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Forest and Rangeland Resource Interactions: A Supporting Technical Document for the 1989 RPA Assessment

John Hof and Tony Baltic

Preface

The Renewable Resources Planning Act of 1974 (RPA), P.L. 93–378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resource Assessment by December 31, 1975, with an update in 1979 and each tenth year thereafter. The Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA. It is composed of nine documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. The complete analyses for each of these resources are contained in supporting technical documents. There is also a technical document presenting available information on interactions among the various resources.

The 1989 RPA Assessment continues a resource analysis heritage that the Forest Service has been carrying out in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report upon forest conditions. Between 1880 and 1974, a number of assessments of the timber resource situation were prepared at irregular intervals. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber alone to all renewable resources from forests and rangelands.

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This paper provides an analysis of the resource interactions implied by the forest planning alternatives for the National Forest System. It is concluded that current levels of production and environmental conditions can be maintained at current cost levels, and that even a modest scenario for future production increases will imply a substantial increase in cost.

Keywords: Resource interactions, optimization, linear programming, multilevel planning

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Forest planners and economists throughout the National Forest System (in Regional Offices and in Forest Supervisor's Offices) were of enormous help in building the National Forest System Resource Interactions Model presented here. Also, in completing the literature review, the "Multiple Resource Interactions" chapter of the first review draft of "An Assessment of the Forest and Range Land Situation in the United States" (for 1980) was utilized extensively.

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INTRODUCTION

Information on resource interactions has been identified in the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) as amended by the National Forest Management Act of 1976 (NFMA) as an essential component of national renewable resource assessments. The term "resource interactions" simply refers to the mutual influence (in production) that different forest and rangeland resources have upon each other. Forest and rangeland resources are interactive in production because they share or are simultaneously affected by common land, labor, capital, and managerial inputs (Hof et al. 1985). The estimation of resource interactions has, however, proved to be very complex, especially where many resource outputs are involved over a large geographical area such as the National Forest System (or even just one National Forest System Region). Even after the completion of two national assessments, quantitative information on renewable resource interactions is still very limited. One major conclusion of the chapter "Multiple Resource Interactions" in the 1979 Assessment (USDA Forest Service 1981) states,

> At the present time, knowledge of these interactions is limited and should be the focus of increased attention from the forestry research community. The accuracy of any modeling efforts to quantify these resource interactions will be limited by the understanding of both the biology and economics of multiresource production.

The "Research Needs" chapter of the same assessment, states,

> Information on physical responses of forest and rangeland and the associated waters to management practices is still inadequate and especially so for multiresource interactions. The effort now going into describing and measuring the responses of these resources to management practices must be greatly expanded to provide the information necessary for efficient administration and management of forest and range lands.

This paper presents an analysis of resource interactions on the National Forest System lands that is based on the information developed in the forest planning effort mandated by the NFMA. The analysis addresses three questions regarding resource interactions:

1. What trends in costs are implied for simultaneously maintaining current production levels of all resources and environmental conditions on the National Forest System?
2. If the National Forest System were to maintain a constant share of total national resource production, would the demand (consumption) projections developed for individual resources in other recent assessment analyses be simultaneously achievable?
3. If an attempt were to be made for the National Forest System to maintain a constant proportion of these demand projections, what would the impacts be on cost trends and environmental conditions?

In both the text and the appendix, information is presented by National Forest System Region (numbered 1, 2, 3, 4, 5, 6, 8, and 9 for Northern, Rocky Mountain, Southwestern, Intermountain, California, Pacific Northwest, Southern, and Eastern regions, respectively). Maps of this regional configuration are available from many sources. No empirical results were included for Region 6 because planning alternatives were not available for this region; an addendum is planned when these alternatives become available.

A terse summary of the salient results is given in the sections entitled "Summary of Empirical Results" and "Conclusions." The analysis presented applies specifically to the National Forest System lands. In some cases, the results may be applicable to other lands, but as a general rule the reader is cautioned against such application.

STRUCTURE OF THE UPPER LEVEL MODELS

The National Forest System Resource Interactions Model (Baltic and Hof 1987) utilizes upper level linear programming (LP) models to develop technically efficient regional production possibilities. Discrete management alternatives generated by the local (forest) level planning LP models (Johnson et al. 1986a, 1986b, 1986c, 1986d; Kelly et al. 1986; Kent et al. 1985; Robinson et al. 1986) are used in the upper level models as the decision variables for quantifying resource interactions. Regional level results from this analysis may be integrated into a national level renewable resource planning process.

This approach was first demonstrated by Bartlett (1974) and Wong (1980). Later, Hof and Pickens (1986, 1987) developed the details of this approach and tested it in a case study. The approach performed very well at the higher level of analysis, given systematically defined lower level alternatives.

The test case involved utilizing a global model as a standard for comparison. Multilevel (two-level) models were then constructed using this global model. The global model used for the test was the NIMRUM model described in the appendix. Lower level models (local planning units) were developed simply by subdividing NIMRUM geographically. Timber and forage were the only outputs modeled in this test case. Five upper level LP model configurations were constructed (1, 2A, 2B, 3, 4) that varied according to the number and range of management alternatives included. Nine tests for suboptimality were performed by solving the global model and each of the upper level models with three different global budget constraints and three price vectors for each global budget constraint. Comparisons of the solutions for the global and upper level models revealed a tendency of the upper level models to be only slightly suboptimal (table 1).

Table 2 shows an abbreviated version of the upper level model. In this example, only two forests (superscripted 1 and 2), two alternative management options (subscripted 1 and 2), and two forest outputs produced over two planning time periods (timber 1, timber 2, range 1, range 2) are included. The upper level models developed in this analysis cover five time periods and include as many as nine forest outputs, nineteen forests, and a total of 190 management alternatives.

In table 2, X_1^1 through X_2^2 are 0–1 decision variables representing selection (1) or rejection (0) of the discrete management alternatives developed by the national forests in their planning analyses. The column vectors of outputs associated with each management alternative are collected in the first six rows (accounting rows) of the model and are represented by the A_{ij} matrix of physical product/cost coefficients (for $i = 1,....6$, $j = 1,....,4$). For example X_1^1 represents the selection ($X_1^1 = 1$) or rejection ($X_1^1 = 0$) of the vector of outputs A_{i1} for $i = 1,....,4$ and cost A_{i1} for $i = 5,6$ associated with management alternative 1 in forest 1. The 0–1 constraint rows force the selection of only one alternative for each forest planning unit by constraining the aggregate value of a forest's deci-

Table 1.—Ratios of objective function solution values of different upper level linear programming models to those of the global model.

Global budget constraint	Relative timber prices	Upper level linear programming configurations				
		1	2A	2B	3	4
High	High	0.9908	0.9900	0.9869	0.9839	0.9723
High	Medium	.9942	.9942	.9942	.9276	.9942
High	Low	.9931	.9911	.9897	.9683	.9725
Medium	High	.9921	.9891	.9881	.9175	.9556
Medium	Medium	.9977	.9898	.9898	.8650	.9898
Medium	Low	.9963	.9918	.9925	.9498	.9633
Low	High	.9632	.9517	.9461	.9093	.8983
Low	Medium	.9922	.9826	.9826	.8850	.9826
Low	Low	.9960	.9928	.9936	.9063	.9415

Source: Hof and Pickens (1986).

Table 2.—An abbreviated upper level (regional) model structure.

		Decision variable				Accounting columns							
		Forest 1		Forest 2		Outputs				Cost 1	Cost 2	Type	Right-hand side (RHS)
		X_1^1	X_2^1	X_1^2	X_2^2	T1	T2	R1	R2	C1	C2		
Accounting rows	Timber 1	A_{11}	A_{12}	A_{13}	A_{14}	-1						=	0
	Timber 2	A_{21}	A_{22}	A_{23}	A_{24}		-1					=	0
	Range 1	A_{31}	A_{32}	A_{33}	A_{34}			-1				=	0
	Range 2	A_{41}	A_{42}	A_{43}	A_{44}				-1			=	0
	Cost 1	A_{51}	A_{52}	A_{53}	A_{54}					-1		=	0
	Cost 2	A_{61}	A_{62}	A_{63}	A_{64}						-1	=	0
	Objective Function									1	1		MIN
0–1 Decision variable constraints	Forest 1	1	1									=	1
	Forest 2			1	1							=	1
Production constraints (targets)	Timber 1					1						$\geqslant$	K_1
	Timber 2						1					$\geqslant$	K_2
	Range 1							1				$\geqslant$	K_3
	Range 2								1			$\geqslant$	K_4

sion variables to equal (Type column) a value of 1 (Right-hand side column). However, the decision variables in this model are continuous such that for any X, $0 \leqslant X \leqslant 1$. Therefore, the solution may include a partial selection of management alternatives, the combination of which satisfies the 0–1 constraints. For example, the management alternative options available in forest 1, X_1^1 and X_2^1, might solve with values of 0.6 and 0.4, respectively. Integer programming was not used explicitly to allow this interpolation. For further discussion of these partial selections, see Hof et al. (1985).

Each accounting row is associated with an accounting column. The accounting columns represent the problem solution variables for the forest product outputs and costs. These columns aggregate the outputs/costs of the alternatives selected to be in the solution. The aggregate outputs are then transferred to the production constraint rows and constrained to meet specified target values. For example, first period timber output (T1) is constrained to be greater than or equal to ($\geqslant$ type) K_1 (RHS). Aggregate costs are transferred to the objective function row and their sum is minimized.

The model in table 2 is structured to minimize the cost of regional forest production subject to constraints that force the selection of a "total" of one management alternative (and its corresponding vector of outputs and costs) per forest and that bound (constrain) the aggregate production of forest outputs.

Upper Level (Regional) Model Algebraic Formulation

The algebraic representation of the upper level model along with definitions for subscripts and variables follow:

Minimize: $$\sum_{t=1}^{5} C_t^* \quad \text{(Objective function)}$$

Subject to: $$\sum_{j=1}^{n} \sum_{i=1}^{m} P_{ijpt}X_{ij} - T_{pt} = 0 \ \forall\ p, t$$

(Production accounting rows—outputs)

$$\sum_{j=1}^{n} \sum_{i=1}^{m} C_{ijt}X_{ij} - C_t^* = 0 \ \forall\ t$$

(Production accounting rows—costs)

$$\sum_{i=1}^{m} X_{ij} = 1 \ \forall\ j$$

(0–1 Constraint rows)

$$T_{pt} \gtreqless K_{pt} \ \forall\ p, t$$

(Production constraint rows)

$$X_{ij} \geqslant 0 \ \forall\ i, j$$

$$T_{pt} \geqslant 0 \ \forall\ p, t$$

$$C_t^* \geqslant 0 \ \forall\ t$$

(Non-negativity constraints)

where

- i represents a management alternative from a lower level model
- j represents a lower level model (forest)
- t represents the time period
- p represents the product outputs from the lower level models considered in each upper level model
- m represents the number of management alternatives in a lower level model
- n represents the number of lower level models

and

- X_{ij} = management alternative i from lower level planning unit (forest) j
- P_{ijpt} = output of product p for time period t from management alternative i of forest j (A-matrix)
- C_{ijt} = cost of management alternative i from forest j and time period t
- T_{pt} = a variable to transfer the aggregate output of product p for time period t from the production accounting rows to the production constraint rows
- C_t^* = a variable to transfer the aggregate cost for time period t from the production accounting rows to the objective function
- K_{pt} = the production target for aggregate output of product p for time period t.

To address the questions posed in the introduction, a set of runs were performed with this model.

DESCRIPTION OF MODEL RUNS

For each region, a series of four solutions was obtained: Base Run, Run 1, Run 2, and Run 3.

The following output codes, followed by time period number (5 decades), are utilized in this paper:

Dispersed motorized recreation: (recreation visitor days (RVD's))	RECM
Dispersed nonmotorized recreation (RVD's):	RECNM
Total dispersed recreation (RVD's):	REC
Direct wildlife habitat improvement (acres)	HAB
Elk (number):	ELK
Deer (number):	DEER
Fish (pounds or number):	FISH
Range forage (animal unit months):	RNG
Timber (cubic feet):	TMBR
Water yield (acre-feet):	WTR
Sediment (tons):	SDMT
Cost (constant dollars):	COST

It was not possible to include some resources, such as minerals and air quality, because of the lack of sufficient data. The literature review in the appendix is similarly limited.

Base Run

The Base Run minimizes cost with lower bounds (constraints) on all outputs, except sediment which has upper bounds, over all periods at "NOW" levels. The NOW output levels are defined as the first period "No Action Alternative" output levels from the forest plans (summed over all forests). The No Action Alternative is the same as the "Current Management Direction Alternative." Base runs for all regions except Region 9 were feasible. Allowing range (RNG) to float (unbounded or unconstrained) in Region 9 resulted in a feasibility.

Run 1

In Run 1 the lower bounds for all outputs, except wildlife habitat improvement and sediment, were set at NOW levels times indexed demand projections (first period equals 100) for the outputs. *It is recognized that these are not true demand function projections in the economic sense, but they will be labeled as such for consistency with other RPA documents.* All indexed demand projections were derived from "An Assessment of the Forest and Rangeland Situation in the United States," USDA Forest Service (1981) or other research documents related to that publication; "An Analysis of the Timber Situation in the United States 1952–2030," USDA Forest Service (1982), and the "The South's Fourth Forest," USDA Forest Service (1987). *Applying these demand projections to the National Forest System implicitly assumes that the National Forest System will maintain its proportion of output production relative to the Nation's production as a whole.* The actual indexed demand projections are given in the results section, below. Habitat improvement and sediment were unconstrained in this run and the following runs because they are tracked as measures of the environmental impacts of meeting the given targets on the other outputs (while minimizing costs). For the results reported below, "rollover" runs were performed to insure that the indicated sediment and habitat improvement impacts are minimized, given the output levels and cost minimization of the given scenario. That is, sediment and habitat improvement were each minimized, subject to the given output levels and cost level. Because of the discrete nature of the data set, these rollovers had no effect.

