INC.
ADAPTIVE ENVIRONMENTAL ASSESSMENTS

SAVAL RANCH RESEARCH DESIGN, INTEGRATION AND SYNTHESIS-- MODELLING WORKSHOP REPORT

USDI BUREAU OF LAND MANAGEMENT
18th and C Streets, NW
Washington, D.C. 20240

SEP 17 1982

Memorandum

To: Members of the Saval Ranch Steering Committee, Participants in the Modelling and Integration Workshops, and Other Interested Parties

From: Peter C. Lent, Resource Sciences Staff

Subject: Completion of Phase One of Saval Ranch Research Design, Integration, and Synthesis Contract

I am pleased to provide for your use a copy of the Phase One Report for the Saval Ranch Research Design, Integration, and Synthesis contract, prepared by Adaptive Environmental Assessment, Inc.

This is a progress report and is thus intended as a tool to help us further focus the research design and direction for the project and refine the concepts presented to improve the overall model.

Direction for Phase Two of the contract will be discussed at the November meeting of the Steering Committee. One of the modellers will be present to interact with the committee. I hope all committee members will take the time to review this progress report prior to the meeting.

Tentative plans have been made for a third technical meeting/workshop early in 1983.

Lent

Enclosure: Phase One Report - Saval Ranch Research Design, Integration, and Synthesis

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SAVAL RANCH RESEARCH DESIGN, INTEGRATION AND SYNTHESIS-- MODELLING WORKSHOP REPORT

to

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September 1982

* A joint venture by LGL Ecological Research Associates, Inc. and ESSA Environmental and Social Systems Analysts, Ltd.

ACKNOWLEDGEMENTS

On behalf of LGL Ecological Research Associates, Inc. (LGL) and ESSA Environmental and Social Systems Analysts Ltd. (ESSA) we express our appreciation for the cooperation and enthusiasm demonstrated by all Saval Program personnel involved in this project. They have made our participation in the project a pleasure.

We especially thank Peter Lent and Dick Eckert for their continuing assistance in maintaining the course of the project. Contracting Officer Jeff Petrino has made it easy for us to deal with project contract details. Saval Steering Committee Chairman Bob Papworth has been particularly helpful during workshop sessions, and BLM Deputy Director, Del Vail, was kind enough to spend a few days of his time attending the first workshop.

Thanks also go to managers and scientists in the following organizations:

Saval Ranch Owners and Managers
Without the cooperation and support of the Saval Ranch owners and management this project could not have been conducted.

Saval Ranch Steering Committee
The Steering Committee members involved in the project have been exceedingly helpful and cooperative.

Saval Ranch Research Scientists
Project Scientists from the University of Nevada at Reno, the U.S.D.A. Agricultural Research Service, the U.S. Forest Service, the U.S. Bureau of Land Management, the U.S. Soil Conservation Service and the Nevada Department of Wildlife contributed extensively to modelling workshops. They worked long hours in many cases to assemble the data to build the model.

Non-Project Scientists
Outside scientists contributed important information and review comments to portions of the program. Special thanks go to Clait Braun of the Colorado Division of Wildlife and to Fred Obermiller representing the National Cattleman's Association.

Finally, we thank Jean Bench-Brahmsteadt of LGL for the drafting, typing and editing efforts crucial to the production of the reports.

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STATEMENT OF PROGRESS, AUGUST 1982

Phase I of the Saval Ranch Research, Design, Integration, and Synthesis is now complete. Two workshops were conducted. The first workshop, held in November 1981, was the most intensive of labor and time. The workshop lasted five days and involved participants from most of the agencies working on the Saval Project. The major product was an initial Saval Ranch simulation model representing the dynamics of the biophysical system including livestock, soils, vegetation, hydrology, and wildlife. After the workshop a substantial model documentation and refinement period occurred based on participant responses at the end of the workshop.

The second workshop was held in January 1982. Over a 3-day period the participants evaluated and modified the 1982 research plans using the refined model as a focus of discussion. Particular consideration was given to the timing, frequency, and spatial extent of the data collection.

Following this meeting a draft report was prepared describing the work done, with recommendations. This report was circulated for review among Saval Ranch Steering Committee members and some other workshop participants.

In June 1982 a week-long training session was held to better acquaint project scientists with the use and applications of the computer and the model.

The original draft report has been revised according to reviewers' comments, and the final version follows this Progress Statement.

EXECUTIVE SUMMARY

Introduction

The Saval Ranch Research and Evaluation Project (SRREP) is an interagency effort begun in 1978 through a cooperative agreement among the Bureau of Land Management (BLM), the Agricultural Research Service, the Forest Service, the Soil Conservation Service, and the owners of the Saval Ranch. The principal objective of the project is to evaluate the effects of the Saval Ranch Coordinated Management Plan, involving a livestock grazing system and a series of rangeland improvement practices, on vegetation and livestock production, fish and wildlife habitats and resources, and water quality. A secondary objective is to extend the lessons learned from the Saval Ranch to other rangeland management situations. To meet this objective, research will be conducted on the Saval Ranch for approximately 15 years, enough to allow for a complete grazing rotation cycle.

The Saval Ranch project, like other projects of its type, is difficult to focus and coordinate because many disciplines, organizations, and individuals are involved. Its scope touches on hydrology, animal science, rangeland management, economics, wildlife biology, and other concerns. Each agency and individual involved has unique perspectives, expectations, and biases. Although initially all research questions seem relevant and important to answer, careful evaluation is necessary to determine which questions are highest priority and can be explored under constraints of limited money and time.

To avoid multidisciplinary research without synthesis and to provide periodic reevaluation of research direction, BLM desired an integrated, interdisciplinary research plan to help project managers and research scientists associated with SRREP plot the course of Saval Ranch research. Adaptive Environmental Assessment, Inc. (AEA) was contracted to assist in the development of the research plan.

Objectives of the Work

The objectives of the work conducted by AEA are to construct a systems model that will aid SRREP to (1) identify the significant hypotheses that should be tested to evaluate the impacts of the Saval Ranch Management Plan, and (2) provide an integrated research plan for SRREP that can be iteratively modified as project results are assimilated. The research plan should maximize efficiency of research effort and interdisciplinary coordination.

Description of Work

The work is scheduled to span 2 1/2 years, from September 1981 to February 1984. The contract calls for two modelling and integration workshops to be conducted within six months of contract award, and a series of smaller meetings between AEA and SRREP personnel over the following two years.

The first two workshops have been conducted. The first workshop, held in November 1981, was the most labor- and time-intensive of the workshops to be carried out under the contract. The meeting lasted five days and involved five workshop staff and approximately 30 participants. The participants represented most of the agencies involved in SRREP and a cross-section of disciplinary expertise required in the program. The initial Saval Ranch model was constructed at this workshop. The relevant data and understanding of the participants concerning livestock, economics, soils, vegetation, hydrology, and wildlife were synthesized and then integrated into a model, giving a conceptual picture of the biophysical and economic dynamics of the Saval Ranch system. Of particular importance at the first workshop was the identification of those variables and parameters which link the various disciplines outlined above.

A substantial documentation and model refinement period occurred after the first workshop. Modifications to the model were made based on the responses of participants to the discussions at the first workshop and results of the first model. Refinements concentrated on better representing the relationships between disciplines, rather than on each particular discipline (e.g., the relationship between forage availability and quality and cattle growth, the relationship between soil water availability and plant growth, etc.).

The second workshop, in January 1982, lasted three days and involved a smaller number of participants and staff. An important objective of the second meeting was to help evaluate and modify 1982 research plans using the refined model to help identify critical hypotheses about the Saval Ranch system. Particular consideration was given to the timing, frequency, and spatial extent of the data collections that would be needed to test the critical hypotheses.

Subsequent to the second workshop, a draft report, describing the work done to date and giving recommendations for the direction of future research and modelling efforts, was written. The report was given to participants of both workshops for review, and has been revised in response to review comments.

In addition to the two planned workshops, a session for helping to train Saval research scientists in the use and application of the computer and model was held in June 1982.

The Saval Ranch Model

The Saval Ranch model developed at the workshops is a dynamic state-dependent representation of the biological/physical/economic ranch system. The model, structured using the FORTRAN language, is currently operational on an AMDAHL 470 computer using the MTS operating system. User interaction with the model is facilitated using an interactive graphics gaming package known as SIMCON.

The spatial bounds of the model are the pastures making up the Saval project area as described in the Coordinated Management Plan (Alternative 2 of the Saval Ranch Project Environmental Assessment). Within each pasture, the model explicitly represents three broadly defined range sites (e.g., clay, loam, and riparian) that are an aggregation of those currently used by the vegetation research group.

To facilitate development of the model, the system was divided into four subsystems--vegetation, hydrology, cattle, and wildlife. The information transfers between each of these subsystems were determined at the initiation of the model-building exercise. Then, each submodel was built separately and later integrated into the overall model.

To improve the model user's ability to evaluate the effects of livestock grazing and range improvement practices on biophysical resources (i.e., vegetation, livestock, fish and wildlife), the range of feasible management alternatives, or actions, was defined and implemented within the submodels. Thus the user of the model can select and activate any collection of actions and run the model to help evaluate the effectiveness of those actions. Indicator variables (i.e., system attributes of interest to the user) can be selected by the user and then displayed graphically on a computer terminal to facilitate rapid, interactive gaming with the model.

The chosen temporal horizon of the model was of the order of 20 to 30 years with a within-year resolution of one week (i.e., the model time-step is one week). The four submodels are briefly described below.

Vegetation

The biomass of seven plant groups--bitterbrush, big sagebrush, other shrubs, forbs, perennial decreasers and increasers, and cheatgrass--are predicted from week to week on each of the range sites within each pasture. Plant growth is assumed to depend on air temperature, soil moisture within three soil layers, and the amount of carbohydrate reserves stored in the roots. Changes in plant protein and shrub cover are also calculated. The management actions included in this submodel are hay pasture irrigation and fertilization, and range plowing, seeding, burning, and spraying.

Hydrology

The soil moisture in three soil horizons (0-10, 10-20, 20-40 in) is predicted daily as a function of rainfall, snow pack, and the rates of infiltration and evapotranspiration. The stream flow in the Mahala and Gance creeks is determined as a function of runoff, and a water quality index (an indicator for cutthroat trout habitat) is expressed as a function of upland and stream bank erosion.

Livestock

The livestock population is allocated to the Saval pastures according to the grazing scheme described in the Coordinated Management Plan. While in each pasture the cattle selectively graze each range site and plant group as a function of water availability and forage palatability. Forage consumed is expressed as total digestible nutrients and used to determine the rate of cattle growth and reproduction. Overwintering cattle are fed exclusively on hay, which, although partly grown on the ranch, may require outside hay purchases.

Ranch revenues are calculated as a function of calf and cattle sales and the costs of ranch operation, including any range management actions enacted by the model user. Indicators of the economic benefit of the ranch to Elko County are calculated.

Wildlife

The numbers of mule deer and sage grouse are predicted annually as a function of the weekly changes in vegetation biomass and hunting pressure.

Mule deer survival and reproduction are calculated in the model as a function of the total intake per animal over the spring, summer and fall periods. Mule deer overwinter off the Saval Ranch and their movement onto the ranch is a function of the timing of first greenup. Over the spring-summer period, the deer migrate towards the uplands, keying in on the timing of greenup in each pasture.

Five groups of sage grouse leks are represented. Sage grouse nest success and reproduction are represented as a function of the average biomass of forbs and grasses in the area around the lek. Survival from predators and other mortality factors are directly related to herbaceous plant biomass and the degree of shrub cover available during critical life history stages.

Recommended Research Design

Two traditional approaches to impact analysis research that could be applied on the Saval are evaluated. The first approach is monitoring, or repeatedly measuring, the status of components of concern (indicators) over time as the range management plan is carried out. The second is hypothesis-testing, in which the response of indicators to specific management actions is measured in an effort to reveal the underlying functional relationship between components of the system.

The latter approach is recommended as the basis for Saval Ranch research for a number of reasons:

(1) By examining functional relationships between different components (e.g., the growth responses of cattle to changes in forage availability and quality), the essential interdisciplinary connections between system components are clarified. It is usually these interdisciplinary connections which become lost in a research project.

(2) It is much easier to adapt and change the research design over time as the understanding about the Saval Ranch system changes and improves if functional hypotheses are being studied. Options in a monitoring-oriented research program invariably become foreclosed as a larger and larger data set is constructed through time.

(3) Transferability of the research results to other areas will be much easier and more relevant if functional relationships are studied. For example, management plans for other ranches may involve different cattle stocking levels and rotation schemes, but the relationship between cattle growth and forage availability and quality (if defined and measured properly) will be the same.

The research must attempt to address the effects of specific management actions at a specific time and place, and then sum over all actions, times and places to get a picture of the cumulative effects of the management plan. Any single indicator is likely to be affected by only a few management actions. Research on any one component of the system can then focus on the few actions affecting that component; adding their effects becomes simple.

Given that the research should emphasize functional relationships between disciplines, cross-disciplinary communication becomes vital. There must be a consistent view among SRREP managers and research scientists of what research is needed for the program to be effective and efficient. In order to insure this consistency, the Saval program should place strong emphasis on:

(1) promoting frequent dialogue among field researchers, and between field researchers and project management;

(2) coordinating data collection activities among the different disciplines;

(3) insuring compatibility among researchers in the way that components are measured and in the units of measure; and

(4) making efforts to overcome semantic difficulties in interdisciplinary communication.

Ideally, the nature and design of the research will continue to evolve as some questions are answered and new ones become obvious. The model itself should help guide this evolution and, as new data surface and understanding improves, the model should become more realistic and useful as a management tool.

Future Directions

The three shorter workshops yet to come will serve to review research findings, refine the model, and define new areas of needed research. In the short term, the model will be transferred to the SRREP. In addition, some obvious model improvements will be made, perhaps by transferring portions of the large model to microcomputers more easily accessible to research scientists and project managers. Also, consideration should be given to a data-base management system. Particular consideration must be given to insuring that the data-base management system be structured to meet the interdisciplinary communication needs outlined above.

1. INTRODUCTION

In September 1981 Adaptive Environmental Assessment, Inc. (AEA) received a contract from the USDI Bureau of Land Management (BLM) to assist in the research design, integration, and synthesis of a multidisciplinary research program conceived to evaluate the ecological and economic consequences of a livestock grazing and management system on a Nevada ranch. The research program--the Saval Ranch Research and Evaluation Project--is an ongoing interagency effort that commenced in 1978 through a master cooperative agreement among the BLM, the Agricultural Research Service (ARS), the Forest Service (FS), and the Soil Conservation Service (SCS). As of the contract award date a series of field studies, largely baseline in nature, had been initiated.

The contract called for two modeling and integration workshops to be conducted within six months of contract award, and for a series of smaller-scale meetings between AEA personnel and Saval Project managers during the following two years. The two workshops have been conducted. This report describes contract performance to date, emphasizing workshop methods and results and giving recommendations for the direction of future research and modeling efforts.

1.1 Project Objective and Expected Products

The objective of this project is to facilitate the development of an integrated interdisciplinary research plan for the project managers and research scientists of the Saval Ranch Research and Evaluation Project. Products to be supplied to meet this objective are specified to be

(1) a systems model that will assist Saval Project personnel to identify the significant hypotheses that

should be tested to evaluate the impacts of the Saval Ranch livestock management plan, and

(2) an integrated research plan for the Saval Project that can be iteratively adjusted through the life of the project (15 years) as the managers assimilate new project research results and refine the model.

Hypotheses to be identified should be testable within the constraints of time, funding, physical environment, and ranch management. The research plan itself should promote the maximum in efficiency of research effort and interdisciplinary coordination. Moreover, it is BLM's desire that the planning strategy and the research results are applicable, to the extent possible, to economic and environmental impact analysis of ranch management in other parts of the Great Basin and elsewhere.

1.2 Background and Study Area

The principal objective of the Saval Ranch Research and Evaluation Project is to evaluate the effects of a livestock grazing management system and necessary range improvement practices on vegetation, livestock production, fish and wildlife resources and their habitats, watershed values, water quality, and other resources and values.

A Steering Committee is responsible for the development of overall plans and actions needed to accomplish the project. This Committee consists of technical representatives from each Federal agency involved, University of Nevada Cooperative Extension Service, Nevada Department of Wildlife, Nevada Cattlemen's Association, and the Saval Ranch.

The Committee determines inventory levels, management practices, improvements, monitoring systems, research needs, and economic evaluations. The Committee has assisted the land managers in preparation of a coordinated range management plan and the environmental analysis for the study area. All research studies, inventories, and management actions are cleared by the Committee to insure they do not disrupt or conflict with overall project objectives.

The Saval Ranch (Fig. 1.1) is located about 40 mi north of Elko, Nevada. Elevation ranges from about 5800 ft on the eastern boundary along Highway 51 to about 8400 ft at the crest of the Independence Mountains on the west. The ranch and grazing allotment contains 14,000 ac of private land, 28,000 ac managed by the BLM and 17,000 ac managed by the Forest Service.

Climate of the area is semi-arid with cold, moist winters and warm, dry summers. Mean daily air temperatures range from about 49°F at the low elevations to less than 42°F in the mountains. Annual precipitation averages about 9 inches in the valley and 18 inches in the mountains.

Flood plain soils are very deep, dark colored, poorly drained, and calcareous. Terrace soils are dark colored, very slowly permeable to water, and have silica hardpans. Upland soils over flint-like bedrock are dark colored, moderately to slowly permeable to water, and occur on steeper slopes.

Natural vegetation is typical of the northern part of the Intermountain region. Common shrubs are: sagebrush, rabbitbrush, bitterbrush, snowberry, serviceberry, chokecherry, and mountain mahogany. Native grasses are represented by species of: needlegrass, bluegrass, squirreltail, wheatgrass, fescue, broomgrass, and wildrye. There are also about 4,500 ac of crested wheatgrass, an introduced grass species. The most abundant broadleaf species are: balsamroot, phlox, aster, milkvetch, hawksbeard, groundsel, wyethia, and eriogonum. Stream-side vegetation is characterized by aspen, willow, and stringer meadow habitats.

Seven creeks originate on National Forest land and cross some or all of the study area. Three of these creeks have water most of the year. Channel cutting is active in spots in lowland areas and ranges from 1-4 ft in most areas to 6-12 ft in one reach of Mahala Creek.

