the harvested forage coefficients, he must specify levels for three characteristics: (a) forage production[2] (in lbs or 1000's lbs) per unit area, (b) allowable use (in percent) per unit area, and (c) grazing intensity (in percent) per unit area. The levels for all three characteristics must represent the average per unit area values of the resource class as a whole. Instead of specifying the levels of forage production, the planner may substitute the levels of herbage production and herbage availability-palatability. Whereas the level of grazing intensity is a decision of range use, levels of the other characteristics are functions of the variable state of the resource class. They can, therefore, be used as state parameters and their specific levels can thus serve to describe the states of a resource class.

When RANGE/MTX is used to calculate the coefficients of harvested forage, then forage production/unit area, or herbage production/unit area and herbage availability-palatability must be specified as state parameters. Allowable use can also be specified as a state parameter, but may, like grazing intensity, be specified separately on the prescribed RANGE/MTX data input forms. The third state parameter may never be used for the calculation of output coefficients, and is reserved for qualitative range resource characteristics. For example, degree of soil surface erosion might be used as a qualitative indicator of the "health" of a resource class.

Equation 1 describes the relationship between forage production, herbage production, and herbage availability-palatability. Equation 2 describes the relationship between harvested forage, forage production, allowable use, and grazing intensity.

$$(1) \quad FP = (HP)\,(HAP)$$

$$(2) \quad HF = (FP)\,(AU)\,(GI)$$

in which FP is the forage production per unit area (in pounds or 1000's pounds); HP is the herbage production per unit area (in pounds or 1000's pounds); HAP is the herbage availability-palatability (in percent); HF is the amount of harvested forage per unit area (in pounds or 1000's pounds); AU is the allowable use factor of the herbage or forage; and GI is the grazing intensity.

To obtain the per interval values of HF (i.e. HF_I or the HF coefficient), time related functions must be known for FP (or HP and HAP), AU, and GI. An estimate of the true value of HF_I is obtained with RANGE/MTX by using equation 3 or 4.

$$(3) \quad \widehat{(HF)}_I = \Sigma_{i=1}^{I} \left\{(HP)_i\,(HAP)_i\right\}\,(AU)_I\,(GI)_I$$

$$(4) \quad \widehat{(HF)}_I = \Sigma_{i=1}^{I} \left\{(FP)_i\,(AU)_i\right\}\,(GI)_I$$

in which $\widehat{(HF)}_I$ is the estimated value of $(HF)_I$; I is the number of years in the planning interval; and $(HP)_i$, $(HAP)_i$, $(FP)_i$, and $(AU)_i$, are the average annual values for herbage production, herbage availability-palatability, forage production, and allowable use. $(AU)_I$ and $(GI)_I$ represent the average allowable use and grazing intensity over interval I.

When HP and HAP, or FP and AU are used as the state parameters, their respective annual values for the first and last year in the planning interval must always be specified by the planner. Furthermore, the planner must specify a "parameter pattern" or "practice implementation pattern"[3] for both the structural and non-structural management practices. In all, the planner has a choice from sixteen alternative patterns from which he can make his selection. The RANGE/

[2] Forage production as used here must represent the production of palatable and available herbage. It is similar to the definition given in the Forest Service Manual 2212.71a, Amendment No. 4, July 1968.

[3] See Range RAM Users' Manual Part I: Users' Guide and Instructions.

MTX program then determines the annual—within the interval—values of the state parameters on the basis of these specified patterns and the first and last year values of the state parameters.

Once the coefficients of harvested forage have been determined, the coefficients for other related output commodities can be derived. For this reason, output conversion factors are used. An output conversion factor constitutes a ratio (expressed as a decimal fraction) that relates the harvested forage coefficients $(\widehat{HF})_I$ to other output commodities. Equation 5 describes this relationship formally.

$$(5) \quad (\widehat{HF})_I \times (cf)_j = C_j$$

in which C_j represents the output coefficient of commodity j; $(\widehat{HF})_I$ represents the estimate of the harvested forage coefficient; $(cf)_j$ represents the output conversion factor for commodity j; and j = 1, 2, . . . n, where n = 9. The conversion factor $(cf)_j$ for a given commodity j may vary for different resource classes. Variability in $(cf)_j$ allows, for example, for the consideration of differences in forage quality, harvested in different resource classes.

Some examples may help explain the use of the conversion factor. Consider a resource class which is grazed by livestock only. Harvested forage is measured in thousands of pounds, and 0.8 thousand pounds of harvested forage supports one animal month (AM) of grazing. Then a value of 1.25 for the conversion factor translates harvested forage into AM's, i.e. $\widehat{HF}_I \times 1.25$ = AM of livestock grazing. If one AM of livestock grazing has a rental fee value of \$1.50, then a value of 1.875 for a second conversion factor translates harvested forage into dollar revenue, i.e. $\widehat{HF}_I \times 1.875$ = dollar revenue. If the resource class were grazed by both livestock and game, and only 75 percent of the harvested forage goes towards livestock consumption, then conversion factors of .75 and .25 will give the forage harvested by livestock and game respectively. If the livestock again requires 0.8 thousand pounds of forage for each animal month of grazing, then the conversion factor C_j which translates $\widehat{HF}_I$ into AM's of livestock grazing must be equal to .9375 (i.e., 75 x 1.25).

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