Run 1 resulted in no feasible solution for all regions, necessitating Run 2. This implies that within the range of alternatives developed in the forest plans, it is not possible for the National Forest System to maintain a constant proportion of national production, if that national production is to simultaneously meet the demand projections developed for individual resources in other recent assessment analyses.

Run 2

Run 2 utilized a cardinal goal programming formulation to determine the minimum weighted and summed underachievement of projected demands from Run 1 that would allow feasibility for each region. Goal programming is a type of linear programming for achieving several objectives (or goals) simultaneously.

Table 3 depicts an abbreviated goal formulation of the problem in this analysis. To save space, only one time period and two outputs are considered, and the A-matrix is represented by the "t," "r," and "c" entries. This formulation differs substantially from the structure in table 2. The aggregate outputs collected in the accounting columns are transferred to the demand constraint rows. The right-hand sides of the demand constraint rows are set to be greater than or equal to projected demands (D_t and D_r) and deviational variables are added to the constraint rows to force any underachievement of demand into these columns, thus insuring that feasibility results. The deviational variables (underachievements) are then transferred to the objective function to be minimized. The objective function coefficients (W's) represent the relative weight assigned to each output underachievement.

Wildlife habitat improvement and sediment yield are not included in these new rows and columns because a projected demand for these outputs was not utilized in Run 1. In this case, the weights (or objective function coefficients) are based on the RPA values (USDA Forest Service 1981) assigned to each forest product output:

Output	**Value**
REC	$10/RVD
ELK	$100/Elk
DEER	$100/Deer
FISH	$.50/Fish
RNG	$8/AUM
TMBR	$40/MCF
WTR	$12/ACFT

Upper Level Cardinal Goal Formulation

The algebraic representation of this cardinal goal formulation along with definitions for subscripts and variables follow:

Minimize: $$\sum_{t=1}^{5} \sum_{p=1}^{k} W_p Y_{pt}$$
(Objective function)

Subject to: $$\sum_{j=1}^{n} \sum_{i=1}^{m} P_{ijpt} X_{ij} - T_{pt} = 0 \quad \forall\ p,\ t$$
(Accounting rows—outputs)

$$\sum_{j=1}^{n} \sum_{i=1}^{m} C_{ijt} X_{ij} - C_t^{*} = 0 \ \forall\ t$$
(Accounting rows—costs)

$$\sum_{i=1}^{m} X_{ij} = 1 \ \forall\ j$$
(0–1 Constraint rows)

$$T_{pt} + Y_{pt} \geq D_{pt} \ \forall\ p,\ t$$
(Demand constraint rows) plus the Non-negativity constraints

where

- i represents a management alternative from a lower level model
- j represents a lower level model (a forest)
- t represents the time period
- p represents the product outputs from the lower level
- k represents the number of outputs considered
- m represents the number of management alternatives in a lower level model
- n represents the number of lower level models

and

- X_{ij} = management alternative i from lower level planning unit (forest) j
- P_{ijpt} = output of product p for time period t from management alternative i of forest j (the A-matrix)
- C_{ijt} = cost of management alternative i from forest j and time period t
- T_{pt} = a variable to transfer the aggregate output of product p for time period t from the accounting rows to the demand constraint rows
- C_t^* = a variable that collects the aggregate cost from the lower level planning units selected alternatives
- D_{pt} = the projected demand constraint (NOW x indexed demand) for each product p in time period t
- Y_{pt} = the positive deviational variable representing the underachievement of demand for product p in time period t
- W_p = the weight or relative worth (RPA prices ÷ 10^4) assigned to each underachieved output Y_{pt} in the objective function.

Run 3

Run 1 showed that the original production targets (NOW x indexed demand projections) could not be satisfied for all outputs simultaneously. The goal formulation of Run 2 provided one set of production levels that are achievable in the model. Run 3 is the minimum cost "rollover" for the output levels obtained from Run 2; that is, the objective in Run 3 is to minimize cost subject to the production levels obtained from Run 2. There may be an overachievement of demand for some outputs in Run 2. In Run 3, these overachievements are disregarded—the bounds are set at projected demand (NOW x indexed demand) or production activity from Run 2, whichever is lower. As in the other runs, habitat improvement and sediment are left unconstrained.

EMPIRICAL RESULTS

This section displays the empirical results from the Base Run and Run 3 by region and discusses the multiresource implications of these joint production scenarios. These implications include cost and environmental impacts of output changes and the identification of limiting factors in terms of cost minimization. The analysis will demonstrate the usefulness and limitations of the upper level (regional) resource interactions models and provide insight as to areas where improvements might be made for future national level resource planning (optimization) analyses.

As described earlier, the Base Runs represent the baseline conditions when the production level of the current management situation (NOW) for the first planning period (each period representing one decade) is held constant as the target for future output projections (over the 50-year planning horizon). Run 3 for each region quantifies the potential resource allocations and interactions based on the attempted achievement of the projected regional demand over the same planning horizon. The results from the Base Run and Run 3 for each region are illustrated in one table. These two regional resource production scenarios are then compared graphically by region. The upper bar graph in each figure compares the

Table 3.—An abbreviated cardinal goal formulation.

		Decision variables				Accounting columns			Deviation variables			
		Forest 1		Forest 2		Outputs		Cost	Underachievement		Type	RHS
		X_1^1	X_2^1	X_1^2	X_2^2	Timber	Range	Cost	Timber	Range		
Accounting rows	Timber	t	t	t	t	-1					=	0
	Range	r	r	r	r		-1				=	0
	Cost	c	c	c	c			-1			=	0
Demand constraints	Timber					1			1		⩾	D_t
	Range						1			1	⩾	D_r
	Objective function								W	W		MIN
0-1 Decision variable constraints	Forest 1	1	1								=	1
	Forest 2			1	1						=	1

total (planning horizon) targeted production levels for those outputs with the baseline (NOW) levels. The lower graphs illustrate the environmental and cost impacts (in terms of projected levels of wildlife habitat improvement, sediment yield, and cost) that result from regional level cost minimization constrained by the targets shown in the upper graph and limited by the range of management alternatives (choice variables) generated in the forest planning effort.

The results presented in the tables are indexed. Thus, they are used to show relative comparisons, not to predict specific quantities of resource allocations. In all tables, the outputs are indexed such that the current (NOW) output levels, determined by totaling the outputs in the "No Action" forest alternatives in the first period, are equal to 100. In all tables, the unconstrained outputs and minimized costs are indexed similarly. Thus, in the Base Run, all targets for all time periods are equal to 100. And, in the Run 3, the targets are 100 in the first time period, and they then change according to the targets determined in Run 2.

Just as the actual quantities of resource outputs are not specified in this report, the discussion of limiting factors is also framed in relative terms. The existence of nonzero shadow prices identifies limiting factors, i.e., outputs whose demands or targets are stressing the resource production systems as modeled in this study. Thus, these are sensitive areas in the system where the potential for problems in resource interactions is greatest. For example, if certain products in specified time periods are shown to be limiting factors in the solution of the planning problem, relieving the constraint (target) on any one or combination of these outputs would reduce the total cost of this production scenario. It is important to emphasize, however, that an output might be indicated as a limiting factor either because of physical production properties or because of the way the forest planning alternatives are defined.

It is also important to emphasize the difference between the "Target" and "Demand" columns listed in the tables for Run 3 for each region. The "Demand" column represents the projected regional demand for each output by period as gleaned from several Forest Service documents previously identified. Based on the range of management alternatives (the choice variables and their related vectors of production outputs) available from the forest planning efforts, no upper level scenario could be developed for any region where all regional demand projections could be met simultaneously. Using goal programming techniques, a set of feasible output levels were determined by setting the objective of the goal problem to minimize weighted demand underachievement. These levels from the goal formulations are represented as the "Target" column in Run 3. Thus, these are also the production targets or constraints upon which determination of the limiting factors depend.

Ideally, a regional production scenario would just meet all targets at minimum cost. As discussed above, the discrete nature and limited range of choice variables available in the analysis results in the overachievement and underachievement of targets for certain outputs. Suppose that a certain product's projected output is in excess of its target. It would not be identified in the model formulations in this analysis as a limiting factor, because its target is not constraining. But, this overproduction may actually represent an additional cost to the system, especially where significant over- and underproduction exist in the same scenario.

Finally, the figures are intended to provide some insight as to the relative environmental and cost impacts that result from meeting output targets. In the figures, the indexes apply to total time horizon output levels. The indexes are again defined such that the total current (NOW) output level equals 100. There is no direct relationship between any environmental or investment indicator in a lower graph and any output target in an upper graph. For example, looking at a given figure, one might be tempted to assume that a large percentage of an increased cost (in the optimum production scenario over baseline) is attributable to a comparatively large increase targeted for, say, recreation. However, the indicated cost is a joint cost, simultaneously affected by all the outputs in a production scenario.

As previously stated, Region 6 is excluded because forest planning alternatives were not available for analysis.

Region 1

The results for Region 1 are shown in table 4 and in figure 1. Note that this is the only region where dispersed recreation could be disaggregated into the motorized and nonmotorized categories.

Base Run

The limiting factors in this scenario are wildlife habitat improvement, range, elk, and timber in period 1 and range in period 2. A number of outputs significantly exceed the current production levels (targets). By period 5, nonmotorized recreation and timber show the largest increases over current production levels (79% and 51%, respectively). While sediment increases over the planning horizon, as might be expected because of the relatively large increases in timber production, it never reaches the current (NOW) levels. This is an indication that environmental mitigation measures are incorporated in the forest planning alternatives. Cost requirements increase between the first and second periods but show a decline after that.

Run 3

All of the outputs except timber are limiting factors in this scenario. Of these limiting factors, only nonmotorized recreation and range in period 5 are targeted at their demand levels.

Demand for recreation and recreation-related outputs (elk and fish), show the largest increases over the plan-

Table 4.—Region 1 Base Run and Run 3 Results.

	Base Run			Run 3			
Output	Output level	Target	Limiting factor	Output level	Target	Demand	Limiting factor
RECM1	111	100		115	100	100	
RECM2	116	100		121	115	115	
RECM3	120	100		126	126	135	+
RECM4	124	100		133	133	155	+
RECM5	129	100		140	140	176	+
RECNM1	119	100		119	100	100	
RECNM2	141	100		132	115	115	
RECNM3	152	100		150	135	135	
RECNM4	163	100		161	155	155	
RECNM5	179	100		176	176	176	+
HAB1	100	100	+	100			
HAB2	102	100		78			
HAB3	102	100		79			
HAB4	103	100		79			
HAB5	103	100		80			
ELK1	100	100	+	100	100	100	+
ELK2	113	100		113	113	113	+
ELK3	116	100		122	122	125	+
ELK4	114	100		121	121	136	+
ELK5	112	100		125	125	141	+
FISH1	101	100		97	97	100	+
FISH2	103	100		95	95	117	+
FISH3	103	100		93	93	135	+
FISH4	103	100		91	91	155	+
FISH5	102	100		91	91	169	+
RNG1	100	100	+	97	97	100	+
RNG2	100	100	+	103	103	116	+
RNG3	100	100		109	109	120	+
RNG4	102	100		112	112	122	+
RNG5	106	100		125	125	125	+
TMBR1	100	100	+	152	100	100	
TMBR2	120	100		185	102	102	
TMBR3	119	100		181	116	116	
TMBR4	137	100		195	118	118	
TMBR5	151	100		243	117	117	
WTR1	100	100		100	100	100	
WTR2	101	100		101	101	104	+
WTR3	101	100		102	102	110	+
WTR4	102	100		103	103	115	+
WTR5	102	100		103	103	119	+
SDMT1	93	100		104			
SDMT2	96	100		99			
SDMT3	96	100		100			
SDMT4	99	100		102			
SDMT5	98	100		99			
COST1	93			147			
COST2	95			125			
COST3	91			121			
COST4	91			121			
COST5	92			130			

ning horizon (between 41% and 76%). Grazing demand increases by 25% while timber and water demands show the smallest increases (17% and 19%, respectively). However, in Run 2, projected demand is met in all periods only for dispersed nonmotorized recreation and timber. Water demand is met only in the first period and fish production not only fails to meet demands in all periods but is underachieved by as much as 46% (fish production decreased over the planning horizon as demand increased). Water and fish are clearly critical factors in this region. Timber is the only output that exceeds its targeted (equivalent to projected demand in this case) production levels in all periods. In fact, timber output exceeds its target levels by as much as 108% (in period 5). Nonmotorized recreation exceeds its target in all but the last period (by as much as 19%).