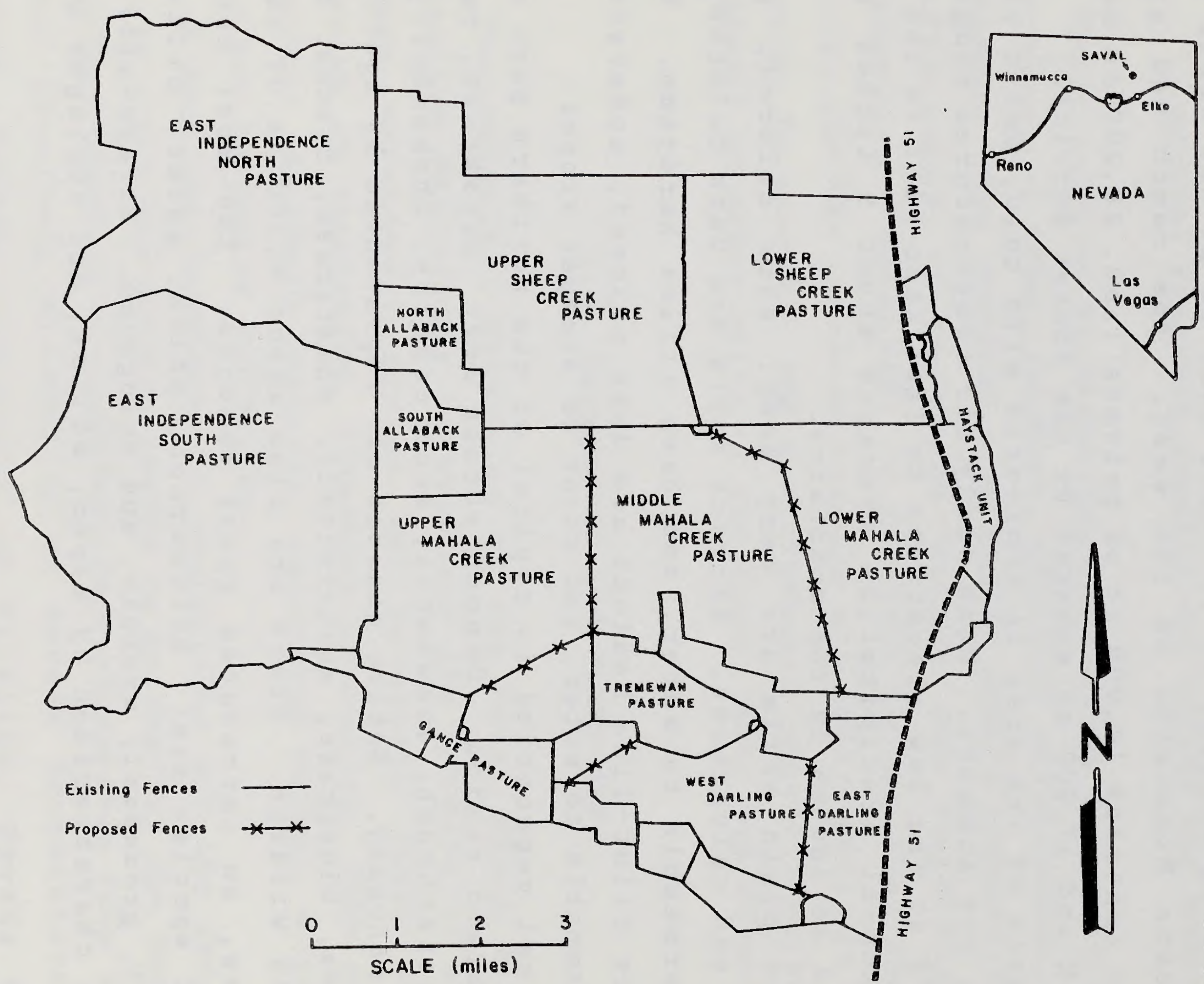

Fig. 1.1. The Saval Ranch and its location in northeastern Nevada.

Mule deer and sage grouse are major game species, although 16 other game species occur. The "threatened" Lahontan cutthroat trout occurs in Gance and California Creeks on National Forest land. Other fish species are sculpin, sucker, shiner, and dace. Non-game animals are represented by 155 vertebrate species, 33 mammal, 112 bird, 7 reptile, and 3 amphibian.

1.3 Project Strategy

This project is built around a series of meetings between AEA and Saval management and research personnel. The first and most intensive of the meetings, upon which this report focuses, are called Adaptive Environmental Assessment and Management (AEAM) workshops. The simulation model and the research design recommendations come about as a consequence of these workshops.

The AEAM workshop procedures have been developed over the past ten years by a group of environmental scientists and systems analysts at the University of British Columbia and the International Institute for Applied Systems Analysis (IIASA) in Austria to deal explicitly with interdisciplinary ecological problems (Holling 1978). They are intensive five-day workshops involving a team of four or five experienced simulation modellers and a group of 15 to 20 or more specialists. The focus of the workshop is the construction of a quantitative simulation model of the system under study. The development of the simulation model forces specialists to view their area of interest in the context of the whole system. This promotes an interdisciplinary understanding of the system, and allows ecological and environmental knowledge to be incorporated with economic and social concerns at the beginning of a strategic analysis rather than at the end of a design process.

Simulation models require unambiguous information. In the workshop setting specialists are forced to be explicit about their assumptions. This objectivity exposes critical conceptual uncertainties about the behavior of the system, and identifies research needs.

1.3.1 First Workshop Activities

The first step in the workshop is to clearly define and bound (limit) the problem. Lists are generated of development actions (alternative controls available to management) and indicators (those measures [of economic benefit, environmental quality, etc.] used by management in evaluating system performance), and the conceptual limits of the model are defined. The model itself embodies the biophysical 'rules' required to transform the actions into indicator responses.

The next step is to define the spatial extent and resolution required to adequately represent the system. Similarly the temporal extent or time horizon must be specified, and a usable time step or resolution must be agreed upon. This procedure makes the modelling problem more explicit, thereby facilitating the division of the system into manageable components or subsystems.

The next activity of the workshop (called 'looking outward') focuses attention on the subsytems and those variables required by each subsystem from the other subsystems. In looking outward the standard questions of analysis are recast. Instead of asking, "What do you need to know to describe subsystem X?", the question is asked, "What do you need to know about all other subsystems in order to predict how subsystem X will behave?" This question demands a more dynamic view and forces one to "look outward" at the inputs into other subsystems. At completion of the looking-outward exercise each subsystem has a list of "inputs" it needs from the other subsystems and a list of "outputs" it must provide to the other subsystems.

At this point the workshop breaks into subgroups; one subgroup for each subsystem. Each subgroup is in charge of developing a submodel for the overall simulation model. One workshop facilitator works within each subgroup and acts as the submodel programmer. Each subgroup has two basic charges: generation of output variables required by other submodels and generation of the indicator variables identified earlier.

At the conclusion of the subgroup meetings the facilitators are charged with putting each of the submodels on the computer. The submodels are then linked together and run under a variety of scenarios to explore the consequences of various actions and hypotheses about system structure. The principal objective of this exercise in an initial workshop is to point out model deficiencies and identify areas requiring improved understanding and information.

The workshop is generally concluded with a formal discussion of the research priorities identified during the development of the model. Ideally, these research priorities will help structure the data to be collected in any field seasons subsequent to the workshop.

1.3.2 Beyond the First Workshop

The first workshop is ideally followed by a period of independent work by the collaborating individuals (modelers and specialists) which will lead to a second workshop and possibly subsequent ones in a phased sequence. Early in the sequence workshops concentrate on technical issues, but later they focus more and more on communication to policy advisors and the constituencies. The emphasis on communication enables an effective and logical move to implementation of the research suggested by workshop exercises and the model.

Throughout the workshop sequence, the simulation model serves as an expression and synthesis of not only new information, but also of the changing mental models of scientists, managers and policy makers. The involvement and interaction of these groups is essential; each group's learning the needs of each other group becomes as much of a product as does problem solving.

Though the simulation model may to some extent replace individuals' mental models, it does not replace management. Management experiments, in which policies are designed both to explore opportunities and pitfalls as well as to fulfill immediate needs, are particularly valuable. They serve not only to test the simulation model's assumptions and predictions, but also tend to reveal new management strategies. To the extent that the simulation model withstands various tests (management experiments, historical data sets from other locations, etc.) its credibility as a predictive tool is enhanced.

1.3.3 Research Design

Research design recommendations that arise from workshop exercises are a consequence of

(1) important gaps in knowledge that need to be filled to complete the simulation of how the system of interest functions,

(2) what kinds and levels of research are feasible within existing time, funding, and management constraints,

(3) what kinds of research approaches are likely to provide useful answers, and

(4) (in the case of this and many other projects) what kinds of answers can be validly applied in other places and times.

The simulation model cannot design the research; it can only suggest where the important data gaps are. Ideas for research design commence from dialogue between the modelers and the specialists as they examine the simulation. Experience in the kinds of research approaches that work, i.e, that tell what changes in indicators will occur in response to specified actions, is helpful background for this dialogue. We will recommend in this report general research approaches that have been found to work with other interdisciplinary studies based on AEA approaches.

2. BOUNDING THE SAVAL RANCH SIMULATION MODEL

The Saval Ranch Project is an interagency effort charged with evaluating the effects of a livestock grazing system and necessary range improvement practices on vegetation, livestock production, fish and wildlife resources and their habitats, watershed values, water quality, and other resources and values. To this end, description of the feasible management alternatives, or actions, and the measures used to evaluate the effects of actions on the biological/physical/economic system, or indicators, begin to describe the realistic limits of the system which will be considered during the workshop. The system to be simulated is further defined by placing the actions and indicators in a manageable spatial and temporal framework.

2.1 Actions

Actions, in the context of the Saval Ranch program, are the feasible human interventions which can alter the characteristics of range vegetation and soil, the cattle numbers and movement, and to some degree, the wildlife. It is important to define the actions as single interventions (e.g., plowing) rather than multiple, or a class of, interventions (e.g., vegetation manipulation). Particular components of the system may respond differently to specific actions which are often grouped into one generic category.

At the workshop, the actions fell into five main categories, each being representative of a definable subsystem within the overall Saval Ranch system (Table 2.1). Certainly some of the actions specified are more realistic than others and many of them are already being executed as part of the coordinated Management Plan. Actions listed but not currently being considered are included here for completeness.

It is important to note that even though an action is listed under one category it does not preclude it being considered for

Table 2.1. List of actions developed at workshop.

1. Vegetation Manipulation

- plowing
- seeding
- burning
- spraying
- fertilization
- chaining
- biological control
- moisture concentration (e.g., snow mgt., etc.)

2. Livestock Manipulation

- supplemental feeding
- distribution of salt by riders
- age ratio of herd (i.e., # of yearlings, calves, etc.)
- breeding season and methods
- introduction of different breeds (i.e., sheep and cattle)
- rotation scheme (i.e., deferred, rest, etc.)

3. Wildlife Manipulation

- hunting season
- hunting permits
- predator control

4. Water Management

- sediment ponds
- dams
- wells
- water development (e.g., meadow improvement, irrigation)

5. Economic

- buying and selling hay
- livestock movement to external pastures (i.e., off Saval)
- employment and labor supply
- amount of financing

another. For example, plowing and seeding, listed as vegetation manipulation, are actions likely applied to ultimately affect cattle production or wildlife habitat.

2.2 Indicators

Indicators are those measurements which individuals use to evaluate the state, or health, of a system. They are the links between the simulation model and the participants' "mental" model of the system. Different people use different measures of system performance and it is therefore important to compile a comprehensive set of indicators that represent the interests of all participating agencies and groups. This ensures that the simulation model remains relevant to the concerns of all participants.

The indicator list generated at the workshop reflected the major areas of focus (Table 2.2). Note that some of the indicators were not clearly defined at this stage. This was left as a subgroup charge and definitive definitions of the indicators included in the model are given in the submodel descriptions.

2.3 Space

The selection of a satisfactory spatial representation is invariably a difficult task in any modelling exercise. The scope of any model is a compromise between the specific (enabling examination of very specific hypotheses) and the general (enabling examination of the more general classes of hypotheses).

At the first workshop the participants felt it was necessary to explicitly represent each pasture since the cattle graze each pasture as a group and on a fixed schedule each year, depending on the rotational scheme. The complicating feature however was that within each pasture there are very specific range sites which correspond to identifiable mixtures of vegetation and

Table 2.2. List of indicators developed at workshop.

1. Vegetation
   - hay production (t)
   - total forage production (lb/ac/yr)
   - percent composition by weight of key species
   - vegetative cover

2. Cattle
   - livestock production (lb/yr) by calves and cows
   - cattle weight (lb/individual)

3. Wildlife
   - number of sage grouse and deer (i.e., females of breeding age)
   - hunter days on deer and sage grouse
   - non-consumptive user days
   - biomass of small mammals
   - diversity of non-game birds

4. Water
   - water quantity (peak, low and total flows)
   - soil moisture (bars tension)
   - stability of stream channel
   - infiltration (cm/hr)

5. Economics
   - net ranch revenue
   - non-market values
   - direct and indirect market values
   - hay sold

soils. These range sites are the major categorical framework for much of the vegetation work that has been carried out to date. The participants felt that the model must maintain a separate representation of each range site within a pasture (e.g., there are a maximum of 10 range types). However, it was agreed that the actual location of the range site in the pasture was not important. This therefore permitted application of an implicit spatial scheme within each pasture. For example, within the Lower Sheep Creek Pasture, 6% of the area is Loamy Bottom, 1% is Wet Meadow, 15% is Claypan 10-12 in, and 78% is Loamy 8-10 in. The fact that there may be two regions of Loamy 8-10 in making up the 78% is not considered in this scheme.

At the end of the first workshop it was agreed to simplify the maximum range site specification within each pasture to three. This was carried out between the workshops and is the structure in the current model (see also Section 3).

2.4 Time

Development of a dynamic simulation model requires specification of a time horizon over which model projections are of interest, and a time step over which the change in value of the state variables will be calculated and displayed. Since the coordinated management plan to be applied to the Saval Ranch requires 12 years for one complete cycle of the livestock rotational scheme, it was agreed that ideally the model time horizon should be about two cycles to adequately evaluate the effectiveness of the management plan (i.e., 25 years). This does not however mean that the model can only simulate 25 year projections. The time horizon only acts as a guide for determining the temporal scale over which questions are being asked of the system.

On the other hand, specification of a time step does limit (i.e., bound) the level of detail in the model. For example, a yearly time step would lose the fine scale growth characteristics of the vegetation while a one hour time step is too detailed for evaluating livestock production. A suitable compromise was necessary.

The participants chose a weekly time step for the period between March 15 and November 30 in each simulated year (i.e., 38 weeks). This corresponds to the period of active vegetative activity and cattle on the range. The period from November 30 - March 15 was represented as one big time step during which the fine scale dynamics were considered at their average level. The choice of the weekly time step does not preclude the use of a different time step within each submodel if necessary. Only the integrated system is really constrained by the weekly specification from the point of view of model output and evaluation. (The hydrology submodel, for example, chose to use an internal daily time step [see Section 4]; the wildlife submodel used a yearly time step for sage grouse [see Section 6].

2.5 Submodel Definition

Having defined the spatial and temporal bounds of the model, as well as the key inputs and outputs, the system was divided into four subsystems. The criteria for proper division are: (1) minimization of information transfers between subsystems (each submodel simulates a relatively isolated, self-contained part of the whole system), (2) efficient division of the expertise of the participants such that each subsystem represents the concerns of a particular subgroup of specialists, and (3) fairly equal programming workloads for each member of the workshop staff.

The four subsystems are:

- vegetation
- hydrology and soils
- wildlife
- livestock and economics

Each participant joined one of the subsystems and helped conceptualize the dynamics describing how the components of the subsystem change with time. The linkages between the subsystems were defined through the looking outward procedure.

2.6 Looking Outward

The purpose of looking outward is to define the pieces of information a particular subsystem requires from all other subsystems in order to predict how that subsystem will behave dynamically. This is a qualitatively different question than the traditional, which requires lists of "factors which affect" a particular component of a system. The product of this exercise is an interaction matrix, with the columns specifying what information a subsystem requires from each of the other subsystems listed on the rows (Table 2.3). The diagonals are crossed out because those represent the internal dynamics of each subsystem, a task left to the subgroups to consider.

In effect, each piece of information listed in the matrix represents a specific hypothesis. For example, the water subgroup stated it needed % cover by range site on each pasture. The hypothesis is that % cover has a significant effect on the movement and infiltration of water at the range site level.

Table 2.3: Looking outward matrix developed at workshop.

FROM \ TO	LIVESTOCK & ECONOMICS	VEGETATION	WATER & SOILS	WILDLIFE
LIVESTOCK		- tons of vegetation consumed (by range site)	- # cattle in riparian area (cattle days/ mile)	- # cattle in riparian area (cattle days/ mile)
VEGETATION	- tons of hay produced - tons of vegetation (tons/acre) for each plant group - % protein in each plant group - cost of fertilization		- % cover by site type & pasture (shrubs, grass) - AWC by range site - erodability	- tons of vegetation by range site - % protein - % cover by site type - grasses, shrubs, trees
WATER & SOILS		- weekly precip. by pasture - soil moisture (0-10", 10-20", >20" depths) - temperature max. - min. flow/wk. - total flow (April - Aug 15)		- precip. & temp. by wk. & pasture - water quality
WILDLIFE	- hunter days/yr. - recreational user days	- tons of vegetation consumed (by range site)		

3. VEGETATION SUBMODEL

The vegetation subgroup's responsibilities are shown in Fig. 3.1 and the sequence of submodel operations in Fig. 3.2. In addition to specifying the rules for change required to implement actions and produce required variables, the subgroup expended considerable effort synthesizing data to provide initial conditions and driving variables for the model. As a result of this latter responsibility, there was insufficient time during the first workshop to accurately conceptualize some of the important processes affecting plant growth. Representation of these processes was much improved during the second workshop, aided by a collapsed version of the model programmed on an APPLE microcomputer.