Wildlife habitat improvements, an output used in this analysis as an indicator of environmental impact, shows a sizable decrease from the current (NOW) situation over most of the planning horizon (approximately 21% less). Projections of fish production over the entire planning horizon also fail to stay above current levels. Sediment, the other indicator of environmental impact, fluctuates but is slightly below current levels by the end of the plan-

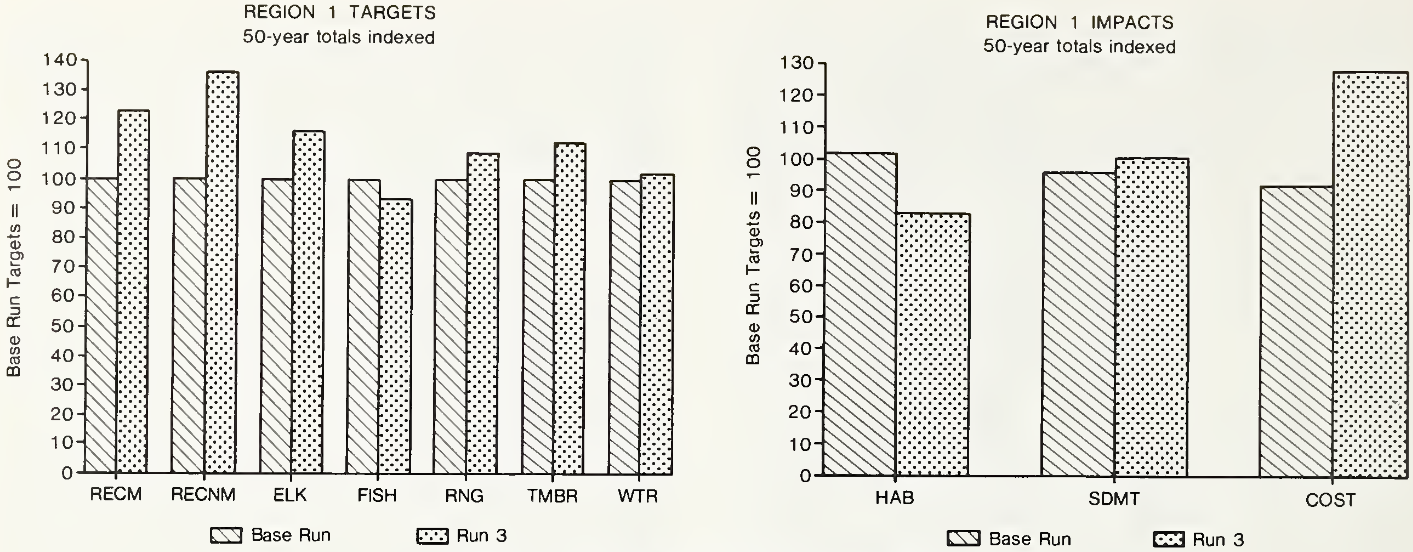


Figure 1.—Fifty-year summary of results: Region 1.

ning horizon. Although costs are substantially above current levels in all periods, they do decline until increasing in the last period.

In view of the very high levels of projected timber outputs in relation to current production, the projected sediment yields suggest a considerable effort in the mitigation of environmental impacts. Overall, costs are at a significantly higher level than current costs.

Graphic Summary of Results

In figure 1, the Run 3 scenario has recreation targeted for the largest production increase in this region, followed by elk and then timber and range. Water is targeted for a very slight increase while the Run 3 target for fish is the only one below the Base level. The environmental and cost impacts that result from the Run 3 scenario that achieves these targets are shown in the right-hand graph of figure 1. As would be expected, costs go up—by approximately 40%. Sediment yield increases slightly while wildlife habitat improvement shows a marked decrease.

Region 2

The results for Region 2 are shown in table 5 and in figure 2. Note that data on fish production were not available for this region.

Base Run

The limiting factors in this scenario are wildlife habitat improvement, range, timber, and sediment yield in period 1 and wildlife habitat improvement in period 4. Thus, the first period and wildlife habitat improvement are of particular interest in this region.

Recreation and elk are projected to have the largest increases over current production (59% and 36%, respectively, by the end of the planning horizon). Timber increases up to 21% by period 5 while range also shows a trend of increases but only up to 7% over current levels. Wildlife habitat improvements increase, then drop back down to current levels in period 4, then jump to their highest level in the last planning period. Water and sediment yields remain almost constant at current levels throughout the planning horizon. Costs start out below current levels and move up to just over the current level by the end of the planning horizon.

Run 3

Recreation and elk are limiting factors in period 5, and range and water are limiting factors after period 1 in this scenario. However, all limiting factors involve targets that are less than projected demand.

Timber is the only output for which projected demands are achieved in all periods in Run 2., Furthermore, it is indicated to be produced in excess of demand by substantial amounts (26% by period 5). Recreation, elk, and range in general come fairly close to meeting projected demands in Run 2, demonstrating moderate underachievements or overachievements in various periods throughout the planning horizon. All outputs whose targets are less than the demand projections, with the exception of water, still show a steady increase in projected output over the planning horizon. The target for water yield stays essentially constant at the current levels, while demand increases steadily up to 18% by the last period. Water appears to be critical in this scenario.

Sediment yield also remains constant at approximately current levels. Constant sediment yield just below current levels indicates concerted efforts at mitigation. Wildlife habitat improvements fluctuate, for the most part remaining above current levels but dropping below current levels in period 4. Costs show a steady increase to 39% above current levels by the last period. Increasing costs would be expected given steadily increasing production of most outputs.

Table 5.—Region 2 Base Run and Run 3 Results.

	Base Run			Run 3			
Output	Output level	Target	Limiting factor	Output level	Target	Demand	Limiting factor
REC1	102	100		106	100	100	
REC2	117	100		124	115	115	
REC3	132	100		139	135	135	
REC4	146	100		156	155	155	
REC5	159	100		172	172	176	+
HAB1	100	100	+	107			
HAB2	106	100		107			
HAB3	112	100		110			
HAB4	100	100	+	92			
HAB5	113	100		108			
ELK1	117	100		117	100	100	
ELK2	118	100		118	113	113	
ELK3	131	100		128	125	125	
ELK4	134	100		132	132	136	
ELK5	136	100		134	134	141	+
RNG1	100	100	+	104	100	100	
RNG2	103	100		110	110	111	+
RNG3	105	100		113	113	116	+
RNG4	106	100		116	116	118	+
RNG5	107	100		117	117	120	+
TMBR1	100	100	+	116	100	100	
TMBR2	104	100		130	114	114	
TMBR3	111	100		137	119	119	
TMBR4	115	100		146	123	123	
TMBR5	121	100		153	121	121	
WTR1	100	100		100	100	100	
WTR2	100	100		101	101	103	+
WTR3	101	100		101	101	109	+
WTR4	101	100		101	101	114	+
WTR5	101	100		101	101	118	+
SDMT1	100	100	+	100			
SDMT2	99	100		99			
SDMT3	100	100		99			
SDMT4	99	100		99			
SDMT5	99	100		99			
COST1	94			111			
COST2	91			120			
COST3	94			129			
COST4	97			127			
COST5	103			139			

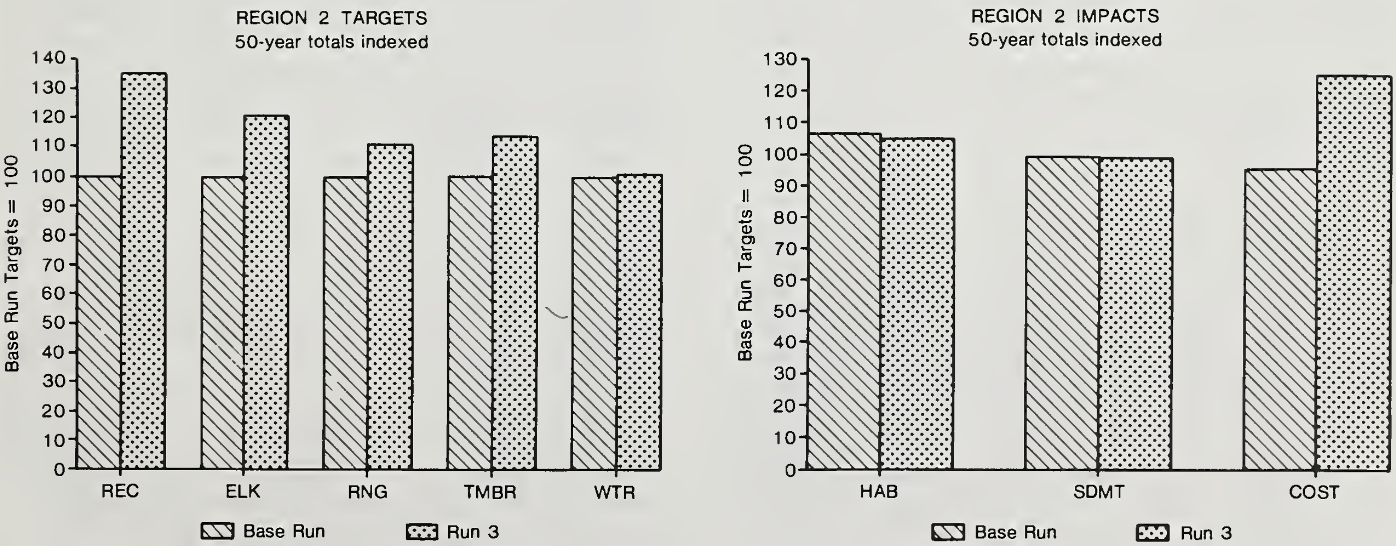


Figure 2.—Fifty-year summary of results: Region 2.

Graphic Summary of Results

Figure 2 depicts the Run 3 scenario as one with recreation output targeted for the largest increase followed by elk, timber, and then range. The water target stays just about constant at Base levels. Environmental impacts resulting from this scenario appear to be minimal. Cost requirements increase by approximately 30% over current levels.

Region 3

The results for Region 3 are shown in table 6 and in figure 3. Note that data on fish production were not available for this region.

Base Run

Limiting factors in this scenario include recreation, elk, and timber in period 1 and range in period 2. Recreation and wildlife habitat improvement show the largest increases in production (59% and 60% over current levels, respectively). Timber increases at a more moderate rate (up to 7%). Elk, range, and water yield remain relatively constant at not much higher levels than current. Sediment yield, however, is indicated to decrease dramatically (as much as 32% less than current levels by period 5). Cost increases slightly through the planning horizon, but remains below current levels in all periods.

A review of the forest plans in this region reveals that current soil and range conditions are often in the very poor category because of a combination of historical overgrazing and unique geologic and weather conditions. Thus, the forest planning alternatives all call for extensive watershed improvement measures as reflected by the figures for sediment yield in this baseline run.

Run 3

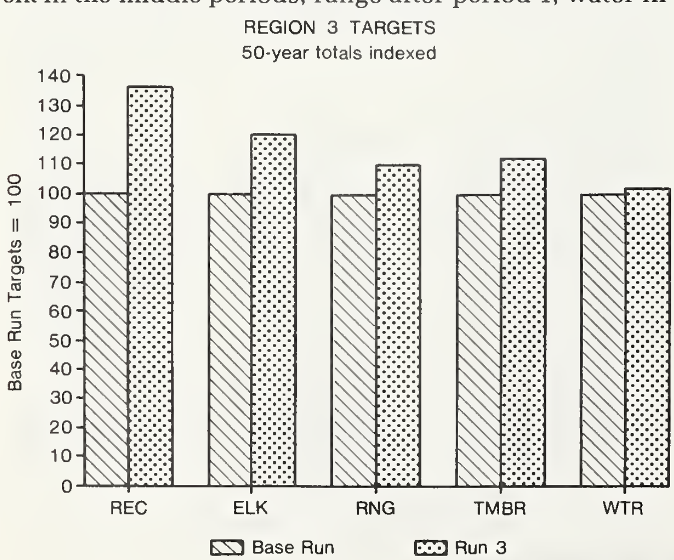
The limiting factors in this management scenario are elk in the middle periods, range after period 1, water in the last two periods, and recreation in period 5. Recreation is the only factor limiting at its projected demand, though the limiting water target from Run 2 is just under its projected demand. Recreation and timber are the only outputs with projected demands that are met in Run 2 in all periods.

Timber is indicated to be substantially in excess of its targets in all periods (between 24% and 35% greater). As in Region 2, water is a critical resource in this region. Unlike Region 2, the water yield targets are close to the demand projections. Range also appears to be a critical resource in this region. Reductions in sediment yield relative to current levels reflect substantial efforts in watershed improvement projects and other mitigative measures (especially in view of the indicated large increases in timber production).

However, the most conspicuous (and also potentially misleading) result from this scenario involves wildlife habitat improvement. An increase in this output over current production of 271% by the last period is indicated. In reviewing the data records from individual forest planning documents, it is apparent that a wide range in this output between alternatives within three forests, the relatively small number of alternative choices, and the discrete nature of the model lead to this result. These large increases in habitat improvement seem consistent with the large projected increase in elk numbers (a wildlife indicator species). Costs rise substantially over current levels. This is not surprising in view of the substantial increases in several outputs and the efforts to reduce sedimentation and improve wildlife habitat.

Graphic Summary of Results

Recreation and a recreation-related output, elk, are targeted for the largest increases in production in the Run 3 scenario (fig. 3). Timber and range also reflect targeted increases (approximately 10%) above the Base level. Environmental impacts appear to be significant on



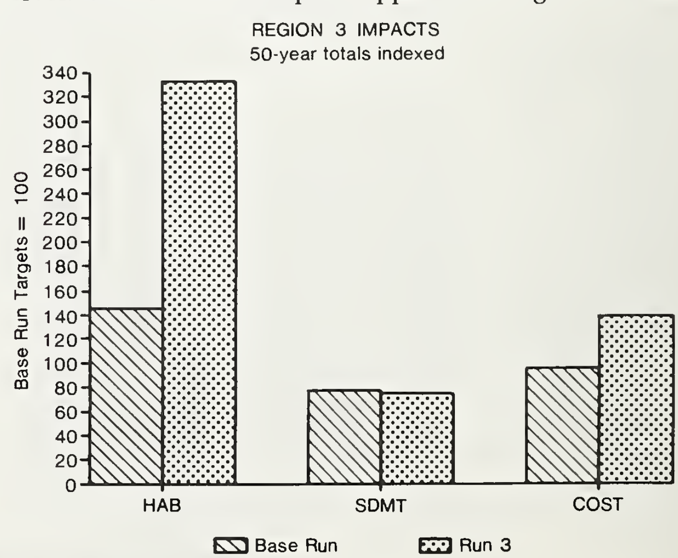


Figure 3.—Fifty-year summary of results: Region 3.

Table 6.—Region 3 Base Run and Run 3 Results.

Output	Base Run			Run 3			
	Output level	Target	Limiting factor	Output level	Target	Demand	Limiting factor
REC1	100	100	+	105	100	100	
REC2	120	100		123	115	115	
REC3	132	100		141	135	135	
REC4	145	100		157	155	155	
REC5	159	100		176	176	176	+
HAB1	131	100		285			
HAB2	141	100		329			
HAB3	145	100		336			
HAB4	150	100		348			
HAB5	160	100		371			
ELK1	100	100	+	105	100	100	
ELK2	101	100		111	111	113	+
ELK3	102	100		121	121	125	+
ELK4	101	100		131	131	136	+
ELK5	101	100		141	141	141	
RNG1	101	100		104	100	100	
RNG2	100	100	+	107	107	119	+
RNG3	101	100		112	112	122	+
RNG4	101	100		115	115	124	+
RNG5	101	100		117	117	126	+
TMBR1	100	100	+	125	100	100	
TMBR2	104	100		139	112	112	
TMBR3	107	100		154	116	116	
TMBR4	106	100		155	118	118	
TMBR5	107	100		158	117	117	
WTR1	100	100		102	100	100	
WTR2	101	100		103	97	97	
WTR3	101	100		105	102	102	
WTR4	101	100		106	106	107	+
WTR5	101	100		106	106	110	+
SDMT1	93	100		91			
SDMT2	81	100		79			
SDMT3	76	100		72			
SDMT4	72	100		68			
SDMT5	68	100		64			
COST1	96			132			
COST2	97			136			
COST3	97			138			
COST4	96			142			
COST5	97			146			

the positive side, especially in view of the tremendous increase in wildlife habitat improvement (although most of this is attributable to only three forests). The sediment levels in figure 3 both represent levels substantially below current levels. Cost increases appear to be in line with the other results summarized in this figure.

Region 4

The results from Region 4 are shown in table 7 and in figure 4. Note that fish data were not available for this region.

Base Run

The limiting factors in this scenario are recreation, wildlife habitat improvement, range, and timber in period 1, range and timber in period 4, and timber in period 5. Recreation shows the largest increase in output (57% by period 5). Wildlife habitat improvement also increases substantially while elk increases at a more moderate rate. All other outputs remain close to current production levels. Cost, however, shows a significant decrease from current levels (approximately 16% below current levels over all periods).

Run 3

The limiting factors in this scenario are elk, range, and water after period 1, and recreation in period 5. Recreation is the only factor limiting at its projected demand, while water yield is limiting at levels well below the projected demand (14% and 17%, respectively, in periods 4 and 5).

Projected demands increase substantially for all outputs (from 76% for recreation to 18% for timber by the last period). However, recreation and timber are the only outputs whose targets from Run 2 are equal to projected demand. Projected timber output exceeds its targets by

Table 7.—Region 4 Base Run and Run 3 Results.

	Base Run			Run 3			
Output	Output level	Target	Limiting factor	Output level	Target	Demand	Limiting factor
REC1	100	100	+	102	100	100	
REC2	114	100		123	115	115	
REC3	127	100		140	135	135	
REC4	141	100		158	155	155	
REC5	157	100		176	176	176	+
HAB1	100	100	+	105			
HAB2	122	100		127			
HAB3	123	100		135			
HAB4	128	100		137			
HAB5	128	100		134			
ELK1	102	100		106	100	100	
ELK2	105	100		108	108	113	+
ELK3	107	100		109	109	125	+
ELK4	108	100		108	108	136	+
ELK5	109	100		107	107	141	+
RNG1	100	100	+	103	100	100	
RNG2	100	100		108	108	119	+
RNG3	100	100		111	111	122	+
RNG4	100	100	+	112	112	124	+
RNG5	101	100		114	114	126	+
TMBR1	100	100	+	148	100	100	
TMBR2	104	100		160	113	113	
TMBR3	102	100		160	117	117	
TMBR4	100	100	+	151	119	119	
TMBR5	100	100	+	150	118	118	
WTR1	100	100		100	100	100	
WTR2	100	100		101	101	105	+
WTR3	101	100		101	101	112	+
WTR4	101	100		101	101	117	+
WTR5	101	100		101	101	122	+
SDMT1	99	100		102			
SDMT2	99	100		101			
SDMT3	99	100		101			
SDMT4	99	100		101			
SDMT5	99	100		101			
COST1	86			124			
COST2	86			129			
COST3	83			127			
COST4	83			130			
COST5	84			127			

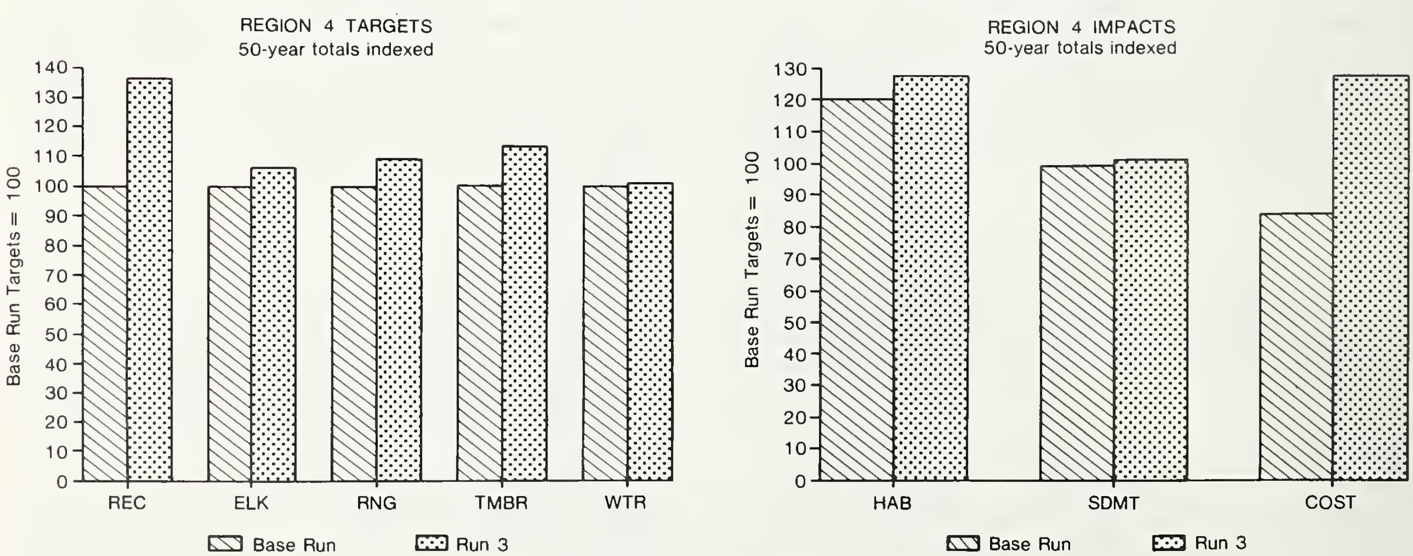


Figure 4.—Fifty-year summary of results: Region 4.

amounts from 27% to 48%. At the same time, elk, range, and water yield meet demand projections only in the first period. Water is clearly a critical factor in this region.

Sediment yield remains constant just above current levels indicating mitigation measures related to timber production are utilized in the forest planning alternatives. Wildlife habitat also shows steady improvements. Cost increases moderately throughout the planning horizon. This is consistent with the other results reported.

Graphic Summary of Results

Figure 4 indicates that recreation is the output targeted for the largest projected increases in the Run 3 scenario. All other outputs except water yield are also targeted for increased production above the Base levels. Environmental impacts from this scenario appear to be limited, while cost displays a substantial increase.

Region 5

The results from Region 5 are shown in table 8 and figure 5. Note that deer replaces elk as the wildlife indicator species in this region. Also, data on sediment yield were not available in this region.

Base Run

The limiting factors in this scenario include recreation and timber in period 1, and water yield in periods 4 and 5. Recreation shows the greatest increase in projected output (46% by the last period). Deer and range increase moderately; all other outputs remain relatively constant at or near current production levels, except wildlife habitat improvement, which decreases. Cost, however, displays a substantial increase (25% by the last period). This would imply that maintaining production at Base levels would involve increased costs.

Run 3

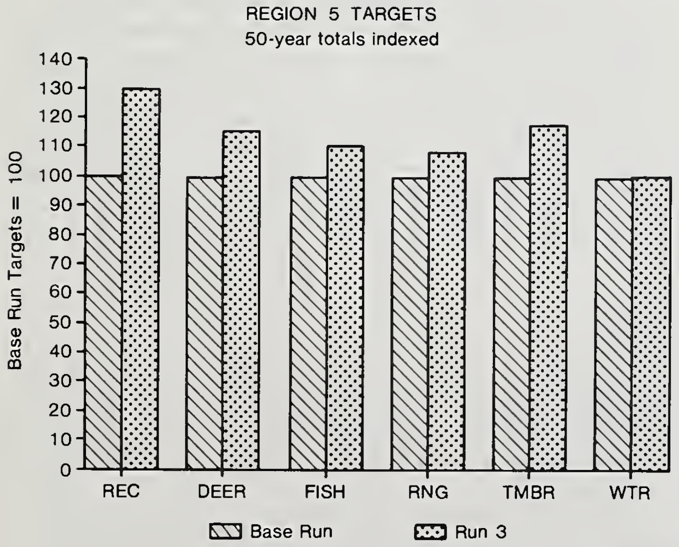
The limiting factors in the Run 3 scenario include recreation, deer, and timber in periods 4 and 5, and fish and water after the first period. Projected demands increase substantially across all resource outputs. The targets from Run 2 for recreation, deer, range, and timber meet or closely approximate their demand projections, while fish and water targets fall short of their projected demands.

Range output exceeds its target in all periods. The results with respect to water may have particularly significant implications. Water is a limiting factor at a target level well below demand. A similar situation exists for fish production.

As in Region 3, the most conspicuous (and potentially misleading) result involves wildlife habitat improvement, where almost a threefold increase occurs between the current (NOW) situation and the Run 3 solution. This occurs for the same reason as in Region 3, but only one forest is involved here. A very large response in this resource in certain alternatives and the discrete nature of the model makes this result occur. Finally, cost shows a substantial increase over current levels throughout the planning horizon. This is consistent with the previously discussed results.

Graphic Summary of Results

In figure 5, recreation and timber are shown to be targeted for the largest increases in production while water is the only output that is targeted to remain constant at Base levels in the Run 3 scenario. Environmental impact, represented by wildlife habitat improvement, would appear to be significantly positive. However, this



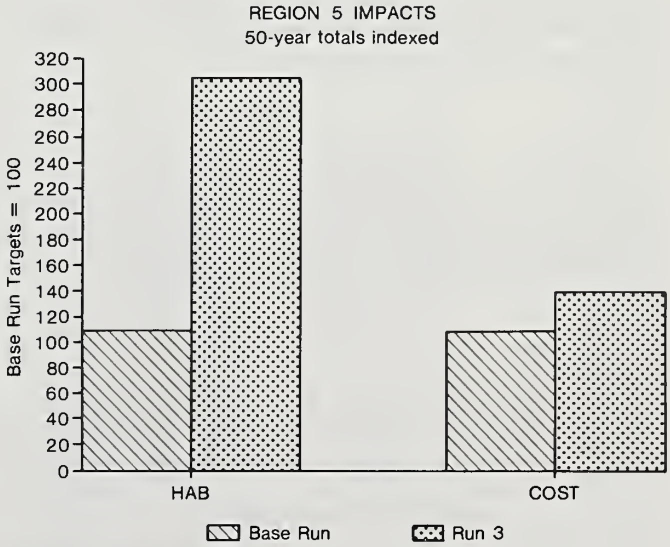


Figure 5.—Fifty-year summary of results: Region 5.

Table 8.—Region 5 Base Run and Run 3 Results.

Output	Base Run Output level	Base Run Target	Base Run Limiting factor	Run 3 Output level	Run 3 Target	Run 3 Demand	Run 3 Limiting factor
REC1	100	100	+	103	100	100	
REC2	113	100		118	114	114	
REC3	124	100		132	131	131	
REC4	135	100		146	146	149	+
REC5	146	100		159	159	168	+
HAB1	121	100		314			
HAB2	110	100		307			
HAB3	106	100		294			
HAB4	106	100		299			
HAB5	103	100		316			
DEER1	103	100		109	100	100	
DEER2	106	100		115	110	110	
DEER3	108	100		121	118	118	
DEER4	110	100		124	124	126	+
DEER5	112	100		128	128	128	+
FISH1	102	100		106	100	100	
FISH2	103	100		111	111	118	+
FISH3	103	100		114	114	132	+
FISH4	102	100		114	114	146	+
FISH5	102	100		116	116	157	+
RNG1	101	100		113	100	100	
RNG2	107	100		118	107	107	
RNG3	112	100		121	111	111	
RNG4	113	100		125	112	112	
RNG5	116	100		129	113	113	
TMBR1	100	100	+	118	100	100	
TMBR2	102	100		123	110	110	
TMBR3	102	100		126	123	123	
TMBR4	101	100		127	127	127	+
TMBR5	102	100		129	129	133	+
WTR1	100	100		101	100	100	
WTR2	100	100		101	101	107	+
WTR3	100	100		101	101	113	+
WTR4	100	100	+	101	101	116	+
WTR5	100	100	+	100	100	120	+
COST1	96			118			
COST2	100			121			
COST3	108			134			
COST4	116			152			
COST5	125			172			

may be a specious result as indicated above. Cost requirements appear to be significantly higher for the Run 3 scenario than for the Base scenario.