3.1 Classification of Vegetation

The model computes changes in the above ground live biomass (in lbs/ac) of seven plant types (Table 3.1). All plant categories except cheatgrass have "storage reservoirs" of potential above ground biomass in plant parts not accessible to grazing. For forbs and perennial grasses, the storage reservoir implicitly represents carbohydrate root storage; in shrubs the reservoir refers to storage in both the roots and above-ground woody material. This classification was considered at the start of the workshop to be the minimum necessary to reflect the effects of plant composition and abundance on beef production, wildlife food and cover requirements, and hydrological processes such as evapotranspiration. The biomass of each plant type at the time of peak perennial grass biomass (late July) was estimated for each range site and pasture from data brought to the workshop (Fig. 3.3). With the exception of wet meadows, the model assumes no difference in range site plant composition across most pastures. However, it is not known at this time whether this simplifying assumption is valid. Prior to the second workshop, the number of

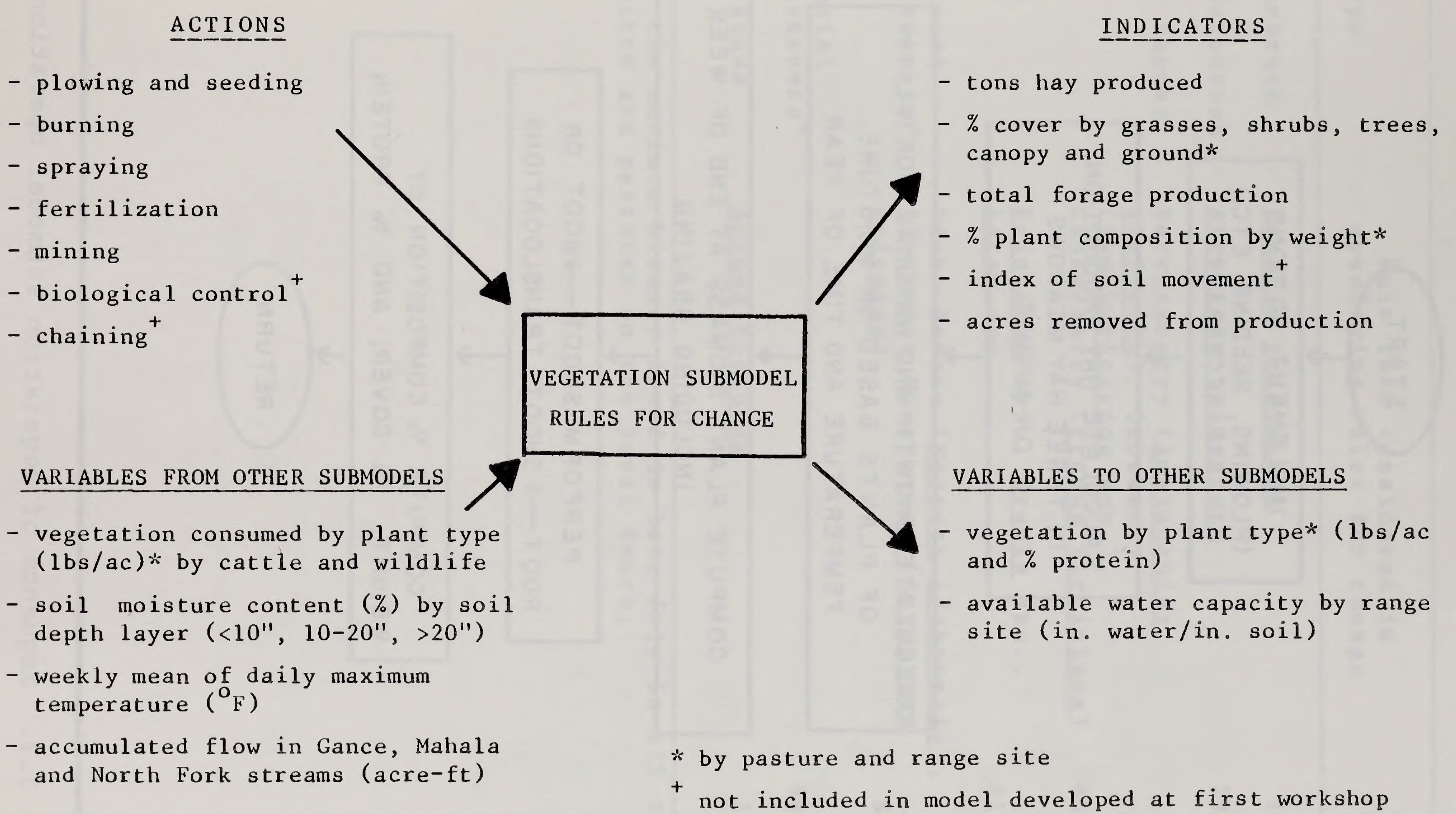

Fig. 3.1. Responsibilities assigned to the vegetation subgroup.

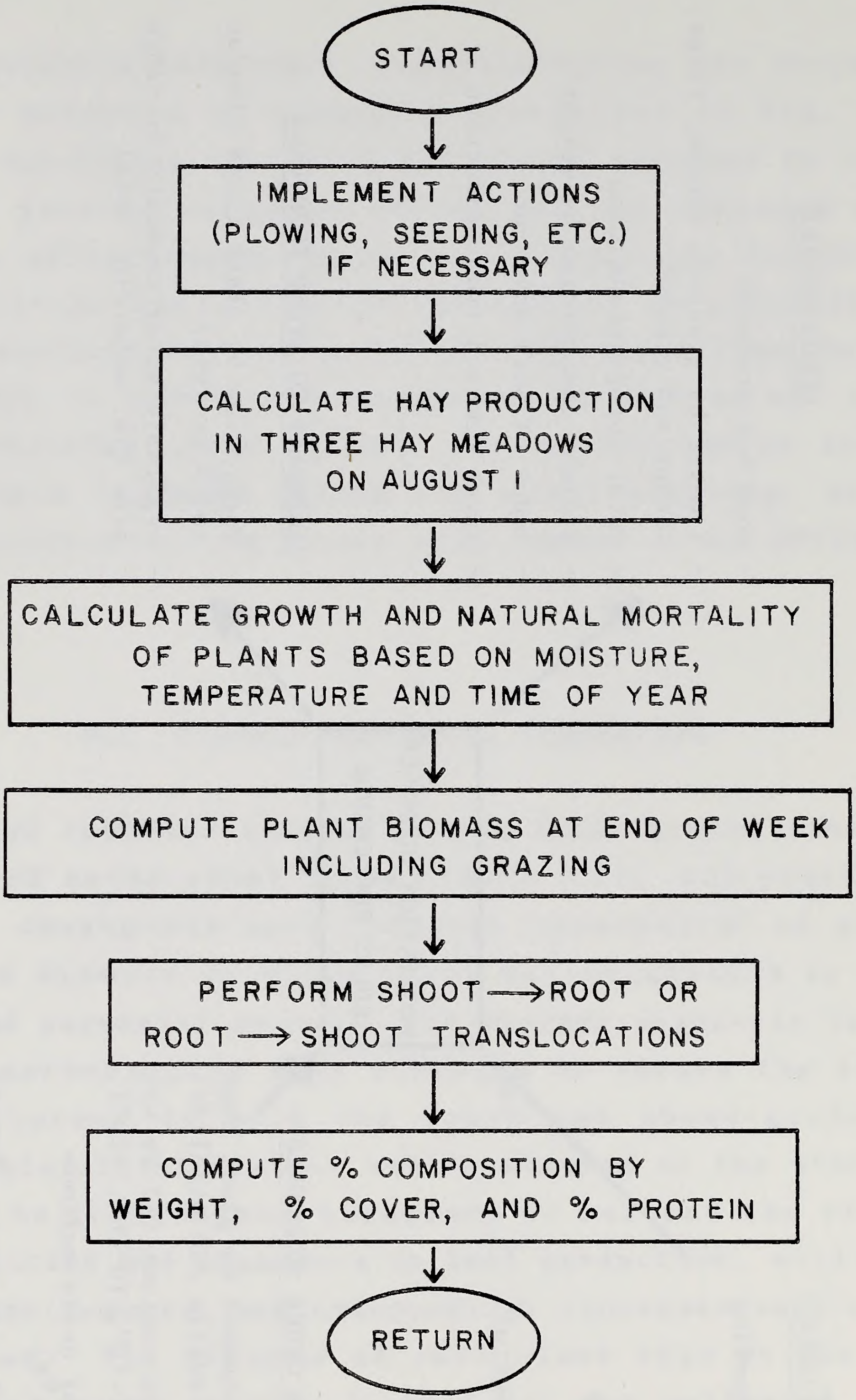

Fig. 3.2. Sequence of vegetation submodel operations.

Table 3.1. Plant types represented in vegetation submodel.

Plant type	Main taxa considered in specifying rules for change	Maximum biomass* (lb/ac)
1. Bitterbrush	*Purshia tridentata*	129
2. Big Sagebrush	*Artemisia tridentata*	2356
3. Other Shrubs	Serviceberry (*Amelanchier alnifolia*), Snowberry (*Symphoricarpos* spp.), Chokecherry (*Prunus virginiana*)	4678
4. Forbs	*Eriogonum* spp., *Crepis* spp., *Aster* spp.	2148
5. Perennial "decreasers"	Idaho Fescue (*Festuca idahoensis*), Bluebunch Wheatgrass (*Agropyron spicatum*)	800
6. Perennial "increasers"		4474
7. Cheatgrass	*Bromus tectorum*	177

*This is the maximum biomass found in late July in all the range sites and pastures on the Saval Ranch.

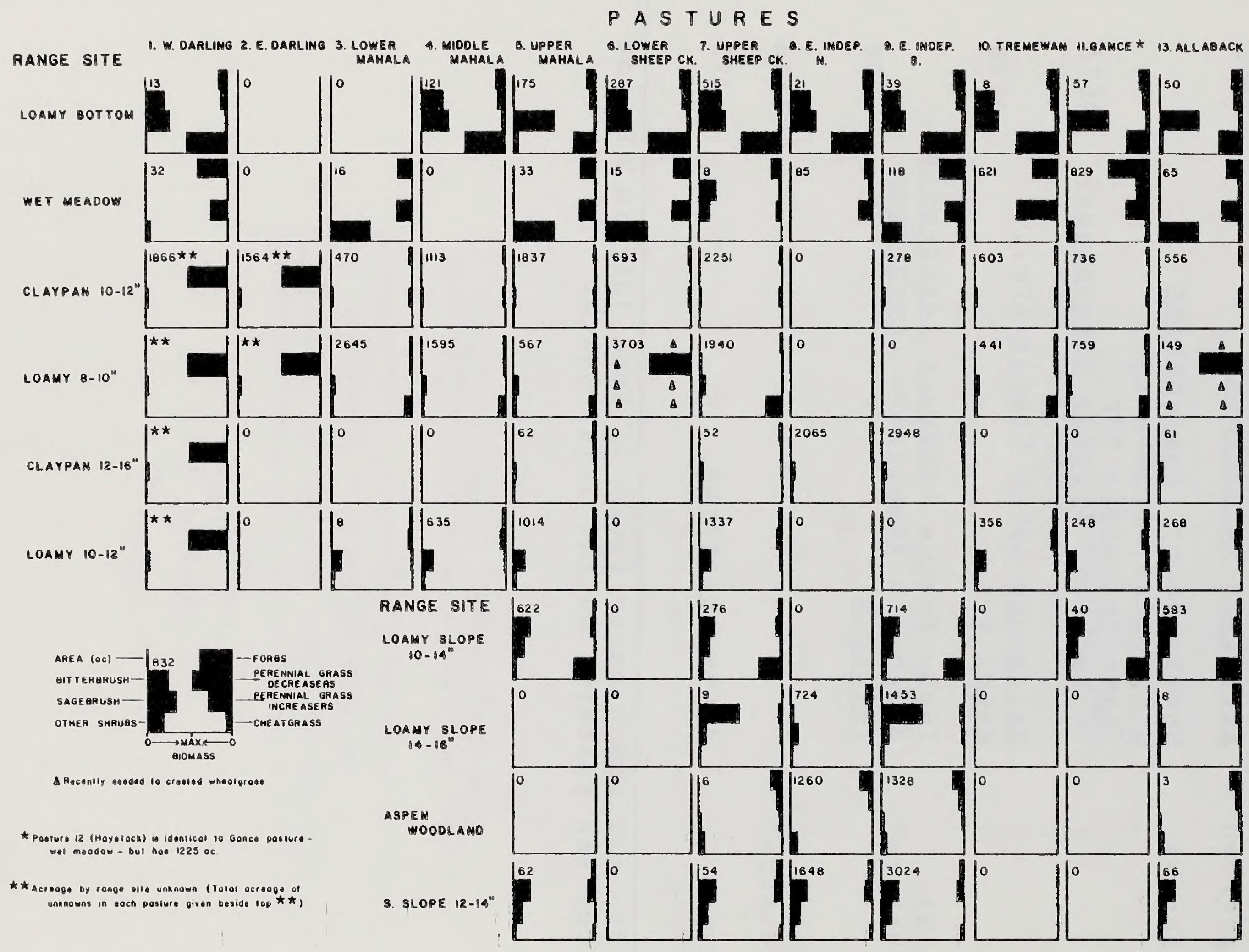

Fig. 3.3. Biomass of plant types by pasture and site (scaled relative to the maximum biomass in each range site, Table 3.1).

range sites was reduced from ten to three based on the soil available water capacity. New plant biomasses and available water capacities were computed for the three new range sites as area weighted averages of the old quantities. This method of grouping range sites preserved much of the between pasture variability (Tables 3.2 and 3.3).

Since each simulated year begins March 15, the available mid-summer biomass data was reduced by a factor of 10 for estimated early spring biomass of each plant type. This factor of 10 was only a rough guess, but produced reasonable model behavior and is likely the right order of magnitude.

Table 3.2. Grouping of range sites used for second workshop.*

New range site category	Old range sites
1. clay	claypan 10-12 in, claypan 12-16 in, s. slope 12-14 in
2. loam	loamy 8-10 in, loamy 10-12 in, loamy slope 10-14 in, loamy slope 14-18 in
3. riparian	loamy bottom, wet meadow, aspen woodland

*The model can easily be changed to group range sites differently (e.g., by adding s. slope 12-14 in to the loam category).

3.2 Plant Biomass

The subgroup participants agreed that conceptualization of the growth dynamics of three plant groups would suffice: one for shrubs, one for forbs and perennial grasses, and one for cheatgrass.

Table 3.3 Peak plant biomass by pasture[+] and new range site category (as used in the second workshop, and currently).

RANGE SITE & PLANT TYPE	Peak Biomass* (lbs/a) by pasture								
	W. Darling	E. Darling	Lower Mahala	Middle Mahala	Upper Mahala	Lower Sheep	Upper Sheep	E.Ind. North	E.Ind. South
CLAY: area(a)	933	782	470	1113	1961	693	2357	3713	6250
bitterbrush	0	0	0	0	0	0	0	20	30
sagebrush	190	190	80	80	90	80	90	280	290
other shrubs	160	160	20	20	30	20	20	140	140
forbs	30	30	110	110	120	110	110	180	190
perennial decreasers	790	790	10	10	20	10	20	110	110
perennial increasers	10	10	80	80	80	80	80	40	40
cheatgrass	0	0	0	0	0	0	0	10	10
LOAM: area(a)	933	782	2653	2230	2203	3703	3568	1984	3495
bitterbrush	assumed	assumed	0	0	20	0	10	0	60
sagebrush			210	330	510	0	430	150	310
other shrubs	same	same	70	110	170	0	160	480	300
forbs	as	as	110	140	170	0	150	570	310
perennial decreasers	clay	clay	30	60	100	800	60	70	70
perennial increasers			50	60	60	0	60	50	150
cheatgrass			40	30	40	0	50	0	20
RIPARIAN: area(a)	45	0	16	121	208	302	523	106	157
bitterbrush	20		0	60	0	60	60	10	20
sagebrush	420		0	1460	1980	1390	1450	290	360
other shrubs	430		4680	20	1190	250	20	0	1530
forbs	1340		860	510	560	520	510	460	1180
perennial decreasers	50		0	190	120	180	180	130	60
perennial increasers	1500		1920	140	450	230	150	1410	1730
cheatgrass	50		0	180	90	170	170	40	70

+ The hay meadows (Tremewan, Gance, Alaback) are now not broken down by range site and plant type.

* March 15 biomass assumed to be one-tenth of peak biomass (see note at end of Section 3.1).

For each plant group the weekly change in edible above-ground biomass (by range site and pasture) is calculated using:

$$\Delta B = G - M - CE - CW - TR \qquad \text{(Equation 3.1)}$$

where:

ΔB = change in live above-ground biomass (lbs/ac)
G = growth of live above-ground biomass (lbs/ac)
M = death of live above-ground biomass (lbs/ac) (conversion to litter)
CE = cattle consumption (lbs/ac)
CW = wildlife consumption (lbs/ac)
TR = translocation to or from roots (equivalent lbs/ac of above-ground live biomass)

The amount eaten by cattle and wildlife is calculated by the Cattle & Economics and Wildlife Submodels, discussed in sections 5 and 6 respectively. Note that the model does not account for cattle and wildlife eating different parts of the plant. Growth, mortality and root translocation are discussed in the following sections.

3.2.1 Weekly Growth

Above-ground plant growth (roughly equivalent to net photosynthesis) was assumed to depend only on temperature and soil moisture; light and nutrients were considered negligible as growth-limiting factors in northeastern Nevada.

The weekly growth (in lbs/ac) of each plant type is computed by multiplying the biomass present the previous week by a % growth rate, calculated from:

$$PGR = PGRmax \star \begin{array}{l}\text{reduction in}\\ \text{growth rate}\\ \text{due to temperature}\end{array} \star \begin{array}{l}\text{reduction in}\\ \text{growth rate due}\\ \text{to soil moisture}\end{array}$$

(Equation 3.2)

where:

PGR = potential growth of above-ground biomass (%/week)

PGRmax = maximum potential growth rate (%/week) under ideal temperature and soil moisture (e.g., in a greenhouse)

The maximum potential weekly growth rates were varied to determine what values produced reasonable changes in plant biomass with and without grazing. At present the model uses the rates shown in Table 3.4. Note that:

(1) temperature, soil moisture and evapotranspiration reduce the actual weekly growth rate to far below the levels in Table 3.4; and

(2) changes in the representation of translocation (section 3.2.3) will likely permit lower maximum growth rates to be used in the model.

Table 3.4. Maximum potential plant biomass growth rates currently used in the model.

Plant types	Maximum potential weekly growth rates
1. Bitterbrush, sagebrush and other shrubs	150%
2. Forbs and perennial grasses	300%
3. Cheatgrass	300%

The reductions in growth rate due to temperature and soil moisture are computed as indices between zero and one (Figs. 3.4 and 3.5). For this method to be successful, it is critical that the bars of tension of soil moisture reflect the variation in soil characteristics across range sites. Since soil moisture is passed from the hydrology submodel as a percentage of available water capacity it is necessary to convert moisture to bars of tension of soil moisture (Fig. 3.6).

The model assumes that shrubs use water down to 40 in of soil depth, forbs and perennial grasses only the top 20 in, and cheatgrass only the top 10 in. To implement this in the model, the soil moisture levels used on the x-axis of Fig. 3.5 were selected according to the following rules:

(1) Shrubs use the maximum soil moisture level within the three soil layers (0-10, 10-20 and 20-40 in). Shrubs experience mortality if all soil moisture levels are greater than 90% (greater than -.01 bars tension). Shrub survival through these moisture saturated weeks is assumed to equal the growth reduction factor in Fig. 3.5.

(2) Forbs and perennial grasses use the maximum soil moisture level within the top soil layers (0-10, 10-20 in).

(3) Cheatgrass use only the soil moisture level in the top ten inches.

This representation was used to reflect competition for water between plants. It is assumed that a high biomass of plants with shallow roots should prevent water from reaching the deeper layers, and thus remove the relative advantage held by deep-rooting plants (e.g., cheatgrass outcompeting perennials, or cheatgrass and perennials outcompeting shrubs). This mechanism requires careful linkage of plant growth and hydrological

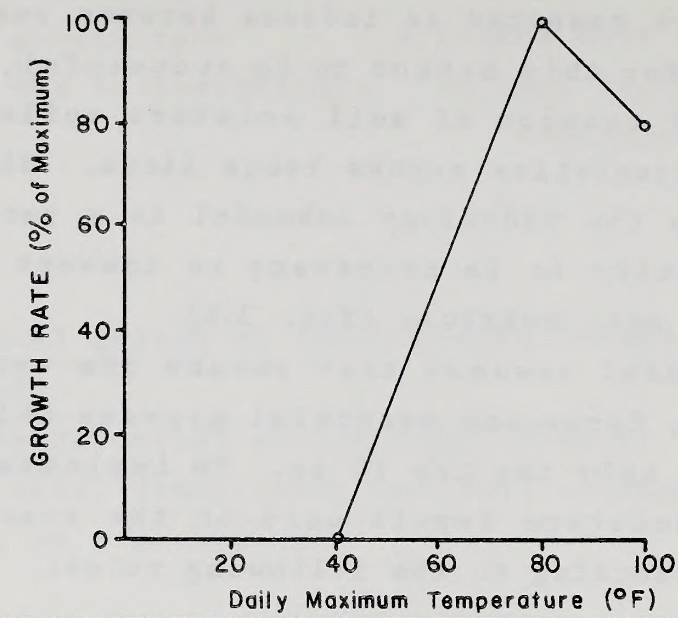

Fig. 3.4. Percent of maximum plant growth rate achieved at different daily maximum temperatures (assuming optimum soil moisture).