Region 8

The results from Region 8 are shown in table 9 and in figure 6. As in Region 5, deer is the wildlife indicator species in this region. Also, data on fish production were not available for this region.

Base Run

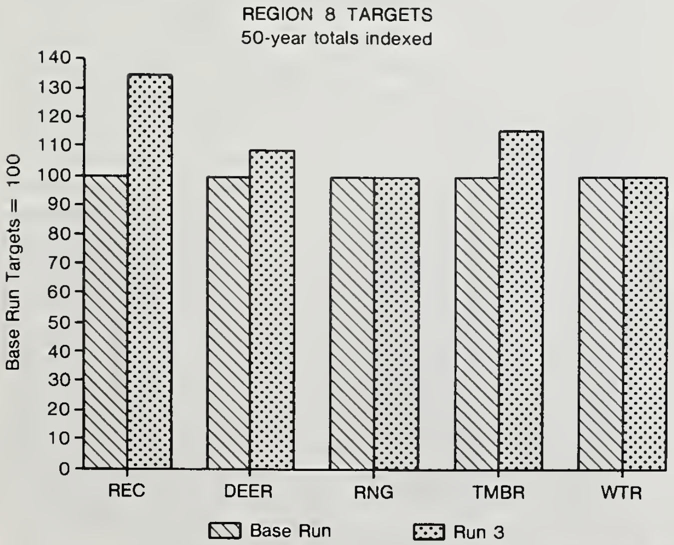
Recreation, deer, range, timber, and water yield in period 1, sediment in period 3, and deer and water yield in period 5 are the limiting factors in the Base scenario. Recreation and timber show large increases in projected outputs (37% and 49%, respectively) while all other outputs except water show much smaller increases, some even declining in later periods. Water yield remains constant at current levels throughout the planning horizon. Sediment yield starts out 11% below current (NOW) levels and rises to the current level by period 4. This would indicate that the forest planning alternatives include substantial efforts at mitigation of this impact in view of the large increases in timber production. Costs are less than current levels early in this scenario, but increase to 10% above current levels by period 5.

Run 3

The limiting factors in this scenario are recreation and range after period 2, and deer and water after period 1. Note that the limiting targets from Run 2 on water yield are well below projected demand. In fact, they are at current production. This suggests that it could be quite costly to meet projected demands for water in this region. While water yield in this scenario falls well short of projected demand, timber output substantially exceeds de-

Table 9.—Region 8 Base Run and Run 3 Results.

	Base Run			Run 3			
Output	Output level	Target	Limiting factor	Output level	Target	Demand	Limiting factor
REC1	100	100	+	104	100	100	
REC2	110	100		119	114	114	
REC3	119	100		134	134	134	+
REC4	129	100		150	150	154	+
REC5	137	100		176	176	176	+
HAB1	103	100		106			
HAB2	103	100		106			
HAB3	104	100		106			
HAB4	103	100		109			
HAB5	104	100		110			
DEER1	100	100	+	107	100	100	
DEER2	102	100		105	105	111	+
DEER3	103	100		111	111	119	+
DEER4	101	100		116	116	127	+
DEER5	100	100	+	113	113	132	+
RNG1	100	100	+	105	100	100	
RNG2	105	100		99	99	109	
RNG3	109	100		99	99	113	+
RNG4	103	100		105	105	116	+
RNG5	104	100		96	96	118	+
TMBR1	100	100	+	110	100	100	
TMBR2	113	100		133	111	111	
TMBR3	127	100		167	118	118	
TMBR4	140	100		187	125	125	
TMBR5	149	100		201	126	126	
WTR1	100	100	+	100	100	100	
WTR2	100	100		100	100	118	+
WTR3	100	100		100	100	134	+
WTR4	100	100		100	100	160	+
WTR5	100	100	+	100	100	166	+
SDMT1	89	100		95			
SDMT2	91	100		102			
SDMT3	100	100	+	107			
SDMT4	100	100		111			
SDMT5	97	100		101			
COST1	92			105			
COST2	97			127			
COST3	101			134			
COST4	108			135			
COST5	110			134			



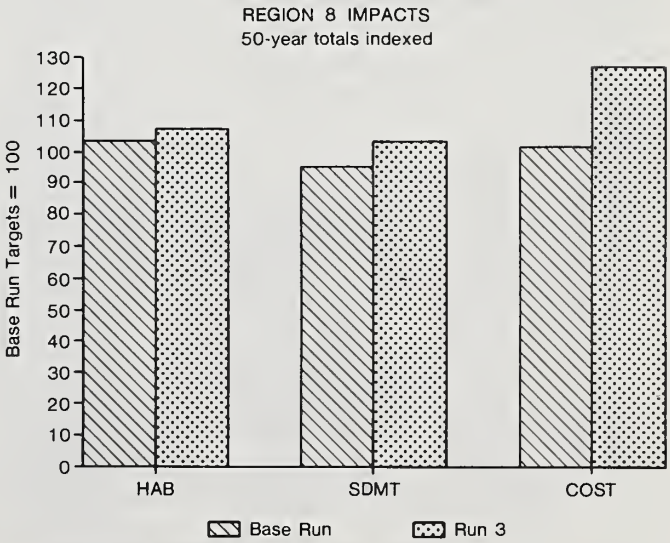


Figure 6.—Fifty-year summary of results: Region 8.

mand in all periods. Recreation shows the largest increase in projected demand and outputs are indicated to meet this demand. Except for the first period, targets from Run 2 for deer and range outputs fall short of their demands. Despite a steady increase in demand from current levels, output for range does not reach current levels in three periods.

Sediment shows mixed results. It increases by up to 11% over current levels by period 4, then falls back to approximately current yield in period 5. Wildlife habitat shows modest increases over current levels. Costs increase steadily to 34% higher than current levels by the last period. These results appear to be consistent with the targeted output increases in this scenario.

Graphic Summary of Results

As figure 6 shows, recreation is targeted for the largest increase in production, followed by timber then deer in the Run 3 scenario. Range and water are projected to remain near Base levels. Both environmental and cost impacts appear to be minimal in this scenario, although some increase in sediment and cost is indicated above the Base levels.

Region 9

The results from Region 9 are shown in table 10 and in figure 7. Note that data for deer, water, and sediment were not available for this region.

Base Run

The limiting factors in this scenario are recreation, wildlife habitat improvement, and timber in period 1. Timber and wildlife habitat improvement are indicated to experience substantial increases in output, while recreation increases are more moderate. Range, meanwhile, is limited to output levels well below current levels throughout the planning horizon. With the forest management alternatives available, it was not physically possible to maintain range output at current levels.

Run 3

The limiting factors in this scenario are timber in period 1, range in period 2, recreation in period 4, and recreation and range in period 5. The targets from Run 2 on range are limiting below its projected demand levels. However, timber output is generally above its demand projection (17% by the last period). Recreation outputs approximate demands while wildlife habitat improvements fall well below current levels in the first two periods. Considering the increase in projected outputs, especially timber, cost results are quite stable.

Graphic Summary of Results

As figure 7 shows, timber is targeted for the largest increase in the Run 3 scenario. Recreation is also targeted for an increase, while range targets remain approximately constant at Base levels. Environmental impact in this scenario appears significant based on the decrease in wildlife habitat improvement, while cost requirements are indicated to be stable between the Base Run and Run 3 scenarios.

Summary of Empirical Results

The Base Run results would indicate that current levels of outputs (timber, range, recreation, water, and wildlife and fish) can generally be produced throughout the planning horizon at current levels of cost. One exception is Region 5; the results indicate that maintaining current output levels would require steadily increasing costs. The same is true to a lesser extent in Region 8.

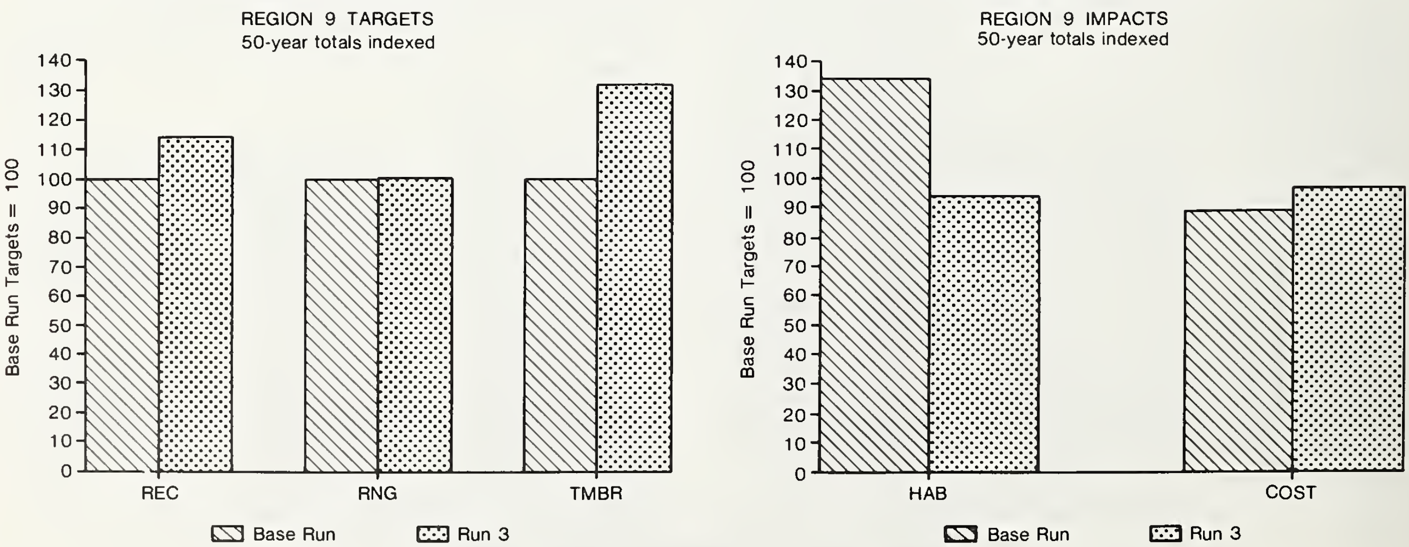


Figure 7.—Fifty-year summary of results: Region 9.

Table 10.—Region 9 Base Run and Run 3 Results.

Output	Base Run Output level	Base Run Target	Base Run Limiting factor	Run 3 Output level	Run 3 Target	Run 3 Demand	Run 3 Limiting factor
REC1	100	100	+	104	100	100	
REC2	108	100		111	106	106	
REC3	112	100		116	115	115	
REC4	115	100		123	123	123	+
REC5	123	100		129	129	129	+
HAB1	100	100	+	61			
HAB2	125	100		93			
HAB3	144	100		102			
HAB4	155	100		110			
HAB5	147	100		105			
RNG1	94			100	100	100	
RNG2	85			99	99	104	+
RNG3	88			102	102	106	
RNG4	84			101	101	108	
RNG5	86			105	105	111	+
TMBR1	100	100	+	100	100	100	+
TMBR2	118	100		124	120	120	
TMBR3	139	100		155	136	136	
TMBR4	150	100		172	148	148	
TMBR5	158	100		183	157	157	
COST1	87			88			
COST2	85			94			
COST3	91			100			
COST4	89			99			
COST5	93			102			

Timber was typically a limiting factor in the Base Runs only in early time periods (Region 4 was an exception). Range was also typically only limiting in early time periods, except in Region 9 where it was not physically possible to maintain current production levels. Recreation was a limiting factor in the Base Runs in early time periods in Regions 3, 4, 5, 8, and 9. Wildlife and fish were limiting factors early in Regions 1, 3, and 8, and late in Region 8. Habitat improvement was a limiting factor in Regions 1, 2, and 9, typically early in the planning horizon. Water yield was a limiting factor in the Base Runs in Regions 5 and 8.

The results from Run 1 indicate that the demand projections for all outputs in recent RPA studies cannot be simultaneously met in all National Forest System regions within the range of the forest planning alternatives currently developed. This is an important result.

Run 2 developed a production scenario that was feasible, and came as close as possible to the demand projections in the sense that a cardinally weighted (by RPA values) sum of deviations from the demand projections was minimized.

Utilizing the output targets from Run 2, the results from Run 3 indicate that simultaneously achieving this production scenario for all outputs (which, again, is less ambitious than the demand projections) will require substantial increases in cost over current levels—on the order of 20% to 45% throughout the planning horizon. The lone exception is Region 9, where Run 3 costs were very close to current levels.

Effects on sediment from simultaneously meeting the output targets from Run 2 appear to be minimal in all regions, apparently because the forest planning alternatives were generally developed with mitigation of sedimentation as a high priority. The negative effects of the Run 3 production scenario on wildlife habitat improvement are indicated to be a bit more significant in Regions 1 and 9, and, to a lesser degree, Region 2. The other regions all show increases in acres of improved habitat in the Run 3 results.

The potential for increased timber production over time appears to be substantial in all regions, and was a limiting factor in Run 3 only in Regions 5 and 9. This was a result of the discrete nature and definition of the forest planning alternatives currently available. Conversely, in Run 3, range outputs were limiting factors in all regions except Region 5. Recreation was commonly a limiting factor late in the planning horizon, when the targets in Run 3 are relatively high. Wildlife and fish outputs are also commonly a limiting factor after the first time period. Water was indicated to be a critical, limiting factor in all regions. The potential for increased water yield in combination with the other output increases in the Run 3 scenario is not indicated to be promising in any region. It is worth repeating that outputs may be indicated to be limiting factors either because of physical production properties, or because of the way the forest alternatives were defined.

CONCLUSIONS

The introduction posed three questions regarding resource interactions on National Forest System lands. The answers, based on the results just summarized, are as follows:

1. It would appear that current levels of production and environmental conditions can be simultaneously

maintained at current levels of cost in the National Forest System. This conclusion is limited to the particular outputs and environmental indicators studied.

2. Within the range of alternatives generated in the forest planning effort, it does not appear to be feasible for the National Forest System to maintain a constant proportion of national production if that national production is to simultaneously meet the demand projections developed for individual resources in recent assessment analyses. It is impossible to determine if this reflects true physical limits to production, or merely the limits of the forest planning alternatives.

3. The Run 3 scenario, which is less ambitious than the demand projections, is achievable with minimal negative impacts on sediment and with negative impacts on wildlife habitat improvement in Regions 1, 2, and 9, only. Achieving this scenario is indicated to require cost increases, however, in the range of 20% to 45% throughout the planning horizons. These are joint costs that cannot be assigned to any particular outputs or environmental conditions.

Although this analysis provides useful information with respect to the requirements for RPA assessments the present analysis falls short of the ideal interactions assessment. For example, no scenario could be developed that could meet all demand projections simultaneously. But, it could not be concluded that meeting these demands is actually impossible on the National Forest System based on the analysis in this report. While several outputs in the optimum production scenarios developed here were underachieved in terms of projected demands, several others displayed demand overachievements. The range between demand overachievements and underachievements in the production scenarios was often quite wide (overachievements of projected timber demands were particularly conspicuous). Attempts to reduce the slack between demand overachievements and underachievements resulted in infeasibilities. The analysis was limited by the relatively small number and narrow variability of the management alternative options available from the forest planning units.

Another shortcoming in this multilevel resource interactions analysis also involves the data base. Complete sets of study data were often not available for the lower level management alternatives as reported in the forest EIS's (even though consistency and availability of the output data reported in these sources were the main determinants of which data elements were included in the interactions analysis). The extensive use of various estimation techniques and referral to other forest planning records (Baltic and Hof 1987) were required to develop or otherwise obtain missing data. Even then, some alternatives had to be eliminated from the study for lack of necessary data, and not all the outputs considered in the interactions analysis could be included in every regional model. It also became apparent during the data collection process that inconsistencies in both reporting and defining production data for certain outputs exist across forest planning units.

It is clear that different levels of resource planning for National Forest System lands should not be carried out as separate or distinct analyses. The forest plans (EIS's and Proposed Plan), the Assessment of the Forest and Range Land Situation in the United States, and the Recommended Renewable Resources Program are the final products of one comprehensive and integrated planning process. Key concepts in this process are coordination of effort between planning levels, standardization of technology, and systematic development of alternatives. These concepts are discussed here in terms of the interactions assessment, but they relate to the National Forest System planning process as a whole.

This study has demonstrated a need for further refinements in the application of these concepts. First, the outputs need to be standardized across local forest level planning units and upper level analyses (the Assessment and Program) as to their definition and measurement. Second, local management alternatives should be developed in a systematic manner in order to best support multilevel national planning analysis (Hof and Pickens 1986). This would not preclude the achievement of local allocative and economic efficiencies. Finally, combining technological standardization and systematic lower level alternative development in an iterative approach could insure local level allocative efficiencies and global optima. Although the theory for such an approach has been developed (by Dantzig and Wolfe (1961), Kornai and Liptak (1965), and others), its detailed application to a national resource optimization analysis has not been. Hof and Pickens (1986) have suggested the development of such an application and described it in general terms. As they state:

> The Kornai and Liptak (1965) approach (for a two-level problem) involves a "game-theoretical model" between a higher level planning authority (the "center") and a set of sectoral planning units. The center makes an initial, provisional distribution of the "available resources, material, manpower, etc. among the sectors, and at the same time also indicates their output targets." The sectors then rigorously analyze this set of "quotas" and report back "one type of economic efficiency index—the shadow prices derived from programming." The center then modifies the resource and output "quotas" based on this information. By iterating back and forth, a sectoral allocation is arrived at that, within a given tolerance level, equates the shadow prices across sectors, and thereby reaches a global optimum.

In further discussing this application with regard to the problems to be overcome, Hof and Pickens (1986) state:

> There are two principal problems in applying a DW [Dantzig-Wolfe] or FP [Kornai-Liptak] model to a national renewable resource planning problem. First, it would be quite rare for all of the local planning units (such as national forests) to complete their planning efforts simultaneously. Second, the communications network and coordinating authority to implement the repeated iterations necessary in a DW or FP model generally are not present.

Thus, the results here suggest the need for further research into improving and refining the multilevel renewable resource optimization modeling capability.

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APPENDIX: REVIEW OF THE LITERATURE

While numerous studies have examined the response of a single resource to a specified management activity, quantitative information on multiple resource interactions over large geographic areas (as would be necessary in a national resource interactions analysis) is limited. Thus, relating previous work to the results presented in this report is difficult. The literature reviewed here is provided as background rather than as comprehensive analysis of resource interactions. The study utilized in the Multiple Resource Interactions chapter of the 1980 Assessment will first be reviewed. Then, this review will summarize the findings of selected resource interactions studies (typically involving microlevel production tradeoffs), organized by National Forest System region and type of analysis—biological or economic. Emphasis will be on the empirics of the studies cited.

Resource Interactions Analysis for the 1980 Assessment

Ashton et al. (1980) developed a system of four models to help evaluate alternative national renewable resource programs. The four models were capable of quantifying interactions in terms of cost-effective resource allocations, employment and earnings effects, loss in future options, and changes in social conflict. Feedback from each model could be used to change the input or parameters of the other models. The four models were the National Interregional Multiresource Use Model (NIMRUM), a regional employment and earnings model called the Regional Industrial Multiplier System (RIMS), the Futures Forgone Model, and the Social Conflict Model.

NIMRUM was utilized to quantify potential resource use allocations and resource interactions. This model actually evolved into a series of seven regional linear programming (LP) formulations that were driven by projected resource demands and had minimum cost objective functions. The Nation's 1.7 billion acres of forest and rangeland were broken into 107 potential natural communities (PNCs). The PNC s were further divided into distinct land types or resource units (RUs). Several alternative management levels (intensities) were then developed for each RU. The production plans or resource output activities associated with an alternative management level depended on the response of the RU to the activities, practices, and costs in that management level. The alternative management level scenarios represented the choice variables in this LP. The regional models were formulated to choose one or more alternative per RU. An interdisciplinary team of 200 scientists and land managers was assigned the task of developing each alternative management level's inputs and then quantifying the analogous resource output vectors (technological coefficients). Thirteen outputs were considered in this model. A description of the interactions results using NIMRUM and the data base developed can be found in USDA Forest Service (1981) and Ashton et al. (1980).

Pickens et al. (1987),[2] used two approaches to illustrate the quantification of multiresource interactions using the NIMRUM model and data base. The first application increased demands over time (1985, 1995, 2020) for the market goods (timber harvest and range grazing) to simulate the impact on the intensity and cost of land management. The nonmarket goods were assigned a target level of production. The model was run using the projected market demands both with and without the nonmarket constraints.

In the Rocky Mountain-Great Plains Region, which was used for this first application of NIMRUM, projected demands for both softwood timber and range grazing were met in 1985 and 1995. However, projected demand for range grazing could not be achieved in 2020 until the model was restructured through the reallocation of range grazing demand among the western regions. The largest changes in resource use and environmental effects resulted from increases in range grazing demand.

Where nonmarket output constraints were not applied, herbage and browse increased to 20% above base year levels while wild ruminant grazing decreased to 13% below the 1977 value. The other nonmarket outputs remained relatively constant. In order to meet rising timber and range grazing demands, the number of acres managed intensively more than tripled.

When nonmarket output constraints were applied, dispersed recreation, herbage and browse, and wild ruminant grazing increased beyond 1977 base levels by 22%, 33%, and 23%, respectively. Total costs increased by 20% using the nonmarket constraints. However, the marginal cost for softwood timber was slightly lower under these constraints, suggesting that the production of certain nonmarket outputs (predominantly wild ruminant grazing) are complementary to this output.

The second application of the NIMRUM model involved single and cross product marginal cost analysis to measure resource interactions. Three outputs were assigned three demand levels, and the model was run 27 times to account for all combinations of production levels. The outputs chosen, considered to be the most sensitive within this modeling framework, included softwood timber harvest, domestic AUM production, and wildlife AUM production. The objective function was always formulated to minimize cost, and marginal costs were identified for each product in each run. Product surpluses resulted from several runs, which would indicate that complementary relationships may have existed for certain outputs. The primary analysis in this second approach involved the development of marginal cost curves. The Pacific Southwest region was used for this example. Marginal cost curves were traced for different production levels of the other outputs. The marginal cost curves were not parallel, indicating a nonzero first order interaction, i.e., the effect of timber production on domestic range production depends on

[2] *Pickens, James B.; Ashton, Peter G.; Thomas, Michael H. 1987. Use of joint production functions in an LP environment to measure resource interactions. (in process).*

the level of wildlife ruminant range production. Also, timber and range seemed to have slightly complementary marginal cost curves (both downward sloping).

Microlevel Production Tradeoffs

Region 1

Bachman (1958) reported on trout streams in Idaho as influenced by logging and forest road construction. Because of the timbering activities, turbidity increased during snowmelt and rapid runoff from storms. Sedimentation increased in both riffles and pools; however, water temperature, volume of flow, and water chemistry showed no change.

In Montana, Marcuson (1968) reported on the effects of stream habitat improvements on Bluewater Creek. Before the projects, sediment was lowest upstream of the project sites and increased progressively downstream. After implementation of three streambank improvement projects, average suspended sediment load was reduced by 1.9 tons/day or 32% nearest the projects, and by 52% and 44% at increasingly further distances downstream from the projects. Trout composition increased from 13% prior to habitat improvements to 37% after improvements.

Schuster and Jones (1985), in western Montana, tested the hypothesis that below cost timber sales (BCTS) and efficient management are not incompatible. Their analysis did not refute this hypothesis. They based their analysis and conclusion on the premise that an assessment of the immediate revenues and costs for specific sales is incomplete. As to the appropriateness of a BCTS, they argue that "It demands a rigorous examination of the role played by specific timber sales and groups of sales in the context of integrated land management, over time and space." The authors suggest that the important measure of management efficiency is discounted net revenue (DNR). In a test case involving two timber sale areas in Montana, they use a mathematical model, the Integrated Resource Planning Model (IRPM), to demonstrate that even with initial BCTS's, positive DNR can result in the long term (NSV stands for Net Sale Value):

Time period	Twin Rocks sale area	Copeland Creek sale area
	Thousands	*of dollars*
NSV–1	–709	–819
NSV–2	–	617
NSV–3	4,121	14,985
Overall DNR	392	3,467

Region 2

Troendle (1987) studied the effects that thinning young lodgepole pine stands in Colorado and Wyoming have on streamflow. Study results indicated soil water depletion is reduced and water available for streamflow is increased in direct proportion to basal area reduction. The same conclusion holds for evapotransporation loss. However, in dry years, basal area was not related significantly to soil water depletion.

Crouch (1985) studied the effects of clearcutting subalpine forests in central Colorado on wildlife habitat. The undercover plant production and cover increased on all sites (average and moist) with few changes in species composition; plant moisture, protein, and digestibility increased; however, herbivore activity varied between species.

Crouch (1983) studied the effects of commercial clearcutting of aspen on vegetation and wildlife habitat values in southwestern Colorado. After the cuts, the aspen resprouted and there were very few lasting changes in understory vegetation. Much of the aspen was mature, and clearcutting seemed to be an economical method of regenerating these stands. However, cavity-nesters and other species requiring mature forests were adversely affected by the clearcuts. Conversely, large herbivore use was enhanced, although cattle mainly utilized the increased herbage production in these clearcut areas.

Schroeder and Sturges (1975), in Wyoming, reported the effects on the Brewer's Sparrow of spraying the herbicide 2,4–D on big sagebrush to convert the cover type to crop and grasslands. Initially, nesting success was not affected by either the spray or the plant's death. The dried leaves remaining on the dead sagebrush provided sufficient shade and protection. However, bird densities dropped by 67% one year after spraying and by 99% two years after spraying; also no nests were observed in the sprayed areas and all birds seen on the sprayed areas were near small areas of sage that survived the spraying.

Bowes et al. (1986) addressed the issue of below cost timber sales from a capital accounting view of costs and the computation of economically relevant separable costs. They defined separable cost as the increase in current expense, plus the increased depreciation in the forest asset value, that results from including a product in the current management plan. A case study involved analyzing a management program for the Shoshone National Forest in northern Wyoming that included timber, recreation, and wildlife services. Their results demonstrate that efficiency conclusions can be affected substantially by a multiresource perspective.

Along similar lines, Bowes et al. (1984) examined a situation where management for a single resource produces indifferent economic prospects, but, if managed in joint production with another resource, may provide a considerable economic return. Their study involved timber production managed in conjunction with watershed augmentation in the subalpine forests of western Colorado. Results are quite dependent on variables such as terrain, road construction costs, and esthetics.