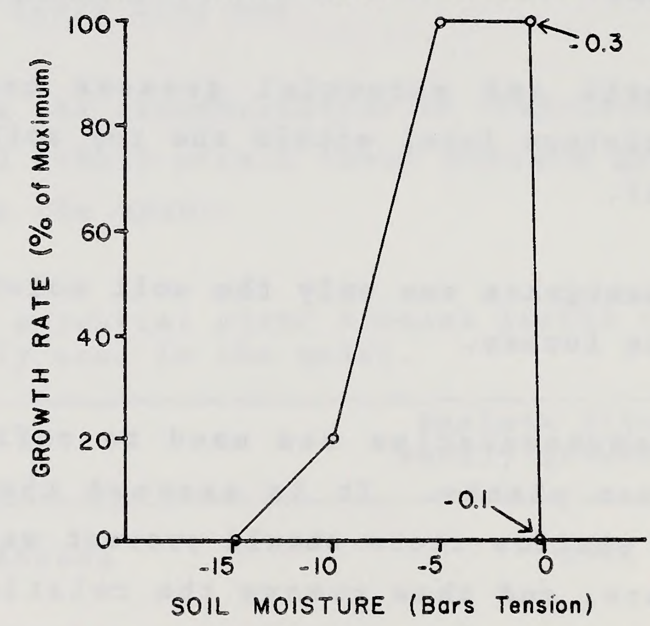

Fig. 3.5. Percent of maximum plant growth rate achieved at different soil moisture levels (assuming optimum temperature).

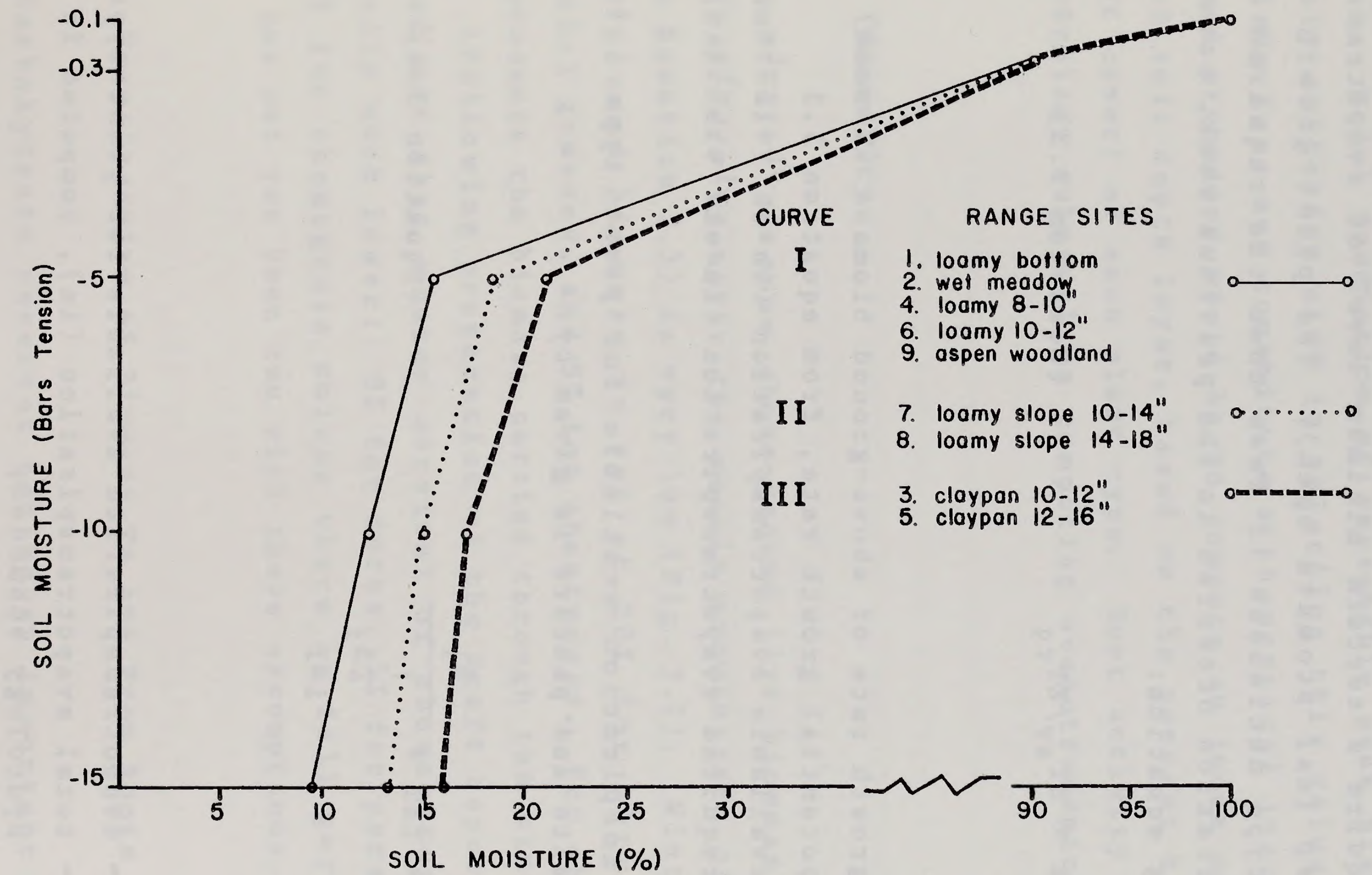

Fig. 3.6. Relationship between percent available water capacity and bars of tension of soil moisture. (Range sites 4 and 6 could alternatively be assigned to Curve II.)

processes. At the first workshop, the only linkage was by means of plant biomass - % cover relationship (discussed in section 3.3) which caused infiltration to increase as plant biomass increased, but did not concurrently increase evapotranspiration.

In the refined version of the model developed after the first workshop, plant growth rates are subject to an additional "water competition constraint". It is assumed that plant growth processes require a certain minimum level of evapotranspiration (e.g., to keep leaf stomata open). The plant growth rate for each plant type decreases if less than the required level of evapotranspiration occurred in the previous week, according to the following equation:

$$GR = PGR * ET_{av}/ET_{rq} \qquad \text{(Equation 3.3)}$$

where:

- GR = growth rate of above-ground biomass (%/week)
- PGR = potential growth rate, from equation 3.3
- ET_{av} = available evapotranspiration ($in*wk^{-1}*lb^{-1}*ac$)
- ET_{rq} = required evapotranspiration ($in*wk^{-1}*lb^{-1}*ac$)

Evapotranspiration available for plant type i (within a given range site and pasture is given by:

$$ET_{av,i} = TET * \frac{B_i}{\sum_{i=1}^{7} B_i} \qquad \text{(Equation 3.4)}$$

where:

- $ET_{av,i}$ = evapotranspiration available for plant type i;
- TET = total evapotranspiration (in), computed in the hydrology submodel;

B_i = biomass of plant type i on the particular range site and pasture considered (i=1 to 7 for seven plant types).

Required evapotranspiration (ET_{rq}) is currently set at 0.003 in per week per lb/ac of plant biomass, equivalent to 10 lb of water (transpired per wk) for each lb of plant biomass (dry weight). Model prediction of reasonable peak plant biomass was the only criterion used in selecting this value of ET_{rq}; this certainly does not constitute a theoretical justification. An improved procedure would be to compute an index of root activity at each soil depth layer, based on the percent biomass (and/or percent cover) of each plant type. Root activity is now used in the hydrology submodel in computing evapotranspiration (Equation 4.2).

3.2.2 Mortality

Mortality of some above-ground live biomass (conversion to litter) occurs whenever the weekly growth rate of a plant group (GR in Equation 3.3) is very low (Fig. 3.7). Winter survival of above-ground biomass is set at 20% for shrubs, forbs and perennial grasses, and 5% for cheatgrass. For cheatgrass, this 5% represents the biomass carried through the winter in the seed pool. (Following preparation of the draft report participants pointed out that winter survival of above-ground biomass is generally much lower: 0% for forbs, 5% for perennial grasses, and 0% for cheatgrass unless there is fall germination. The model has not yet been run with these assumptions.)

3.2.3 Translocation of Biomass To and From Roots

Carbohydrate reserves can be an important buffer against grazing. In the first workshop, root storage was only considered for forbs and perennial grasses; the model now also includes shrub carbohydrate storage in roots and inedible above ground woody material.

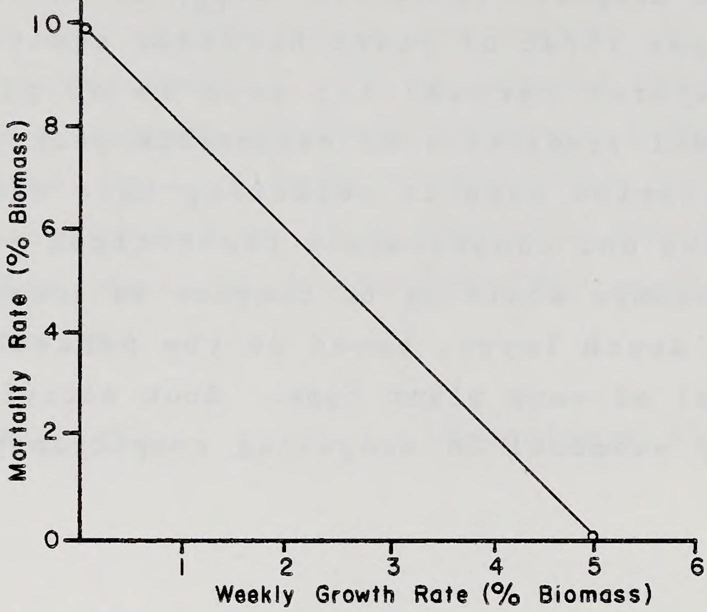

Fig. 3.7. Mortality rate of above-ground plant biomass at low plant growth rates.

The model produced at the first workshop contained very simple rules to move "potential above ground biomass" to and from storage reserves. Seed production represented a critical "switching time": prior to seed production, the plant each week transferred a fixed proportion of its root stores to above ground biomass; after seed production the reverse occurred. The following three parameters therefore had a strong influence on the biomass of plants seen throughout the season (the values used in the workshop model are in brackets):

IFDATE = time of seed production [the last week of July]

PSTR = % of above ground biomass transferred to storage each week after seed production [10%]

PRTS = % of storage transferred above ground each week before seed production [10%]

Root storage of "potential above ground biomass" was set initially at ten times the above ground biomass.

Several refinements were made to the translocation rules following the second workshop:

(1) BEFORE SEED SET:

If cattle or wildlife are reducing above ground biomass through grazing, the amount of translocation from storage is computed to be just sufficient to maintain constant above ground live biomass (the "cropping effect"). If root storage is insufficient to replace all the above ground losses that occurred in a given week, 50% of the existing storage is shifted above ground per week. If above ground biomass has not been reduced by grazing, the percent of storage reserves shifted above ground (PRTS) is time dependent; between March 15 and the time of seed production PRTS decreases linearly from 20% to 0%.

(2) AFTER SEED SET:

The weekly increment in storage reserves is still computed as a fixed percentage of above ground biomass (PSTR), but the biomass above ground is not reduced. This change reflects the fact that after seed set, above ground dry weights remain relatively constant (in the absence of grazing). Translocation of storage reserves to above ground biomass does not occur after seed set, with or without grazing.

Currently in the model storage reserves of forbs cannot exceed 400 lb/ac of potential above ground biomass, and perennial grasses and shrubs can store up to 1000 lb/ac. Over the winter, respiration demands of the plant use up 70% of the reserves remaining on November 30.

3.2.4 Percent Protein

The change in percent protein over the growing season is structured as a function of time in any given year (Fig. 3.8). Future refinements should attempt to establish a representation of % protein that reflects more directly the actual plant growth taking place. For example % protein could be made a function of the weekly increment in live above-ground biomass.

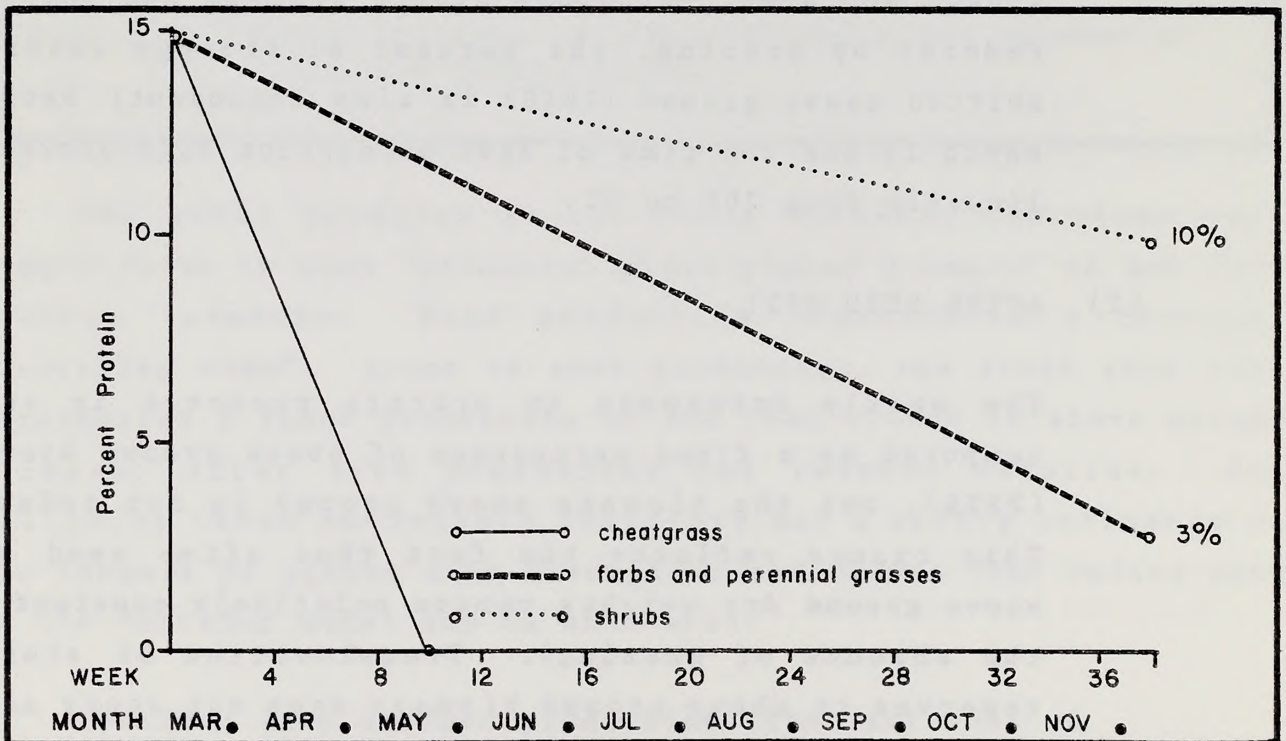

Fig. 3.8. Change in plant protein content over the growing season.

3.3 Range Site Available Water Capacity, Percent Cover and Erosion Potential

In addition to plant biomass composition, each range site is characterized by available water capacities for three soil depth layers, a distribution of vegetation cover, and a soil erosion index (Table 3.5 in the first workshop and 3.6 currently). The available water capacities of each range site, which are kept constant over time, are important in determining the outcome of the competition between plant types for water at different soil depths. Range site erosion potential is also held constant across pastures and over time.

It was agreed that the percent of grass, shrub and litter cover change over time, although it was not clear how to calculate percent cover from percentage weight composition of plant types. Note that percent cover here refers to the hydrologist's use of the term (i.e., area of bare ground covered) where 100% is the maximum total cover.

In the first workshop, it was assumed that the percentage of area under shrub cover was linearly proportional to the percent biomass of shrubs, and the areal percentage of grass cover was linearly proportional to the percent biomass of forbs, perennial increasers, perennial decreasers and cheatgrass. (Percent biomass refers to the percent of maximum biomass potentially present on the range site [see Table 3.1].) The relationships used for these conversions assumed the percentage cover values in Table 3.5 corresponded to the maximum percent biomass values for each range site across all pastures. These linear relationships and the single point used to form them are shown in Figs. 3.9 and 3.10.

This method of calculation of percent cover had several inadequacies:

(1) The range sites with the maximum percent biomass used in Figs. 3.9 and 3.10 may have levels of shrub and

Table 3.5 Available water capacity, range site cover and soil erosion potential used in the first workshop.

Range Site	Available water capacity (AWC) by soil layer (in/in) 10"	10-20"	20-40"	AWC relative to other range sites	Percentage cover by: Tree & shrub canopy	Bare	Herb. canopy	Rock	Litter	Soil erosion potential (k)
1. Loamy bottom	0.13	0.13	0.10	moderate	50	15	20	0	15	0.37
2. Wet meadow	0.16	0.16	0.16	high	1	1	90	0	8	0.49
3. Claypan 10-12"	0.13	0.13	0.08	moderate	30	40	10	13	7	0.37
4. Loamy 8-10"	0.14	0.11	0.08	moderate	40	40	6	0	14	0.43
5. Claypan 12-16"	0.06	0.08	-	very low	40	48	5	2	5	0.37
6. Loamy 10-12"	0.14	0.15	0.12	high	33	23	32	1	11	0.37
7. Loamy slope 10-14"	0.14	0.08	0.05	low	31	10	36	3	20	0.32
8. Loamy slope 14-18"	0.12	0.08	0.06	low	27	20	40	1	12	0.32
9. Aspen woodland	0.17	0.17	0.14	high	40	20	30	0	10	0.28
10. S. slope 12-14"	0.10	0.07	0.03	very low	16	46	35	1	2	0.28

Table 3.6(a). Range site cover and soil erosion potential now used for the collapsed range sites (calculated as averages from original range sites).

% COVER BY: RANGE SITE	Tree and shrub canopy	Bare	Herbaceous canopy	Rock	Litter	Soil Erosion Potential
clay	30	45	15	5	5	0.34
loam	35	20	30	0	15	0.36
riparian	25	5	60	0	10	0.38

Table 3.6(b). Available water capacities (in/in) now used for the collapsed range sites (by pasture).

PASTURE	RANGE SITE AND SOIL DEPTH								
	CLAY			LOAM			RIPARIAN		
	<10"	10-20"	20-40"	<10"	10-20"	20-40"	<10"	10-20"	20-40"
W. Darling	0.13	0.13	0.08	0.14	0.11	0.08	0.15	0.15	0.14
E. Darling	0.13	0.13	0.08	0.14	0.11	0.08	0.*	0.	0.
Lower Mahala	0.13	0.13	0.08	0.14	0.11	0.08	0.16	0.16	0.16
Middle Mahala	0.13	0.13	0.08	0.14	0.12	0.09	0.13	0.13	0.10
Upper Mahala	0.13	0.13	0.08	0.14	0.12	0.09	0.13	0.13	0.11
Lower Sheep	0.13	0.13	0.08	0.14	0.11	0.08	0.13	0.13	0.10
Upper Sheep	0.13	0.13	0.08	0.14	0.12	0.09	0.13	0.13	0.10
E. Ind. North	0.08	0.08	0.01	0.15	0.14	0.11	0.15	0.15	0.15
E. Ind. South	0.08	0.08	0.02	0.14	0.11	0.09	0.15	0.15	0.15

* no riparian in E. Darling.

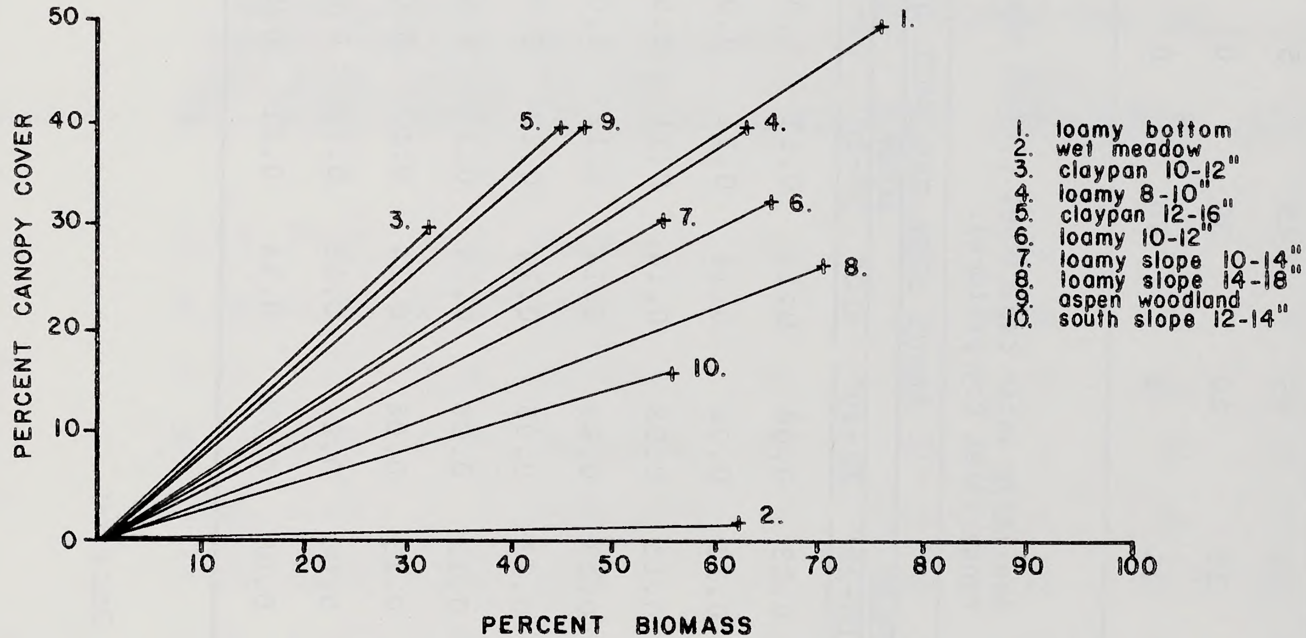

Fig. 3.9. Assumed relationships (first workshop) between percent of maximum biomass of shrubs and percent shrub canopy cover for each range site. Plus signs plot maximum percent biomass in range site and percent canopy cover from Table 3.5 and Fig. 3.3.

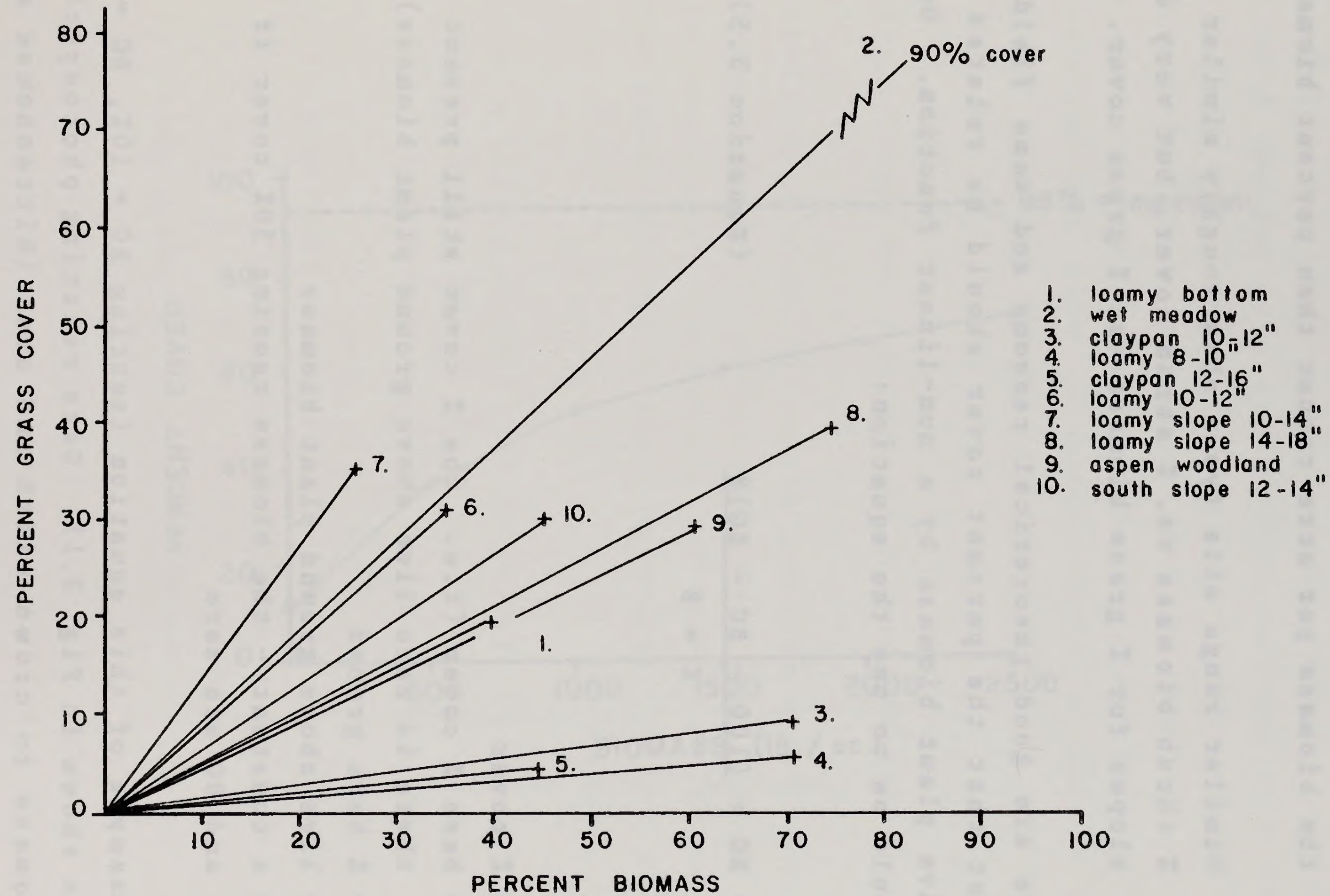

Fig. 3.10. Assumed relationships (first workshop) between percent of maximum biomass of forbs, perennial grasses and cheatgrass, and percent ground cover of grasses for each range site.

canopy cover very different from the "typical" percentages in Table 3.5.

(2) The relationships between percent cover and percent biomass, although unknown, are almost certainly non-linear; percent cover may in fact be better related to the biomass per acre rather than percent biomass.

(3) Similar range site types show roughly similar slopes of % shrub biomass vs. % shrub cover, but very different slopes for % grass biomass vs. % grass cover.

There are good theoretical reasons and some field evidence to suggest that the percent cover should be related to above ground live plant biomass by a non-linear function. One simple method would be to use the equation:

$$PC = BC + \frac{(100 - BC - BG)B}{K + B} \qquad \text{(Equation 3.5)}$$

where:

PC = % cover

BC = base % cover (i.e. the % cover still present when there is zero live above ground plant biomass)

BG = % bare ground

B = live above ground plant biomass

K = a constant - the biomass causing 50% cover if BC and BG are zero

An example of this equation (setting BC = 10%, BG = 5% and K = 1000) is shown in Fig. 3.11. Data relating photosynthetic and woody biomass to crown width and area (Rittenhouse and Sneva 1977) appears to support the general form of this relationship, and use of this equation in the APPLE model in the second

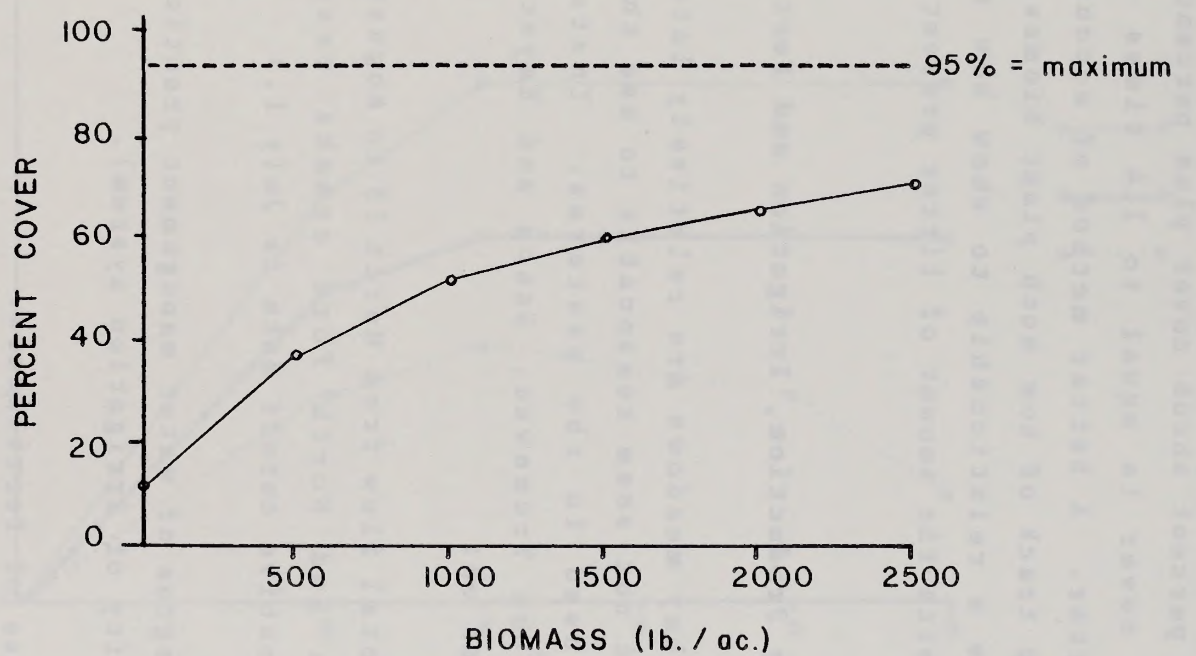

Fig. 3.11. Example of function recommended for computing percent cover from percent of maximum biomass. (This is a schematic curve and does not represent any particular species.)

workshop produced reasonable results. However, further discussion is needed in determining the parameter values to substitute in Equation 3.5 for each plant type; the large model currently still uses a linear function relating % biomass to % cover based on Table 3.6 (a).

Tree cover is assumed constant at 30% in Aspen Woodland range sites, and 0% elsewhere. Percent canopy cover is calculated from percent shrub cover plus percent tree cover, and percent ground cover is equal to 1.4 times grass cover, to account for litter. A better method of accounting for litter would be to keep track of how much plant biomass dies each year, and then derive a relationship to show how percent cover by litter changes with the amount of litter present.

3.4 Hay Production, Irrigation and Fertilization

Since the hay meadows are relatively intensively managed systems, it did not seem reasonable to use the same rules for plant growth used in the pastures. Instead, annual hay production in the Tremewan, Gance and Haystack meadows was assumed to depend on:

(1) The total flow from March 15 to August 1 in the Mahala, Gance and North Fork creeks respectively. (An alternative cutoff date is July 1.)

(2) The degree of water management practiced on the meadows (quality of irrigation system).

(3) The use of fertilizers.

These factors are drawn together by means of the relationships shown in Fig. 3.12. Water management can be either "poor" (the present level) or "good", and fertilization can either take place to the "optimum level" under good water management, or not

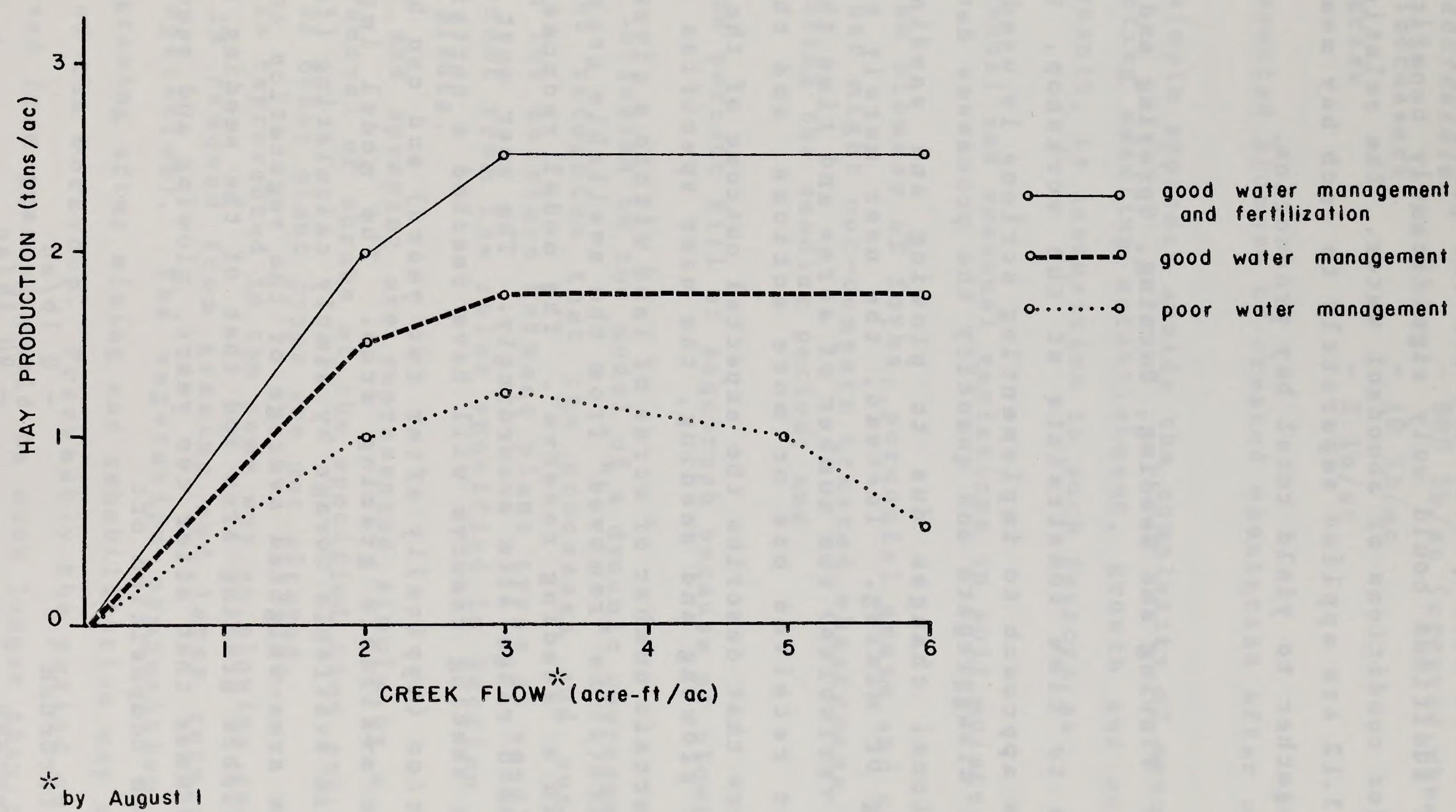

Fig. 3.12. Effects of accumulated creek flow, water management and fertilization on hay production.

at all. These assumptions reflect the participants' belief that nutrient additions could only significantly benefit hay production under conditions of abundant water. The relationships shown in Fig. 3.12 are applied separately to each hay meadow and then added together to yield total hay production.

3.5 Plowing and Seeding, Burning, Spraying and Mining

Due to time constraints at the workshop, the simplest possible approach to implementing actions is used. The model does not disaggregate and quantify the processes determining the vegetational changes due to plowing and seeding, burning, spraying or mining. Instead, the user merely specifies (as driving variables) the number of acres and time that a certain location receives one or more actions, and the values of parameters that describe the expected outcome of the actions.

For plowing and seeding, the user specifies at some time that a certain number of acres of land within a given pasture and range site(s) is "removed" from the available grazing area and placed in a "seeding reserve". The model reduces the acreage within each range site accordingly. The user must also specify when the seeding reserve will have reached a certain vegetation composition (typically after two years) and can be added back into the available grazing area. The model implements the changes in available forage by simply calculating (for each range site) the area-weighted average of the vegetation composition in the available grazing area and that of the seeding reserve. The model assumes that after two years, plowing and seeding yields a vegetation composition of:

bitterbrush	- 0 lb/ac
sagebrush	- 90 lb/ac
other brush	- 90 lb/ac
forbs	- 30 lb/ac

perennial grasses:

decreasers	- 800 lb/ac (crested wheatgrass)
increasers	- 10 lb/ac
cheatgrass	- 2 lb/ac

The expected biomass of crested wheatgrass after one year is 250 lb/ac.

This simple approach avoids the complexity of specifying the rules affecting seedling establishment, growth and competition, but, as a result, is insensitive to such factors as:

(1) annual and seasonal variations in soil moisture;

(2) the biomass of forbs, perennial grass and cheatgrass that might out-compete crested wheatgrass seedlings during the seeding period; and

(3) the percent kill of sagebrush because of plowing.

Future inclusion in the model of a dynamic representation of seeding must recognize that the processes and outcomes of competition for moisture between plant types as seedlings are quite different from the rules specified in Section 3.2.1 for established plants.

Burning and spraying are represented simply by a transient percentage removal of shrubs at the specified time and location. The biomass of other plant types are not altered.

Mining is represented in the same way as plowing and seeding (i.e., land is removed from grazing and later returned with different vegetation). The vegetation composition of land returned to grazing after mining and rehabilitation was not known at the time of the workshop. Presumably the period over which land is removed from grazing would be much longer than the 2 - 3 years typical for plowing and seeding.

3.6 Review of Submodel Hypotheses

A weekly time step is optimal.

Though a weekly time step allows for detailed examination of vegetation processes, and flexibility in implementing different grazing schemes, many of the participants' "mental models" of vegetation dynamics are essentially seasonal or annual. It would be valuable to eventually construct a mini-computer vegetation model based on an annual time step. This would permit easier and faster examination of the overall (i.e., whole ranch level) impacts of different grazing schemes and consequences of alternative hyoptheses. Repeated runs of the existing weekly time step models could be used to help generate seasonal or annually-based functional relationships.

Three range sites (clay, loam and riparian) are sufficient.

Since the available water capacities and initial plant biomasses assigned to each of the three range sites are computed as a weighted average of the ten range site representations on each pasture, the spatial heterogeneity of vegetation and soils is reasonably well preserved. Sensitivity analysis of the importance of available water capacities, percentage cover assumptions and soil erosion indices could be used to determine the effects of grouping range sites on the overall behavior of the model. Also, the history of the range site may generally alter plant composition and potential growth. This should be considered in parameterization of the model.

Seven plant types are necessary and sufficient.

Each plant type in the model is functionally different from the others, either in its growth functions or its value to cattle and wildlife. It therefore does not seem appropriate to further reduce the number of plant types. Participants seemed generally satisfied that this categorization was an adequate compromise between accuracy and parsimony.