Brown (1981) analyzed the problem of resource tradeoff considerations in the overall process of developing alternatives for local land management planning. He defined a tradeoff as the relationship between two or more effects of a change in some condition (such as the condition of the forest or a particular resource). Hypothetical resource base situations were defined and empirical results of potential tradeoffs presented. Tradeoffs included individual and dual resource responses to a single management practice. As an example of some of the empirical results presented in the study, a basal area maintenance of 60 square feet would result in maximum timber yield, fairly low livestock forage production and soil erosion, medium or better scenic quality, high deer habitat quality, and medium squirrel habitat quality and streamflow. Maintaining a basal area of 120 square feet would result in maximum squirrel habitat, low streamflow, soil erosion, livestock forage, and deer habitat quality, and medium sawtimber production and scenic quality.

Bottoms and Bartlett (1975) demonstrated how goal programming can be used to help solve resource allocation problems. They utilized an area in north-central Colorado as a case study. In the process of demonstrating goal programming, they also revealed some resource interactions. They showed that the different users of grazing (cow-calfs, steers, elk, and deer) interact strongly, and that timber interacts with almost all other resources. Dyer et al. (1979) utilized this same model in further investigating goal programming, and in so doing provided additional sensitivity analysis on this case study. They showed that substantial changes in the multiple resource output set from this model were possible by altering production priorities.

Rideout and Hof (1987) demonstrated some game-theoretic approaches to joint cost allocation. Their case study involved a multipurpose forest road in northern Colorado. Their cost data indicate that the cost of building forest roads can be highly dependent on the combination of purposes they serve.

Region 3

Brown et al. (1974) reported on resource interrelationships driven by basal area reduction in the ponderosa pine type of Arizona. Changes in productivity were quantified based on five levels of forest thinning and clearing. Sawtimber, herbage, scenic quality, deer use, streamflow, flood peaks, and sediment were all substantially affected by reductions in basal area.

Patton (1969) studied the effects of timber harvesting on the distribution and abundance of game animals (deer and elk) in the ponderosa pine type of the Castle Creek watersheds near Alpine, Ariz. Both animals' day use per acre was substantially higher on the harvested areas.

Clary and Larson (1971) also reported on elk and deer use in the ponderosa pine type of Arizona on the Beaver Creek watershed. No clear relationships for deer were identified. Elk use was found to be directly related to total herbage production, and inversely related to basal area.

Clary et al. (1968) studied the effect of the accumulation of organic matter above mineral soil (the forest floor) on herbage production on the Beaver Creek watershed in north-central Arizona. Herbage production decreased from over 300 pounds per acre to less than 10 as total forest floor accumulations increased from essentially zero depth to over 2.5 inches.

Brown (1976) analyzed the resource tradeoffs resulting from four alternative harvest regimes. Physical yields of sawtimber, pulpwood, water, forage, and effects on wildlife habitat and esthetics were estimated and reported for each alternative timber management emphasis. The study area was a 562–acre mixed conifer watershed, South Thomas Creek, on the Apache-Sitgreaves National Forest in Arizona. All outputs were substantially affected by the alternative harvest regimes.

O'Connell and Brown (1972) developed product-product production functions for water, timber, and herbage based on several alternative timber cutting regimes on the Beaver Creek watershed of northern Arizona. These timber-driven tradeoff models indicated the supplementary, complementary, and competitive output scenarios obtained within a multiple use framework.

Hof et al. (1985b) studied the joint costs of producing timber and forage in a paper about discrete choices in resource decisionmaking. They determined four points on a constant-cost production possibilities frontier (IIA, IIB, IIC, IID) and a low-intensity reference point (I) using the Coconino National Forest (in central Arizona) FORPLAN model. The results indicate a fairly strong tradeoff between timber and forage:

Alternative	Total timber Bd. Ft.	Total forage AUMs	Minimum cost $1000
IIA	15,333,600	88,991,600	308,440
IIB	30,892,300	85,675,000	308,440
IIC	39,701,200	72,347,800	308,440
IID	41,467,500	52,347,800	308,440
I	16,387,800	19,871,500	205,627

Region 4

Horton and Campbell (1974) reviewed studies in all the southwestern states (Regions 3, 4, and 5) on management of phreatophyte and riparian vegetation, and concluded that "the few riparian treatments performed indicated rather consistent increased water yields were obtained following riparian treatments....In summary a working hypothesis somewhere between 1 and 2 acre-feet of water savings is as close an approximation as possible." Related to these water gains, however, Johnson (1970) had reported that thinning cottonwood for water savings and flood control reduced nesting bird populations as follows:

Treatment	Pairs of nesting birds per 100 acres 1969	1970
Severely thinned (10.1 trees per acre)	583	524
Moderately thinned (26.0 trees per acre)	963	886
No treatment (46.6 trees per acre)	1325	1006

These results demonstrate the importance of considering a complete set of outputs in analyzing resource interactions.

Buckhouse and Gifford (1976) studied the impacts of burning and grazing on the water quality parameters of phosphorus, potassium, sodium, calcium, and nitrate-nitrogen on sites that had been chained and then seeded to crested wheatgrass in southeastern Utah. Undisturbed areas were left adjacent to the treated areas to act as a control. Following burning, significant increases in potassium and phosphorus were observed at the soil surface. If a hydrologic runoff event occurred, these chemical elements could cause eutrophication of water supplies. No significant treatment changes were observed for the other water quality parameters. No treatment differences because of grazing were detected (stocking rate was 2 ha/AUM).

Region 5

Graves and Burns (1970) reported on the yields of downstream migrant salmonoids before and after logging road construction on the South Fork Casper Creek in Mendocino County, California. Road construction took place in the summer of 1967. Eighty-three percent of the total salmon population and 86% of the total steelhead population died or emigrated from the area affected by road construction. The combined species population of smolts decreased 20%. In 1964, 5% of the fish sampled from the study area were fry. In 1968, 81% were fry. Steelhead smolts were smaller in 1968 while salmon smolts were larger. Salmon fry were smaller in 1968. The increase in length of the salmon smolts may have resulted from a decrease in competition because of the high mortality in 1967. However, the average length of all fish decreased.

The California Resources Agency Task Force (1969) report on the sediment problems in the Trinity River, near Lewiston, concluded that the elimination of flows during reservoir filling and the subsequent release of steady, regulated flows has worked in combination with increased sediment production from adjacent logged lands to drastically reduce habitat quality and salmon populations in this formerly productive fishery.

Kirby et al. (1986) developed a mathematical programming model, the Integrated Resource Planning Model (IRPM), that deals with the interactions between natural resource investments and transportation network investments as the means of generating alternative land management plans. In a case study, IRPM was implemented on the French Creek Basin of the Plumas National Forest in northern California to assess the effects of harvest activities. Their results are complex, but essentially all outputs studied are affected substantially by timber harvest levels.

Region 6

Thomas et al. (1978) reported that the optimum ratio of forage areas to cover areas is 60% to 40% for deer and elk in the Blue Mountains of Oregon. Thus, harvest alternatives that leave less than 40% cover would be expected to reduce deer and elk populations.

The International Pacific Salmon Fisheries Commission (1966) studied the effects of log driving on the salmon and trout populations in the Stellako River, and reported that log jams caused gravel erosion and bark deposition over approximately 8% of sockeye spawning grounds. Subsequent spawners tended to avoid the damaged areas. Laboratory tests indicated that moderate gravel erosion and gouging by individual logs could have destroyed incubating trout eggs.

Lantz (1970) studied the aquatic environmental impacts from logging on the Alsea watershed in Oregon, and concluded that the primary changes caused by logging were the following: an increase in stream temperature, a decrease in dissolved oxygen levels in surface waters during summer when logging debris was present, a decrease in intragravel dissolved oxygen levels, a decrease in the permeability of the intragravel environment when salmon embryos were present, an increase in suspended sediments, and a decrease in the cutthroat trout populations.

Wustenberg's (1954) findings on trout environment impacts from logging in mature Douglas-fir stands in Oregon were as follows: an increase in localized sediment entering the stream because of maintenance and use of logging roads, no pronounced increases in sediment as a result of logging itself, a fine silt consistency for most sediments, a preponderance of sediment concentrations in the upper parts of small tributaries, greater streambed effects from tractor logging than from high lead logging, severe scouring in logged streams during high flows, elimination of cutthroat trout populations in logged streams, adverse effects on aquatic insects for at least one year, and the possibility of reduction in water temperatures through the use of streamside buffer strips.

Wick and Canutt (1978) reported that timber management practices in the Blue Mountains of Washington and Oregon to increase the diversity of wildlife habitats or to mitigate adverse effects of logging on fish and wildlife habitats may cause slight to moderate decreases in timber production.

Schaumburg's (1973) investigation of the effect of water storage of logs on water quality in the Pacific Northwest concluded that soluble leachates (BOD, COD, PBI, solids, and toxicity) from logs floating in water are not a significant water pollution problem. However, sinking bark that can form benthic deposits that exert an oxygen demand may influence the biology of the benthic zone. Also, floating bark may be regarded as esthetically displeasing and could interfere with other beneficial uses of a lake, stream, or estuary.

Fredriksen (1970) reported on the erosion and sedimentation caused by road construction and timber harvest on unstable soils, on three small western Oregon watersheds. No action was taken on one of the watersheds so that it could be utilized as a control. Sedimentation and soil loss increased substantially from the harvesting and roading activities.

Hof et al. (1985a) studied joint costs of producing timber and forage on the Fremont National Forest in southern Oregon. Their results indicate that the portion of total costs that cannot be assigned to either output (joint cost) varies from 8% to 60%, depending on the output levels—the greater the production of either (or both) outputs, the more interaction can be anticipated.

Region 8

The first four studies discussed in this section are part of a larger work, the "South's Fourth Forest: Alternatives for the Future" (USDA Forest Service 1987), which states:

> The basic purpose of this study of the timber situation in the South is to determine what kind of forest is evolving, what kind of forest will be of greatest benefit to the economy and society, and how can it be achieved.

Implicit in this description is the consideration of several alternative futures or scenarios based on different sets of assumptions concerning the determinants of timber demand and supply. Furthermore, the implications section (Chapter 4) of this work identifies forage production, wildlife and fish abundance, and water quantity as important products and uses of forest lands affected by changes in the forest environment. Four studies quantifying the responses of these resources to the alternative timber management scenarios (Flebbe 1987, Joyce 1987, Ursic 1987, Flather 1987) were performed under a consistent framework, and together constitute a multiresource analysis. The studies were based on the following scenarios.

Baseline.—The level of timberland management is much more intensive than that practiced today. By 2030, the area in pine plantations is nearly doubled; large areas of mixed pine-hardwoods and upland hardwoods are converted to pine. Planting or conversion of these areas to pine would require investments of $2.7 billion, with most of the investment occurring within the next 15 years. Substantial increases in timber yields and in the intensity of management are also assumed for large areas of pine plantations. Thus, the base projections reflect what would happen if there continues to be progress in forestry in the South—including continued expansion in the technical and financial assistance, protection, research, education, and management programs that have brought about the improved forestry situation in the past.

Increased stumpage costs.—The future, as described by the basic assumptions and other specified and implied assumptions in this report, is modified by increasing stumpage prices above the base projections by 5% by 1990, 10% by 2000, 15% by 2010, and 20% by 2020.

Reduced timberland area.—The future, as described by the basic assumptions and other specified and implied assumptions in this report, is modified by reducing the projected area in timberland in the South by 2 million acres in 1990, 5 million acres in 2000, and 11 millions acres in 2030.

Reduced timber growth.—The future, as described by the basic assumptions and other specified and implied assumptions in this report, is modified by reducing by 25% the net annual growth on pine plantations, natural pine, and mixed pine-hardwood stands shown in the empirical yield tables used in developing the base-level projections.

Reduced national forest harvest.—The future, as described by the basic and other specified and implied assumptions in this report, is modified by reducing timber harvests on the national forests to 8.1 billion board-feet in 1990 and maintaining this level through 2030.

Economic opportunities on private timberlands.—The future, as described by the basic assumptions and other specified and implied assumptions in this report, is modified by assuming that all the economic opportunities for increasing timber supplies on timberland in private ownerships that yield 4% or more net of inflation or deflation would be utilized.

The softwood roundwood timber supply projections for these six scenarios are reproduced in table A1.

Flebbe (1987) reported on coldwater fish population responses to the timber scenarios on a study area that included portions of Virginia, North Carolina, South Carolina, and Georgia. Discriminant function analysis was used to predict trout densities within watersheds based on land use and cover type and water quantity. Data on water flow, land use, land-cover type, and trout population densities were derived for each watershed using various sampling techniques. The discriminant function model captured the statistical relationships between trout density and significant land use/cover and water quantity variables. Then, the analogous variables from each alternative timber scenario were applied to this model to derive a schedule of trout production (table A2). Generally, fish populations decrease in response to increased urbanization and land use shifts that decrease mature forest areas.

Joyce (1987) reported on forage production responses to the timber scenarios. She used several modeling approaches to quantify forage production for three different land types—forestland, pasture, range—and all lands. The analysis was driven by the land use and timber inventory projections as reflected in the alternative timber management scenarios. The study area encompassed 12 states divided into two regions, Southcentral and Southeast. Climatic data, past management, and timber stand characteristics were related to forage production. No forage management to timber management feedback existed in the analysis that would affect timber outputs: "The forage analyses predict what might occur when forage is not the primary resource being managed." Tables A3 through A6 show that land use shifts out of pasture/range significantly decrease forage, while shifts to the more open canopy of planted pine increase forage production.

Ursic (1987) reported on water response to the timber scenarios. Statistical regression models were developed to estimate water yields using precipitation, land use, and cover type as independent variables. Certain shortcomings in this modeling approach required a supplemental technique, referred to as "response modeling." Both models were then utilized to develop a water yield schedule by alternative timber scenario. Different yields were obtained over all periods and alternatives using the two methodologies. An adjustment technique was then developed to derive one water yield figure. Table A7 illustrates the water yield (in area inches) response to alternative management scenarios; this yield table relates to the entire 12–state study area. A small increase in water yield is indicated, reflecting the conversion of land from forest and pasture to urban use.