The maximum potential growth rates in Table 3.4 *are reasonable.*

The growth rates appear too high, even allowing for the temperature and moisture growth constraints which are subsequently applied. The rates were set at these high levels after observing the devastating effect on plants of even moderate levels of grazing. Improvement in the translocation rules will likely allow more reasonable maximum potential growth rates to be used.

If evapotranspiration is less than 0.003 *in/wk per lb/ac of plant biomass, plant growth is constrained.*

This arbitrary method of ensuring water limitation of plant growth should be replaced by an estimate of root activity at each soil layer, which is used in the hydrology submodel's calculation of evapotranspiration.

A high biomass of plants with shallow roots can prevent water from reaching deeper layers.

This assumption has been discussed by Walker et al. (1981) as the dominant mode of competition between shrubs and grasses in semi-arid areas. It is not certain whether this mechanism also applies in the Saval Project area.

Plants and shrubs deplete carbohydrate reserves prior to seed set and replenish them afterwards. When grazing occurs prior to seed set, reserves are depleted in proportion to grazing intensity, but grazing after seed set does not deplete carbohydrates.

The stability of grazing systems generally increases with the size of plant reserves (Noy-Meir 1975). Hence, these translocation rules deserve close scrutiny, particularly the response of plants and shrubs to cropping. Though the above rules are generally supported by the literature, fall regrowth can also deplete carbohydrate reserves (Garrison 1971). The "causes" and "effects" of storage reserve depletion need further clarification.

Percent cover can be calculated from above ground biomass.

This hypothesis is discussed in detail in Section 3.4.

The actions of plowing and seeding always produce the plant composition shown in Section 3.6.

This assumption is clearly invalid. Seedling competition has very different rules from the ones used in the model for mature plants. The plant composition after seeding is also highly dependent on variations in weather.

4. HYDROLOGY SUBMODEL

The main responsibility of the hydrology subgroup was to produce a dynamic representation of soil moisture which would be sensitive to changes in the vegetative cover. In addition, it was necessary to represent water quality and flow rates in the upper Mahala and Gance creeks and produce estimates of bank stability and erosion.

Figure 4.1 represents the detailed charge of the subgroup defined during the bounding and looking outward exercises. These inputs and the required outputs define the level of abstraction of the submodel.

In view of the rapid fluctuations in rainfall and temperature it was decided that the weekly timestep used by the rest of the model would be insufficient to capture the important dynamics of infiltration and the snowpack. Therefore, a daily timestep is used within the submodel and values are averaged over weeks for use as indicators and for communicating with other submodels.

The sequence of calculations is diagrammed in the form of a flowchart in Figure 4.2. Each of these steps is explained and discussed in further detail below.

The bookkeeping for soil moisture within the model is carried out independently for each range type within each pasture. Runoffs within the Mahala and Gance basins are summed for calculation of the flow rates of the two streams at the USFS boundary.

Daily temperature and precipitation estimates form two important driving variables. In the limited time available it was felt that these were best provided by generating representative time streams and using these every year. Wetter or dryer, hotter or colder years could be simulated by adjusting the standard time stream with a suitable multiplier. Daily temperature records were available for 1980, but daily rainfall figures were only available for the second half of 1979. An artificial series was therefore generated using monthly figures.

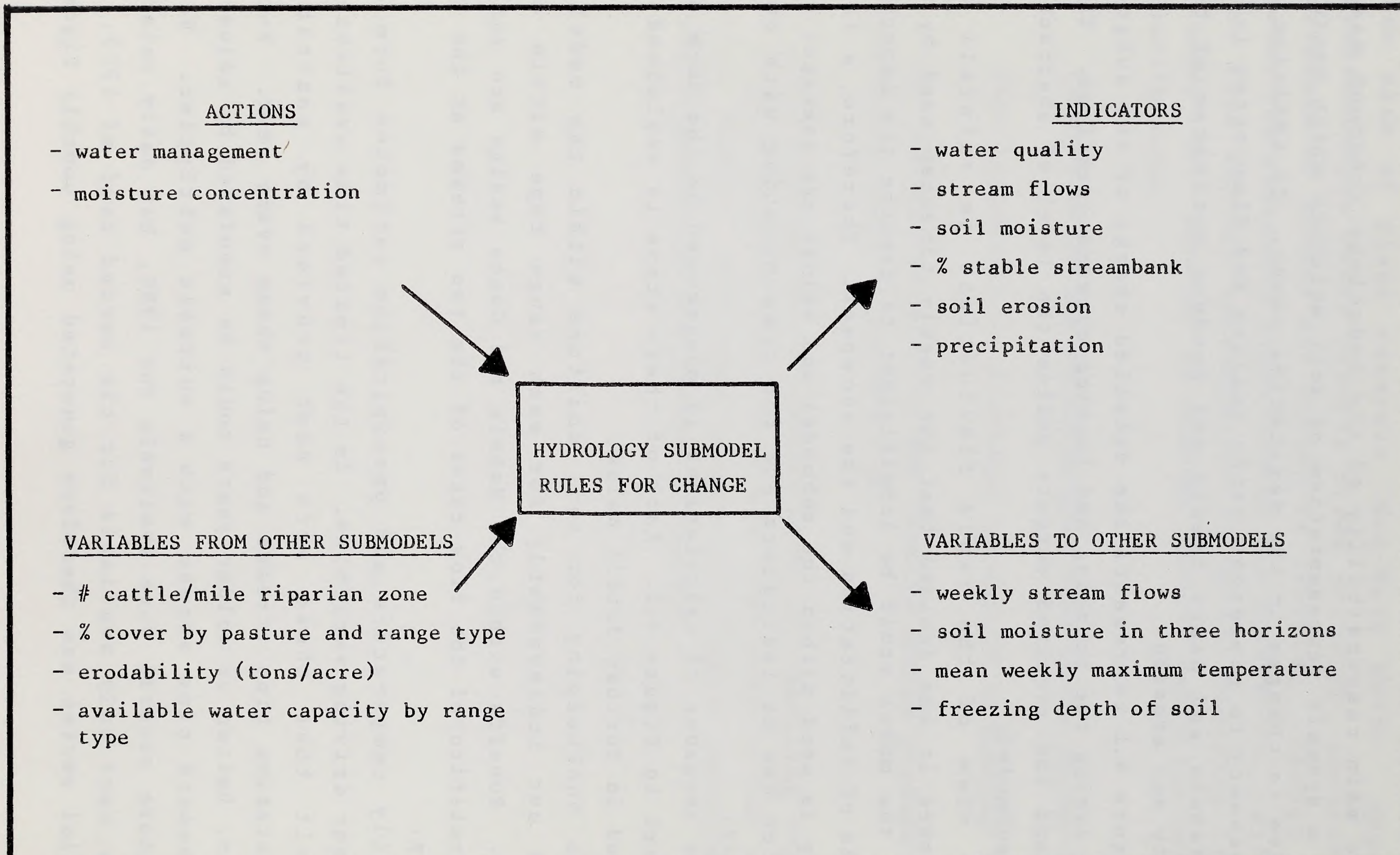

Fig. 4.1. Responsibilities assigned to the hydrology subgroup.

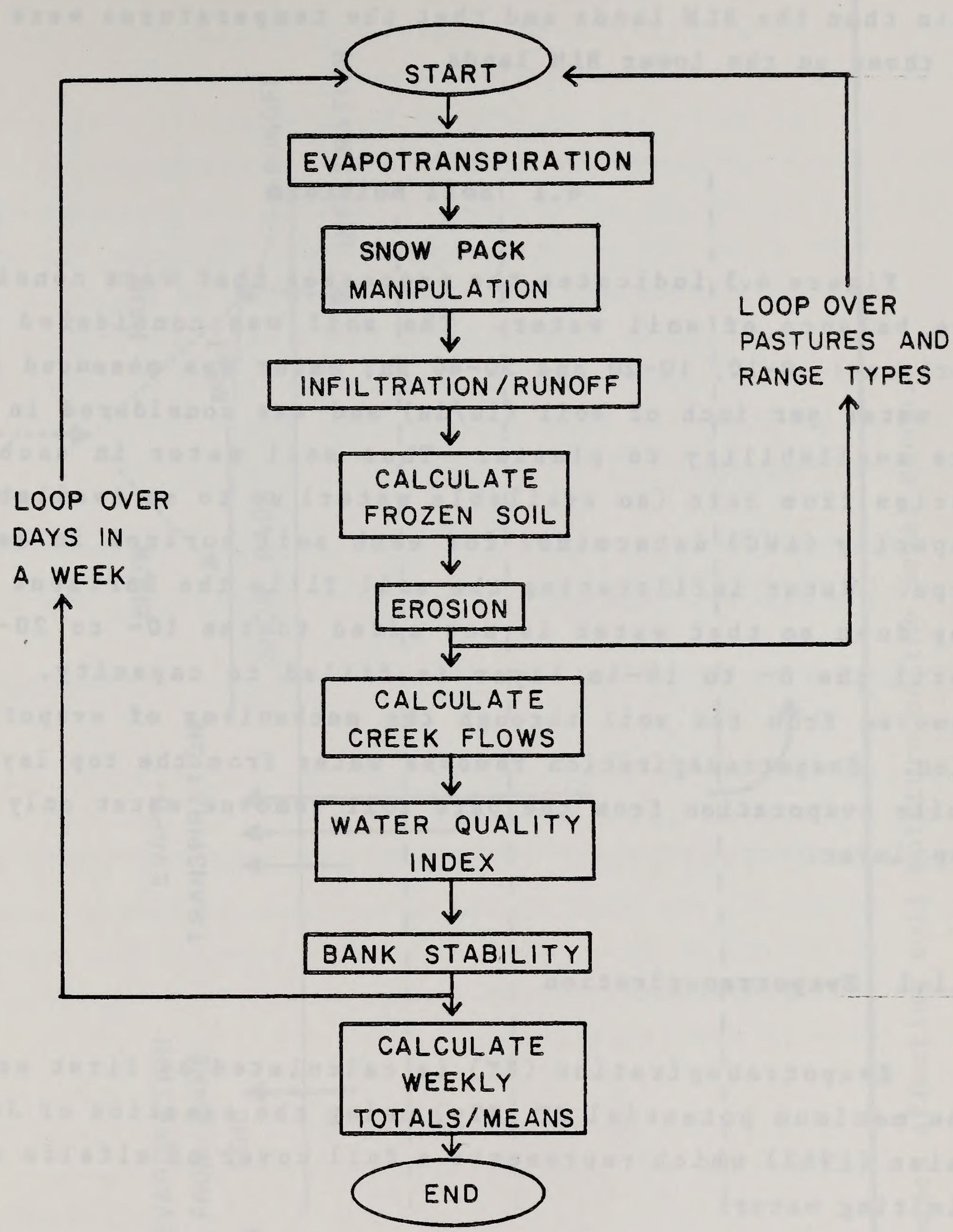

Fig. 4.2. Sequence of hydrology submodel operations.

It was assumed that the USFS pastures received 2.3 times more rain than the BLM lands and that the temperatures were only 85% of those on the lower BLM lands.

4.1 Soil Moisture

Figure 4.3 indicates the processes that were considered in the balance of soil water. The soil was considered in three horizons: 0-10, 10-20 and 20-40 in; water was measured as inches of water per inch of soil (in/in) and was considered in terms of its availability to plants. Thus soil water in each horizon varies from zero (no available water) up to an Available Water Capacity (AWC) determined for each soil horizon in each range type. Water infiltrating the soil fills the horizons from the top down so that water is not added to the 10- to 20-in layer until the 0- to 10-in layer is filled to capacity. Water is removed from the soil through the mechanisms of evapotranspiration. Evapotranspiration removes water from the top layers first while evaporation from the bare soil removes water only from the top layer.

4.1.1 Evapotranspiration

Evapotranspiration (ET) is calculated by first estimating the maximum potential ET (ETp) using the equation of Jensen and Haise (1963) which represents a full cover of alfalfa with non-limiting water:

$$ETp = (0.014 * \underset{\text{in } ^{o}\text{ Fahrenheit}}{\text{Daily mean temp}} - 0.37) * \text{Radiation}/580 \text{ in Langleys} \qquad \text{(Equation 4.1)}$$

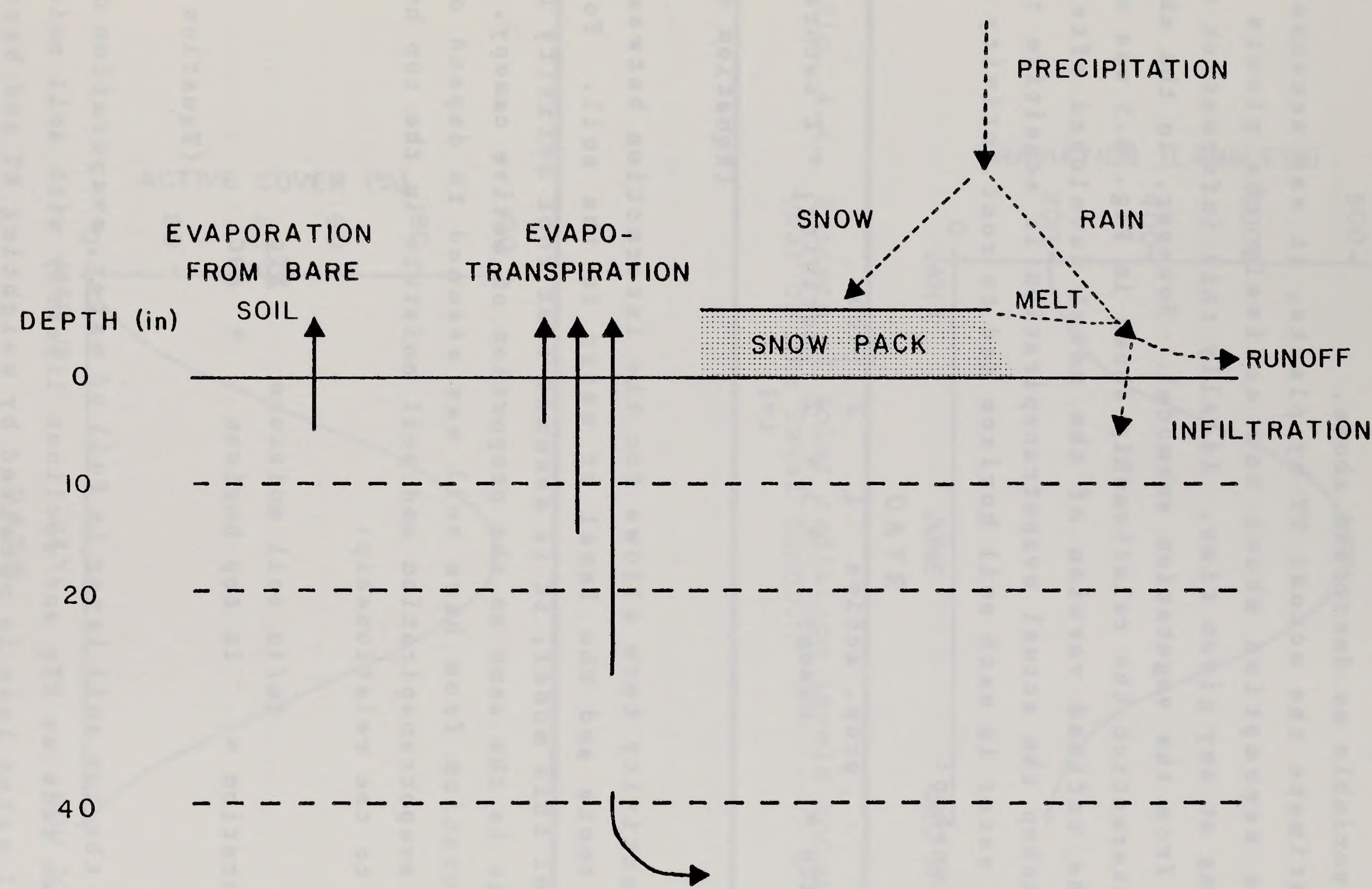

Fig. 4.3. Processes affecting soil moisture on the Saval Ranch.

The solar radiation in Langleys was assumed to follow the sine curve shown in Fig. 4.4 and daily mean temperatures were input as a driving variable as described above.

To estimate the actual ET by plants, it was necessary to make some assumption about how actively the plants were transpiring at any given time. Ideally this information would have come from the vegetation submodel. However, in the absence of this interaction the relationship shown in Fig. 4.5 was used.

In the refined version of the model developed after the first workshop the actual evapotranspiration is sensitive to the amount of water in each soil horizon and to root activity using the relationship:

$$ET = ETp * \text{prop. active canopy} * \frac{1}{3} * \sum_{i=1}^{3} \left[\text{root activity}_i * \% \text{ saturation}_i \right]$$

(Equation 4.2)

The root activity term allows for the interaction between the depth of roots and the level of water in the soil. For the purposes of this model, it is assumed that root activity in all soil levels is the same as the proportion of active canopy.

Evaporation from bare soil was assumed to depend on the potential evapotranspiration and soil moisture in the top horizon according to the relationship:

$$\text{Evaporation} = \text{in/in soil moisture in top horizon} * \frac{ETp}{AWC}$$

(Equation 4.3)

Thus when the top soil layer is full of water, evaporation occurs at the same rate as ETp and declines linearly with soil moisture.

Total water loss is obtained by weighting ET and bare soil evaporation by the relative percentages of soil surface, covered and bare respectively.

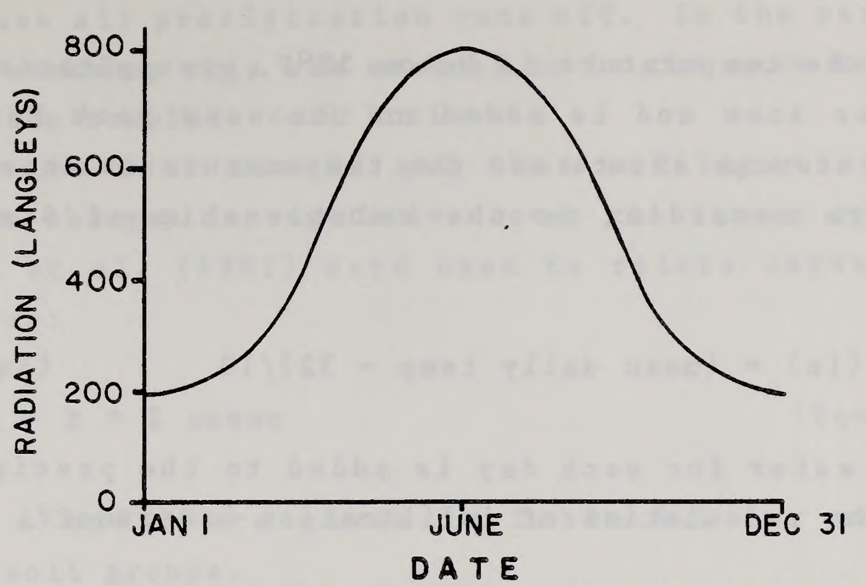

Fig. 4.4. Pattern of solar radiation levels through the year on the Saval Ranch.

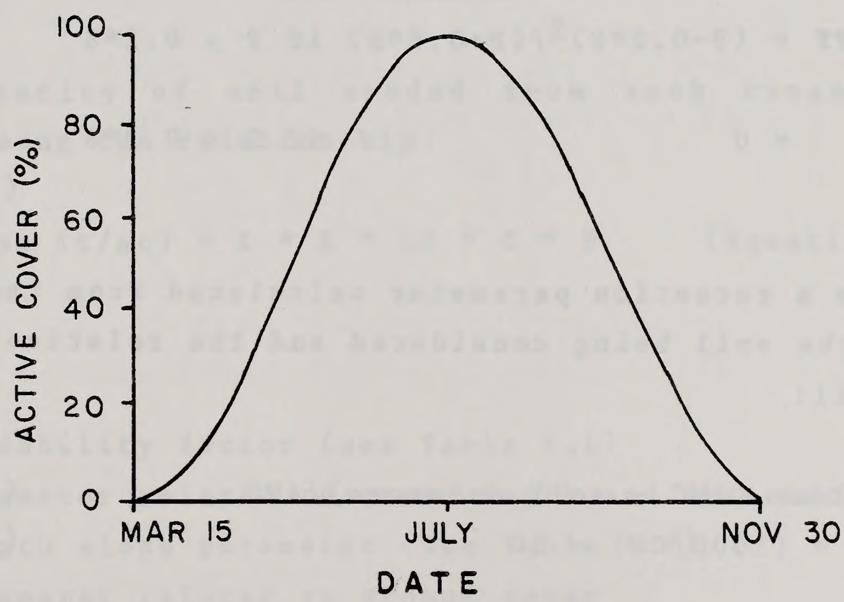

Fig. 4.5. Pattern of activity of vegetative cover through the year on the Saval Ranch in terms of effective evapotranspiration levels (maximum = 100%).

4.1.2 Snow Storage

When the temperature is below 32°F, precipitation is assumed to occur as snow and is added to the snow pack for each area. When snow storage exists and the temperature is above 32°F, snow melt occurs according to the relationship of Stewart et al. (1975):

MELT (in) = (mean daily temp - 32)/10 (Equation 4.4)

Melt water for each day is added to the precipitation and used for the calculation of infiltration and runoff.

4.1.3 Runoff and Infiltration

The calculation of runoff was based on the soil conservation service (SCS) curve number technique as described in Smith and Williams (1980). For daily precipitation (P), runoff is calculated using the relation:

$$\text{RUNOFF} = (P-0.2*S)^2/(P+0.8*S) \quad \text{if } P > 0.2*S$$

$$= 0 \quad \text{if } P < 0.2*S$$

(Equation 4.5)

where S is a retention parameter calculated from the curve number (CN) for the soil being considered and the relative water content of the soil:

$$S = Smax\ (AWC - \text{soil moisture})/AWC \quad \text{(Equation 4.6)}$$

$$Smax = (1000/CN) - 10 \quad \text{(Equation 4.7)}$$

In the version of the model produced during the first workshop only the water content of the top soil layer was considered in this calculation. Unfortunately this means that as soon as the top layer is saturated, none of the lower layers can fill, because all precipitation runs off. In the period before the second workshop this was amended to be the mean water content (in/in) of the complete soil horizon.

To ensure that runoff and thus infiltration would be sensitive to changes in vegetative cover the linear relationships of Branson et al. (1981) were used to relate curve number to percent cover:

$$CN = A - B * \% \text{ cover} \qquad \text{(Equation 4.8)}$$

Values of A and B are given in Table 4.1 for each of the hydrologic soil groups.

In the updated version of the model produced prior to the second workshop, the values shown in Table 4.2 were used.

The amount of precipitation and snow melt left over after the removal of runoff represents infiltration and is added into the soil water.

4.2 Erosion

The quantity of soil eroded from each range type was calculated using the relationship:

$$\text{Soil loss (t/ac)} = K * R * LS * C * P \qquad \text{(Equation 4.9)}$$

where:

K = erodability factor (see Table 4.1)
R = parameter related to storm depth and intensity
LS = length slope parameter (see Table 4.1)
C = parameter related to ground cover
P = mechanical factor related to soil conservation.

Table 4.1. Length slope and curve number parameters for various range types and hydrologic soil groups (first version of model).

Range type	Hydrologic soil group	Erodability	Length slope (LS)	A[1]	B[1]	
—	A		—	77	0.56	<50% cover
				63	0.28	>50% cover
Loamy slope 14-18	B	0.32	5.90	83	0.28	
Aspen woodland		0.28	1.33			
Loamy bottom	C	0.37	0.19	89	0.18	
Loamy 8-10		0.43	0.97			
Loamy 10-12		0.37	2.22			
Loamy slope 10-14		0.32	3.53			
South slope 12-14		0.28	9.75			
Wet meadow	D	0.49	0.13	91	0.13	
Claypan 10-12		0.37	1.19			
Claypan 12-16		0.37	2.57			

[1]Parameters for calculating SCS curve number based on percent cover according to:

$$CN = A - B * \text{percent cover}$$

Table 4.2. Length slope and curve number parameters for the second version of the model.

Range type	Length slope (LS)	A[1]	B[1]
Clay	4.5	83	0.28
Loam	2.8	89	0.18
Riparian	0.16	91	0.13

[1] Parameters for calculating SCS curve number based on percent cover according to:

$$CN = A - B \times \text{percent cover}$$

Assuming that storms have a two hour duration, "R" was calculated using:

$$R = 10 * \text{Total Precipitation}^{0.0374} \qquad \text{(Equation 4.10)}$$

The parameter "C" was calculated directly from percent ground cover using the relationship of Wischmeier and Smith (1978):

$$C = 10^{-0.552\ (1\ +\ 0.029\ \%\ \text{cover})} \qquad \text{(Equation 4.11)}$$

"P" was set at 1 for current purposes. Possible soil conservation actions would reduce the value of P and thus reduce soil loss.

In general then, the amount of soil lost to erosion depends on two factors; a relatively invariant set of physical parameters, and the percent cover. The effect of percent cover in any given area is shown in Fig. 4.6.

No attempt was made to determine the fate of eroded material and so there is no deposition of soil anywhere in the model.

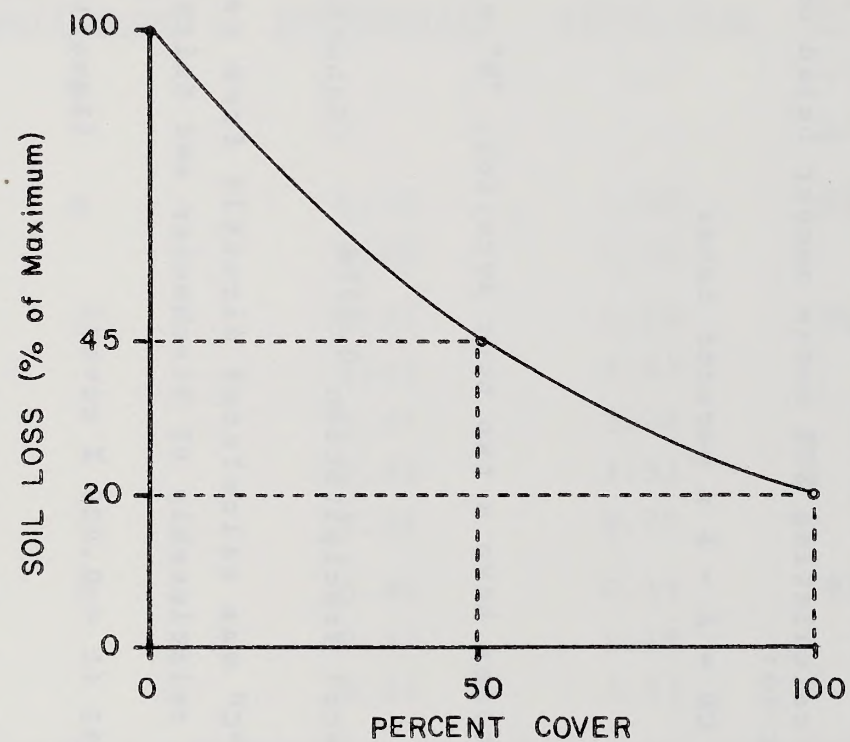

Fig. 4.6. The relationship between percent vegetation cover and soil loss on the Saval Ranch.

4.3 Freezing of Soil Water

Due to constraints of time the dynamics of the freezing of soil were not considered in great detail. The maximum depth of freezing on the ranch was considered to be 30 in with a more normal figure being 6 in. It was assumed that the soil melted and froze at the bottom at a rate of 0.1 in per degree day.

$$\text{Change in frozen depth in inches} = 0.1 * (32 - \text{Daily mean temperature } ^{o}F)$$

(Equation 4.12)

In the current version of the submodel there is no interaction between infiltration and soil freezing. It was felt that when the soil surface was frozen, infiltration would be reduced by as much as 80%. However, the chosen representation of freezing dynamics did not allow determination of the state of the soil surface.

4.4 Streamflow

The flow in the Mahala and Gance Creeks was considered down to the USFS boundary. These streams are important for hay production and their populations of cutthroat trout. The flow in the North Fork is not dependent on any processes internal to the Saval system and so was input as a driving variable.

Virtually the entire upper Mahala basin is contained within the South East Independence pasture while the portion of the upper Gance basin not in this pasture is outside the Saval boundary. Given the runoff calculations described above and the area of each range type, total runoff can be calculated for each of the basins within the Saval area (Table 4.3). The area of the Gance basin outside of the ranch is considered to have a uniform soil type and the same rainfall as the USFS pastures allowing calculation of runoff.

No attempt was made to take account of the dynamics of water within the stream bed.

Table 4.3. Areas of range types in Gance and Mahala Basins within South E. Independence Pasture.

Range type	Areas (mi^2) Upper Mahala	Upper Gance
Loamy slope 14-18	0.63	1.66
Aspen woodland	0.85	0.64
South slope 12-14	1.27	2.19
Wet meadow	0.10	0.16
Claypan 12-16	1.34	1.97

Area of Gance Basin outside Saval = 2.07 mi^2
Representative curve number = 80

4.5 Water Quality

A water quality measure is required in the model solely as an indicator of cutthroat trout habitat for the wildlife subgroup. In view of this specialized function a decision was made to only consider sediment delivered to the streams. No attempt was made to dynamically model the deposition and resuspension of sediment within the stream although the water quality index was scaled by flow rates.

Sediment delivered to streams has two components:

(1) upland erosion, and
(2) stream bank erosion.

For upland erosion the model assumes that of the total quantity of soil eroded in a watershed only a proportion (0.2) reaches the streams, the rest being redeposited.

Bank erosion is assumed to be a linear function of the number of cattle per mi in the riparian zone:

$$\text{Tons Soil Eroded/Day} = \frac{1}{500} * \text{\# cattle/mi of riparian} \quad \text{(Equation 4.13)}$$

Thus, a water quality of zero indicates crystal clear water and higher values represent higher sediment loads and lower water quality.

4.6 Bank Stability

Bank stability is considered to depend on two factors in the riparian zone: number of cattle per mi and percent cover, (Figs. 4.7 and 4.8) and are combined linearly:

$$\text{\% Stable Bank} = \text{\% Vegetative Cover} - 0.2 * \text{\# cattle/mi} \quad \text{(Equation 4.14)}$$

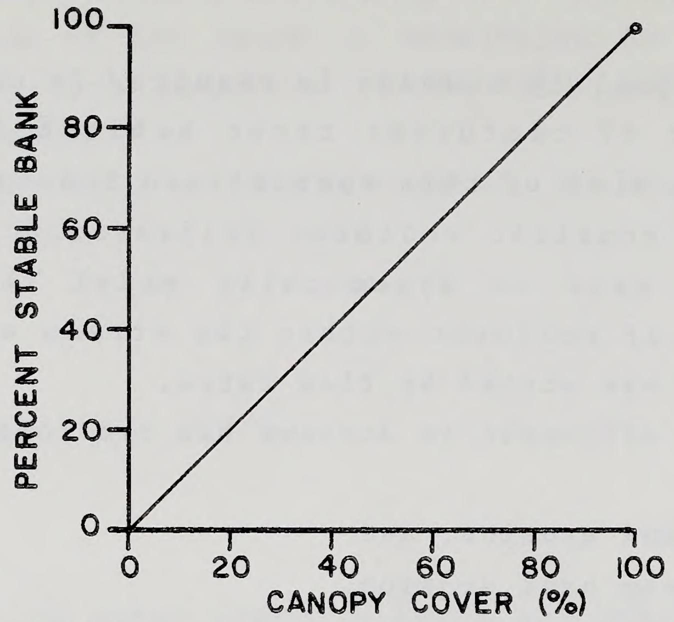

Fig. 4.7. Relationship between vegetation canopy cover and stream bank stability on the Saval Ranch when cattle are absent.

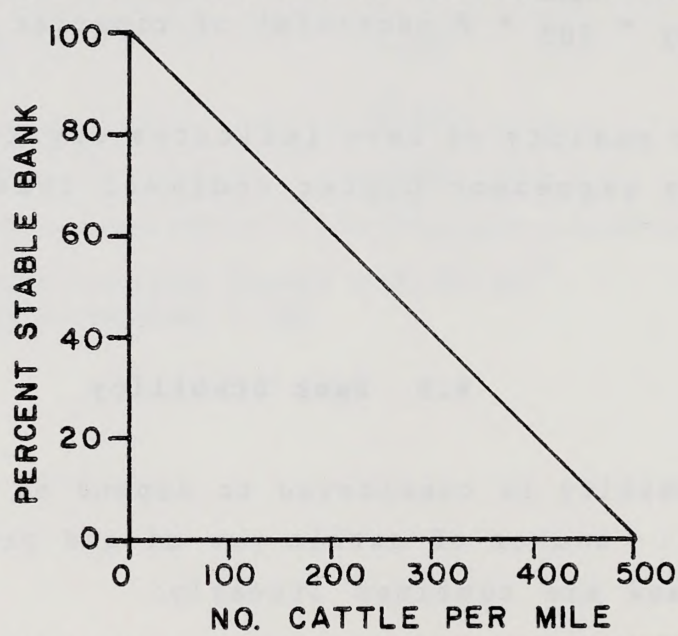

Fig. 4.8. Relationship between cattle per mile of riparian zone and stream bank stability on the Saval Ranch when vegetative canopy cover is 100 percent.

Percent vegetative cover is calculated as a weighted average of the percent covers of the various vegetation types:

$$\%\ \text{Vegetative Cover} = \frac{4 * \%\ \text{Woody Cover} + 3 * \%\ \text{Shrub Cover} + 2 * \%\ \text{Grass Cover}}{4}$$

(Equation 4.15)

This reflects the fact that woody vegetation holds the banks together best but shrubs and grass are still much better than bare soil.

4.7 Review of Submodel Structure and Hypotheses

4.7.1 Time Resolution

The one overriding feature of the hydrology submodel is its use of a daily timestep. This level of resolution was considered by the subgroup to be necessary for a reasonable representation of the important dynamics of soil moisture.

The main drawback of using a daily timestep is that it greatly increases the running time of the final model. This in turn makes gaming and manipulating the model more time consuming and expensive.

In view of the timescale of events (such as rain storms) a daily timestep is probably necessary to produce a precise prediction of soil moisture dynamics. However, because of the level of understanding of the relationships between vegetation and soil water, a cruder representation may be more useful in the framework of this model.

The possibility of using a weekly timestep was investigated using the simple APPLE microcomputer model presented at the second workshop. This produces timestreams of soil moisture that resemble those produced by the larger model suggesting that a weekly timestep is feasible.

4.7.2 Important Hypotheses

The hypotheses which relate vegetation, physical parameters such as temperature and solar radiation, and evapotranspiration and infiltration seem weak in this model. This is partly due to the poor linkage between the vegetation and hydrology submodels but there also appears to be a gap in understanding. Given the possible importance of water/plant interactions (Walker et al. 1981) this would seem to be an important place to direct field studies.

4.7.2.1 Water

Maximum potential evapotranspiration is calculated using an empirical relationship based on daily mean temperature and solar radiation.

This relationship may or may not be applicable to the Saval Ranch. Although it is largely a physical relationship, other factors such as wind and relative humidity are not considered.

Evaporation from bare soil is the maximum potential evapotranspiration reduced in proportion to the percent saturation of the top soil layer.

This would seem to be qualitatively correct. If the top soil is dry then there will be minimal evaporation and if there are pools of water on the surface then evaporation will occur at some maximal rate. It seems likely that there is information in the literature on the maximal rate and the form of the intervening curve.

Evapotranspiration by plants is the maximum potential evapotranspiration reduced as a function of the activity of the canopy *and (in the second version of the model) the soil moisture content and root activity in each horizon.*

This linkage between vegetation and evapotranspiration is weak and needs to be reconsidered. At present, the percent active canopy and root activity figures are created in the hydrology submodel completely independently of the state of the vegetation. The simplest way to improve this relationship would be for the vegetation submodel to calculate root activities in each soil horizon based on the composition of the vegetation.

Water is added to the soil by infiltration and fills the horizons from the top down.

This seems reasonable although it seems probable that lower horizons start to fill before the upper ones are completely saturated.

Curve numbers used to calculate infiltration rate are linear functions of percent cover.

This is almost certainly incorrect but was the simplest way to include a perceived effect of percent cover on infiltration. Better relationships may be available in the literature but it seems likely that field studies will be necessary if this is to be improved on.

Water is removed from the soil by evapotranspiration from the top down.

This hypothesis is all right as a first approximation but it reflects the lack of linkage with the vegetation submodel.

Water does not diffuse between soil horizons in the unsaturated state.

This is a commonly made assumption in hydrology models and does not seem to lead to large problems.

Streamflow is the sum of all runoff in a given watershed.

This hypothesis should give a qualitatively correct picture of variations in streamflow. But the absence of any subsurface flow and interchange with the stream bed results in a more variable flow than that observed.

The snow pack melts at the rate of 1/10 *in for every degree day above freezing.*

This estimate is probably not accurate due to the effects of other factors, particularly rain. There is not however a high priority to improve this as the effect on the model would not be great.

The presence of frozen soil has no effect on the infiltration rate.

This is obviously false but to model this better requires a more accurate representation of the way in which soil moisture freezes, especially at the surface.

4.7.2.2 Soil

Soil loss in t/ac is a function of the percent cover and the physical characteristics of a particular area.

The applicability of this relationship to the Saval Ranch is unknown. It seems likely that the species composition of the vegetation may be important as well as the percent cover. (The percent cover vs. C factor values and subsequent relationships were derived from data for pasture and rangeland as a lumped land type. The values were for a vegetation canopy of "tall weeds or short brush with average drop-fall height of 20 inches".)

The fate of eroded material not delivered to streams (a constant proportion) is not considered.

No attempt was made to model the transport of eroded material as the quantities involved were not considered to be significant.

Bank stability is a simple function of percent cover (weighted so that woody plants are more effective) and number of cattle in the riparian zone.

This relationship is almost certainly too simplistic and should be looked at in more detail. The vegetation information should be either available or easily collected, but the trampling effects due to animals are much more in question. Number of cattle per mi is not the only variable--season of use and duration of use are likely to be very important.

5. LIVESTOCK AND ECONOMICS SUBMODEL

The livestock and economics subgroup was responsible for:

(1) developing a conceptual framework relating range conditions and winter food supply to livestock growth and reproduction; and

(2) using these dynamics of livestock production plus costs of management actions taken in all submodels to examine the economics of the Saval Ranch operation and some economic considerations pertaining to Elko County (Fig. 5.1).