Flather (1987), reporting on wildlife responses to the timber scenarios, utilized discriminant function analysis to derive statistical relationships between land use and cover type and the relative abundance of indicator wildlife species. The analysis covered the 12–state study area and was performed on a county-by-county basis. Wildlife species modeled included white-tailed deer, wild turkey, and red-cockaded woodpecker. While the wildlife models were based on county level information, the alternative timber management scenarios described changes in land base statistics at the regional and state level. A technique referred to as "raking" was utilized to modify the land use and cover type changes reflected in the alternative scenarios to a county level basis. The wildlife responses to the alternative timber scenarios are shown in tables A8 through A10. Wildlife decreases reflect the land use changes such as increased urbanization and increased young planted pine stands.

Wright et al. (1976) reported the effects of prescribed burning on erosion, runoff, and water quality in Texas. Juniper was dozed into piles and then burned. Twelve watersheds representing three slope classifications were involved in this study. Two treated and two control areas were chosen for each slope class. No significant effects were observed on the level areas. Water quality was lowered by treatment on moderate slopes. Total effects were so adverse on steep slopes that it was recommended that these areas be left in their natural state.

Hof and Field (1987) studied part of the Talladega National Forest in Alabama, testing a variety of joint cost allocation approaches. In the process of carrying out this study, some resource interactions information was also provided. Cost estimates were determined with a FORPLAN model for all combinations of timber, recreation, and quail in five different "alternative" output sets (varying timber only). The results indicated that the costs were strongly interactive. This study also determined "core conditions"—rational bounds on the limits of how much cost could tenably be assigned to each output. A large portion of total cost was joint—the lower bounds and upper bounds are widely disparate. Allocation of this joint cost is thus arbitrary.

Region 9

Hornbeck and Reinhart (1964) studied the effects of logging steep terrain on water quality and soil erosion. The study site was the Fernow Experimental Forest in the mountains of West Virginia. The study compared commercial clearcutting with no regard for environmental impacts to intensive selection cutting with careful planning to protect environmental quality. Streams in the commercial clearcut displayed maximum turbidities of 56,000 ppm, while the maximum turbidity in the watershed with the intensive selection cutting was 25 ppm.

Brown et al. (1977) reported the effects of recreational use on forest soils and vegetation. The study area included eight camping and picnic sites in forest stands in Rhode Island. The stands were typical of those found throughout southern New England. Recreation use resulted in significant compaction of soils, which decreased water infiltration rates, reducing vegetation growth and increasing surface runoff. The runoff, in turn, eroded both surface soils and litter which led to nutrient depletion. Not only were ground and understory vegetation affected but also the radial and height growth of some tree species such as scarlet oak and white pine were reduced. The trampling of ground cover vegetation in recreation areas was perhaps the most dramatic impact.

Moulding (1976) studied the impact of insecticide use on forest birds. Bird censuses were conducted before and after a gypsy moth control program in New Jersey. The control program involved the aerial spraying of a low-persistence insecticide (Sevin). Forest bird abundance fell by 55% 8 weeks after spraying. Bird diversity declined with the spraying, which affected some species more than others. One year later, bird populations continued to be depressed at a level 45% lower than the pre-spray period. There was no evidence of bird mortality in the study area. Thus, the actual mechanism that caused declines in abundance and diversity are not known. Hypotheses include reductions in food sources causing migration outside the area to feed, reduced reproductive success, and shifts in site loyalty.

Table A1.—Simulated effects of selected futures on projected softwood roundwood supplies (million cubic feet) in the South.

	(All projections at equilibrium levels)					
Item Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
Forest industry						
Southeast						
1984	679	679	680	668	679	679
1990	771	771	772	719	770	744
2000	980	962	982	863	985	948
2010	1115	1080	1115	923	1112	1081
2020	1237	1201	1243	1051	1253	1213
2030	1334	1289	1336	1117	1341	1314
South-central						
1984	1053	1053	1053	1042	1053	1053
1990	1130	1115	1132	1060	1140	1100
2000	1259	1224	1261	1086	1281	1224
2010	1378	1327	1386	1120	1394	1344
2020	1456	1406	1471	1179	1482	1429
2030	1522	1477	1416	1263	1542	1514
Other private						
Southeast						
1984	1526	1526	1526	1534	1526	1526
1990	1472	1461	1472	1494	1458	1506
2000	1450	1428	1448	1480	1445	1519
2010	1432	1397	1426	1429	1431	1530
2020	1422	1379	1414	1331	1437	1528
2030	1427	1378	1416	1268	1441	1534
South-central						
1984	1308	1308	1308	1315	1308	1308
1990	1351	1337	1350	1367	1362	1392
2000	1360	1329	1353	1388	1390	1430
2010	1343	1297	1328	1343	1371	1438
2020	1293	1237	1265	1244	1327	1410
2030	1239	1183	1198	1142	1268	1377
National Forest						
Southeast						
1984	45	45	45	45	45	45
1990	46	46	46	46	46	46
2000	48	48	48	48	46	48
2010	58	58	58	58	46	58
2020	72	72	72	72	58	72
2030	77	77	77	77	62	77
National Forest						
South-central						
1984	139	139	140	140	139	139
1990	165	165	165	165	141	165
2000	205	205	205	205	135	205
2010	221	221	221	221	135	221
2020	259	259	259	259	135	259
2030	289	289	289	289	135	289
Other public						
Southeast						
1984	85	85	85	85	85	85
1990	100	100	100	100	100	100
2000	104	104	104	104	104	104
2010	106	106	106	106	106	106
2020	109	109	109	109	109	109
2030	114	114	114	114	114	114
South-central						
1984	50	50	50	50	50	50
1990	55	55	55	55	55	55
2000	61	61	61	61	61	61
2010	61	61	61	61	61	61
2020	61	61	61	61	61	61
2030	61	61	61	61	61	61

Source: USDA Forest Service (1987).

Table A2.—Trout density (trout/acre of stream) for Southeastern cold-water watersheds under baseline and alternative scenarios.

	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
1985	173	173	173	173	173	173
1990	176	176	178	177	178	174
2000	163	162	173	168	168	156
2010	133	130	156	135	129	127
2020	128	124	155	128	119	126
2030	126	122	155	123	119	124

Source: Flebbe (1987).

Table A3.—Forage production (million tons) on all lands for baseline and alternative scenarios for Southeast (SE) and South-central (SC) regions.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
			South-central region			
1985	71.57	71.60	70.72	71.52	71.57	71.60
1990	70.99	71.12	70.27	71.20	70.99	71.57
2000	70.01	70.18	69.64	70.56	69.96	70.64
2010	68.45	68.70	68.56	69.31	68.35	69.31
2020	66.56	66.86	67.20	67.75	66.43	67.48
2030	64.85	65.09	65.91	66.20	64.69	65.70
			Southeast region			
1985	53.77	53.81	53.54	53.67	53.78	53.81
1990	52.69	52.76	52.48	52.78	52.72	53.24
2000	52.72	52.83	52.60	53.40	52.79	53.13
2010	52.41	52.50	52.46	53.52	52.49	52.88
2020	51.82	51.85	52.00	53.28	51.84	52.26
2030	50.51	50.44	50.84	52.35	50.50	50.81

Source: Joyce (1987).

Table A4.—Forage production (million tons) on forestland for baseline and alternative scenarios for Southeast (SE) and South-central (SC) regions.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
			South-central region			
1985	7.076	7.108	7.077	7.024	7.076	7.108
1990	7.740	7.864	7.666	7.953	7.743	8.322
2000	9.015	9.186	8.807	9.561	8.967	9.648
2010	9.570	9.822	9.310	10.429	9.466	10.430
2020	9.875	10.170	9.606	11.062	9.738	10.789
2030	9.736	9.975	9.459	11.080	9.572	10.576
			Southeast region			
1985	8.846	8.875	8.846	8.736	8.846	8.875
1990	8.848	8.920	8.815	8.943	8.875	9.398
2000	9.342	9.447	9.257	10.013	9.409	9.745
2010	9.500	9.580	9.401	10.603	9.566	9.962
2020	9.457	9.487	9.377	10.924	9.482	9.901
2030	8.935	8.873	8.862	10.781	8.929	9.233

Source: Joyce (1987).

Table A5.—Forage production (million tons) on pasture for baseline and alternative scenarios for Southeast (SE) and South-central (SC) regions.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
			South-central region			
1985	49.54	49.54	48.78	49.54	49.54	49.54
1990	48.52	48.52	47.96	48.52	48.52	48.52
2000	46.43	46.43	46.35	46.43	46.43	46.43
2010	44.58	44.58	45.00	44.58	44.58	44.58
2020	42.78	42.78	43.72	42.78	42.78	42.78
2030	41.58	41.58	42.94	41.58	41.58	41.58
			Southeast region			
1985	32.72	32.72	32.53	32.72	32.72	32.72
1990	32.40	32.40	32.27	32.40	32.40	32.40
2000	32.27	32.27	32.28	32.27	32.27	32.27
2010	32.01	32.01	32.19	32.01	32.01	32.01
2020	31.66	31.66	31.96	31.66	31.66	31.66
2030	31.09	31.09	31.52	31.09	31.09	31.09

Source: Joyce (1987).

Table A6.—Forage production (million tons) on range for baseline and alternative scenarios for Southeast (SE) and South-central (SC) regions.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
			South-central region			
1985	14.96	14.96	14.87	14.96	14.96	14.96
1990	14.74	14.74	14.65	14.74	14.74	14.74
2000	14.56	14.56	14.49	14.56	14.56	14.56
2010	14.30	14.30	14.25	14.30	14.30	14.30
2020	13.91	13.91	13.87	13.91	13.91	13.91
2030	13.54	13.54	13.51	13.54	13.54	13.54
			Southeast region			
1985	12.21	12.21	12.16	12.21	12.21	12.21
1990	11.44	11.44	11.39	11.44	11.44	11.44
2000	11.11	11.11	11.06	11.11	11.11	11.11
2010	10.91	10.91	10.87	10.91	10.91	10.91
2020	10.70	10.70	10.67	10.70	10.70	10.70
2030	10.48	10.48	10.46	10.48	10.48	10.48

Source: Joyce (1987).

Table A7.—Water yield (area inches) for baseline and alternative scenarios for entire Southern study area.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
1985	15.64	15.64	15.63	15.64	15.64	15.64
1990	15.64	15.65	15.67	15.65	15.64	15.58
2000	16.05	16.06	16.17	16.10	16.05	15.94
2010	16.35	16.36	16.53	16.44	16.34	16.26
2020	16.48	16.47	16.76	16.63	16.47	16.38
2030	16.57	16.55	16.94	16.77	16.56	16.47

Source: Ursic (1987).

Table A8.—Red-cockaded woodpecker responses (counties with RCW present) to baseline and alternative scenarios for Southeast (SE) and South-central (SC) regions.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
			Southeast region			
1985	115	114	115	114	115	114
1990	93	92	94	88	93	97
2000	43	43	43	37	43	50
2010	36	36	37	36	36	35
2020	35	35	35	35	35	35
2030	35	35	35	35	35	35
			South-central region			
1985	56	56	56	56	56	56
1990	50	50	50	50	50	50
2000	49	49	48	51	50	44
2010	51	51	50	51	51	50
2020	49	50	47	49	50	49
2030	47	48	41	46	50	48

Source: Flather (1987).

Table A9.—Wild turkey density (turkeys/mi^2) responses to baseline and alternative scenarios for Southeast (SE) and South-central (SC) regions.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
			Southeast region			
1985	5.3	5.3	5.3	5.3	5.3	5.3
1990	5.2	5.1	5.1	5.1	5.1	5.2
2000	4.9	4.9	4.8	4.9	4.9	5.0
2010	4.7	4.7	4.5	4.6	4.6	4.7
2020	4.7	4.8	4.5	4.7	4.7	4.8
2030	4.8	4.9	4.6	4.9	4.8	5.0
			South-central region			
1985	6.6	6.6	6.6	6.6	6.6	6.6
1990	5.8	5.8	5.8	5.8	5.8	5.7
2000	5.5	5.5	5.6	5.5	5.5	5.6
2010	5.8	5.8	5.8	5.8	5.8	5.8
2020	6.0	6.1	6.1	6.1	6.0	6.2
2030	6.4	6.6	6.5	6.5	6.3	6.8

Source: Flather (1987).

Table A10.—White-tailed deer density (deer/mi^2) responses to baseline and alternative scenarios for Southeast (SE) and South-central (SC) regions.

Year	Baseline	Increased stumpage cost	Reduced timberland area	Reduced timber growth	Reduced NFS harvest	Economic opportunities on private
			Southeast region			
1985	17.0	17.0	17.0	17.0	17.0	17.0
1990	16.9	16.9	17.0	16.9	16.9	16.8
2000	16.6	16.5	16.9	16.4	16.6	16.6
2010	15.8	15.7	16.4	15.8	15.8	15.5
2020	15.1	14.8	15.7	15.1	15.1	14.8
2030	14.5	14.3	15.2	14.5	14.4	14.3
			South-central region			
1985	17.6	17.6	17.6	17.6	17.6	17.6
1990	16.9	16.9	16.9	16.9	16.9	16.8
2000	16.5	16.6	16.6	16.5	16.6	16.7
2010	16.0	16.2	16.1	15.9	16.0	16.4
2020	14.3	14.9	14.3	14.3	14.2	15.0
2030	13.6	14.4	13.3	13.7	13.5	14.4

Source: Flather (1987).

Rocky
Mountains

Southwest

Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526