The submodel had to be able to mimic the cattle movements specified in the Saval Management Plan but also had to be sufficiently flexible to mimic any other grazing system participants might wish to simulate.

The livestock population is divided into three subpopulations: cows, calves, and yearlings. The subgroup did not have time to consider the consequences of stocking other domestic animals, other breeds of cattle, or salting as a means of livestock distribution control. The group considered the county economic effects of hunting effort on the Saval Ranch but did not incorporate the rules for change into the model because the wildlife subgroup only considered effects of constant hunting effort.

5.1 Cattle Movement

A major objective of the subgroup was to simulate movement of the cattle on the Saval project area according to alternative 2 in the Management Plan and yet maintain enough flexibility to ensure the model could be used to mimic other realistic grazing schemes. The Management Plan grazing schedule is shown in Table

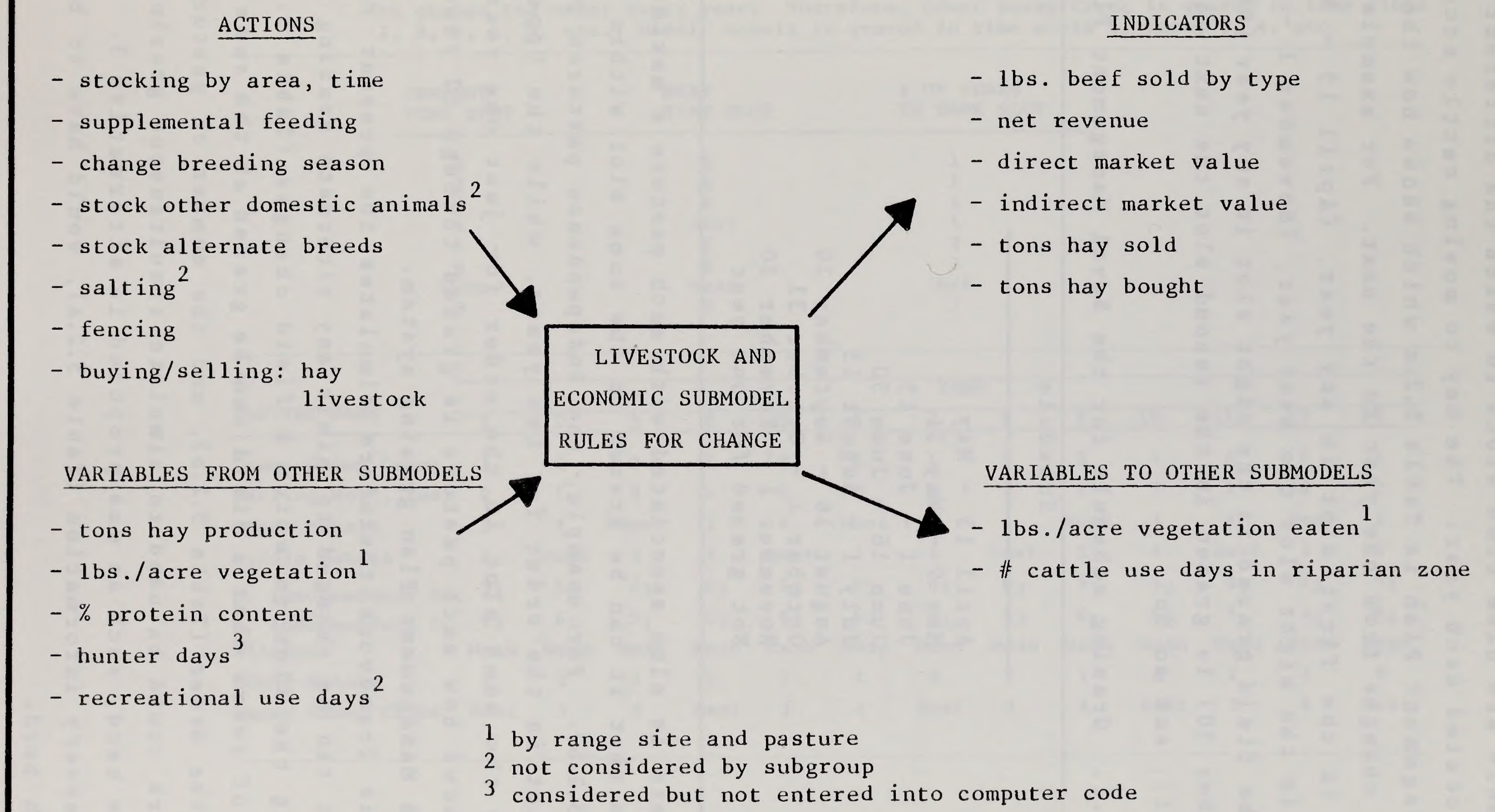

Fig. 5.1. The responsibilities of the livestock and economic subgroups.

5.1. There are nine time slots to which the different pastures are allocated each year. The key to moving cattle according to the Management Plan is Table 5.2.a which shows how the order of grazing changes from one year to the next. For example, a field grazed in the first slot in any year, (April 15 - May 8) is grazed in the eight slot the next year, (November 1 - November 30). The field grazed in the eight slot in any year (November 1 - November 30) is grazed in the second slot the next year (May 9 - May 31), and so on.

Table 5.1. Grazing schedule for the Saval Management Plan.

Slot	Schedule	# weeks
1	April 15 - May 8	3
2	May 9 - May 31	3
3	June 1 - June 15	2
4	June 16 - June 30	2
5	July 1 - August 15	6
6	August 16 - September 30	6
Wean	October 1 - October 31	4
8	November 1 - November 30	4
Rest	Not grazed for one year	-

There is also associated with each pasture a maximum number of years that it can be grazed in the same slot within the order (Table 5.2.b). For example, the Independence pastures retain the same slot in the order for two years, while the Upper Mahala retains the same slot in the order for just one year. Table 5.2.b shows how each pasture is grazed through 12 years of the accepted Management Plan grazing system.

This framework therefore simulates the present Management Plan but can be changed to mimic any alternate grazing system by changing the slot to which a field changes (Table 5.2.a), the number of years that a field can be grazed at the same position within the order (Table 5.2.b), and the number of pastures. This framework could be used to simulate simultaneous grazing by more than one herd, such as was proposed in alternative 3. To do so, the necessary information (Table 5.2.a), would have to be derived for each herd.

Table 5.2. The simulation of the Saval grazing system: a) algorithm for determining grazing sequence for consecutive years, b) a 12 year grazing pattern. The pastures in the left are grazed in the order listed along the rows. The table in (A) below is used to change the order every year. Therefore, Lower Sheep Creek is grazed in time slots 1, 8, 2, 1, 8, etc., Middle Mahala is grazed in time slots 4, rest, 3, 4, etc.

a.

CURRENT TIME SLOT	NEXT TIME SLOT	# OF YEARS IN SAME SLOT
1	8	1
2	1	1
3	4	1
4	Rest	1
5	6	2
6	5	2
Wean	Wean	N/A
8	2	1

b.

PASTURE NAME	YEAR 1	2	3	4	5	6	7	8	9	10	11	12	13
Lower Sheep Creek	1	8	2	1	8	2	1	8	2	1	8	2	1
Darling West, East	2	1	8	2	1	8	2	1	8	2	1	8	2
Upper Mahala	3	4	Rest	3	4	Rest	3	4	Rest	3	4	Rest	3
Middle Mahala	4	Rest	3	4	Rest	3	4	Rest	3	4	Rest	3	4
E. Independence N.	5_1	5_2	6_1	6_2	5_1	5_2	6_1	6_2	5_1	5_2	6_1	6_2	5_1
E. Independence S.	6_1	6_2	5_1	5_2	6_1	6_2	5_1	5_2	6_1	6_2	5_1	5_2	6_1
Allaback	Wean	Wean	Wean	Wean	Wean	Wean	Wean	Wean	Wean	Wean	Wean	Wean	Wean
Lower Mahala	8	2	1	8	2	1	8	2	1	8	2	1	8
Upper Sheep Creek	Rest	3	4	Rest	3	4	Rest	3	4	Rest	3	4	Rest

The actual Management Plan is flexible in the timing of cattle movement to and from pastures (i.e., ± one week). Participants stated this was designed to prevent over- or under-utilization of pastures. Cattle are usually moved after approximately 50% utilization of the preferred plant types (perennial decreasers, forbs) has been reached. There was insufficient time during the workshop to include this state-dependent rule to determine cattle movement and the model presently considers the schedule in Table 5.1 as fixed.

5.2 Feeding

5.2.1 Forage Selection

There was considerable discussion in the subgroup about how cattle feeding is influenced by availability of different types of forage, availability of water and the interrelation of these two factors. Two extreme hypotheses were proposed:

(1) water availability is the dominant factor and cattle will consume low quality food near a water source before moving far from the water; and

(2) availability of good forage is the dominant factor and cattle will roam far from a source of water in search of highly-preferred food types.

The first hypothesis (hypothesis 1) was implemented in the model during the first workshop. Discussions later in the workshop revealed that an intermediate hypothesis (hypothesis 3) is probably more realistic; cattle will search far from water for preferred forage but will stay near water and feed on unpreferred forage if preferred forage is not available anywhere. This hypothesis was implemented between the first and second workshops. Either hypothesis can be used when executing the model.

Currently, the submodel considers two forage classes within each forage type: forage "near" water (within 1/2 mile of a water source) and forage "distant from" water. For each pasture participants estimated the percentage of forage "near" water (Table 5.3). This percentage is assumed to be the same for all range sites within each pasture, an invalid assumption for extremes such as riparian and south slope sites. Management actions such as construction of stock ponds, irrigation systems, and actions that change the land area cattle find near water, can therefore be crudely simulated by changing the percentages of land near water.

Table 5.3. Percentages of pastures classified as "near" water for cattle. The percentages are assumed the same for all range sites within the pasture.

Pasture	% Pasture "near" water
Darling West	100
Darling East	100
Lower Mahala	100
Middle Mahala	100
Upper Mahala	100
Lower Sheep Creek	50
Upper Sheep Creek	65
East Independence North	80
East Independence South	65

The distribution of grazing within a pasture is determined by three factors: range site, food preferences, and nearness to water. Under hypothesis 1, cattle attempt to meet all their nutritional requirements on particular food types, range sites, and nearness to water, following a preference order structured within each category (Table 5.4). Residual nutritional requirements are met on the next preferred combination of food types, range sites, and nearness to water. That is, any residual nutritional requirements will be met by changing distance to

Table 5.4. Cattle preferences for plant types, water availability, and range sites. It is assumed that cattle will graze first on the most preferred combination of the three selection factors.

Plants	Water	Range Sites
1. Perennial grass decreasers		I. Wet meadow
2. Forbs	A. Near water	II. Aspen woodland
3. Cheatgrass	B. Distant from water	III. Loamy bottom
4. Perennial grass increasers		IV. Loamy 8-10
5. Bitterbrush		V. Loamy 10-12
6. Other Shrubs		VI. Claypan 10-12
7. Sagebrush		VII. Claypan 12-16
		VIII. Loamy slope 10-14
		IX. Loamy slope 14-18
		X. South slope 12-14

water first, plant type second, and range site last. This implies that cattle will stay on a particular range site and feed on all plant types near and distant from water before moving to another range site within that pasture.

There are obvious inconsistencies in this conceptualization. For example, the proportion of range sites near to water is not constant across all range sites. Also, cattle are likely to select on the basis of nearness to water or food preferences, rather than range site. The fact that cattle appear to select riparian range sites over others is probably due primarily to proximity to water, rather than the kind of vegetation found in a riparian zone. Another problem is that cattle were assumed to first try to meet all their requirements on the most preferred forage irrespective of the abundance of the forage, then all their residual requirements on the next most preferred, again irrespective of forage abundance and so on. It is more probable that cattle selection is made according to both relative abundance and simple preferences.

In hypothesis 3 cattle selection is made according to both forage abundance and simple forage preferences. The model used is drawn from predation research (Holling 1959, Charnov 1973). The formulation given below calculates the biomass of each forage consumed by cattle given cattle intake rates, and forage preferences and relative forage abundances:

$$E_{i,j} = \frac{\dfrac{a_{i,j}P_{i,j}F_iC_j}{L}}{1 + \sum_{n=1} a_{n,j}P_{n,j}F_n h_{n,j}} \qquad \text{(Equation 5.1)}$$

where:

- $E_{i,j}$ = the biomass of forage type i consumed by cattle type j (lb/ac)
- F_i = forage biomass (lb/ac)
- C_j = # cattle of type j/ac
- $P_{i,j}$ = preference by cattle type j for forage type i
- L = total number of forage types
- $h_{n,j}$ = the # weeks required to digest and process a pound of forage type n by cattle type j (the inverse of the weekly maximum intake rate)
- $a_{i,j}$ = the rate of effective search by cattle type j on forage type i (i.e., the area of ground animals cover in a week)

There are 42 different forage types: 7 forage species over 3 range sites over 2 water availability types. The preferences given in Table 5.5 are estimates made without consultation of grazing experts and likely bear no resemblance whatsoever to the

Table 5.5. Preferences by cattle (all types) for forage species, range sites and water availability for the alternate feeding model developed between workshops. The preferences are directly proportional, i.e., forage near water is twice as preferred as forage distant from water.

Forage type	Preference	Range site	Preference	Water Availability	Preference
Bitterbrush	0.1	Clay	1	Near	2
Other shrubs	.05	Loamy	2	Distant	1
Sagebrush	.05	Riparian	3		
Forbs	.2				
Perennial grass decreasers	.3				
Perennial grass increasers	.1				
Cheatgrass	.2				

real world. These preferences are assumed fixed throughout a year. This assumption may be invalid; some participants stated at the second workshop that preferences for the plant types changed through a season. The rate of effective search was set to 126 ac/wk for all cattle types. (This assumes cattle travel 5 mi per day and are able to begin recognizing different plant types at a distance of within 30 ft.)

The form of equation 5.1 is given in Fig. 5.2. Cattle switch between forage types as their relative availabilities change.

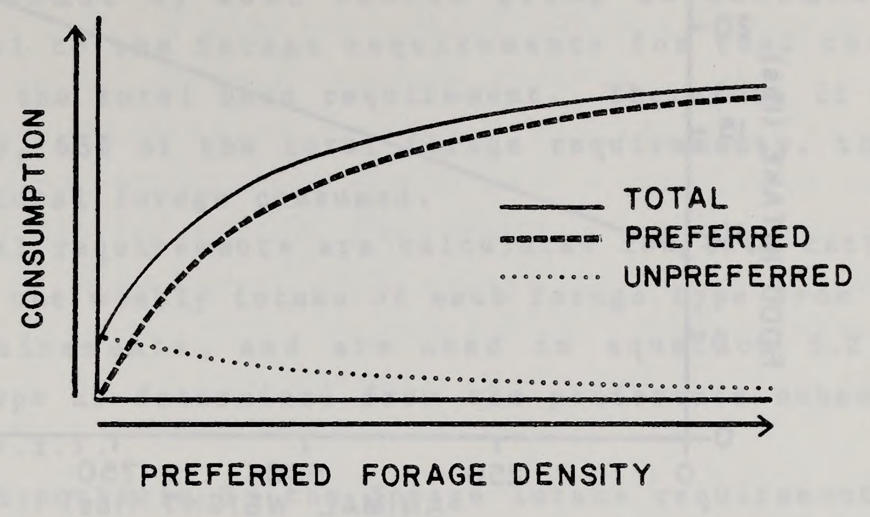

Fig. 5.2. Form of the cattle feeding response curves developed after the first workshop. Cattle are hypothesized to switch between forage types according to both relative preferences and availabilities.

5.2.2 Forage Consumption

Under both hypotheses, the consumption of forage is simulated by assuming cattle have a size dependent forage intake requirement (Fig. 5.3). This function does not take into account the observation of participants that food intake is also mediated by forage quality. Cattle can process a fixed amount of fiber per day, so that intake of high fiber food is lower than low fiber food. The simulated calf population feeds independently of the mother cows throughout the time on the range. (This is an invalid assumption for approximately the first four months of the calves' lives; during that time they gain their nourishment directly from the mother.)

Under hypothesis 1, the total daily intake requirement is multiplied by the days per week and number of cattle in each type and then summed over the three cattle types to give a total weekly intake requirement for the herd. The total intake is then

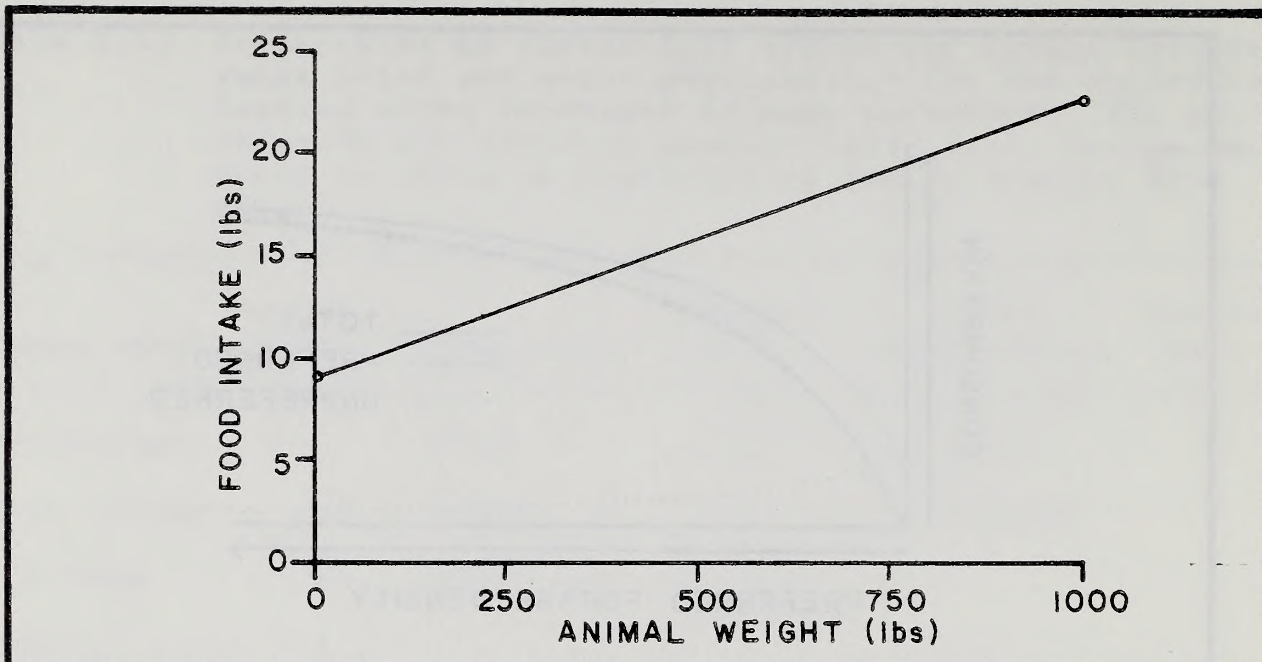

Fig. 5.3. Relationship between animal (cattle) weight and daily food intake. Food intake is the amount of food an animal of a given size can process in a day.

modified by the biomass of the most preferred forage type to ensure actual forage intake never exceeds the forage biomass available. The following is used to compute actual forage intake:

$$EAT_i = F_i \left[1 - e^{-\left(\frac{R}{F_i}\right)} \right] \qquad \text{(Equation 5.2)}$$

where:

R = total weekly herd requirements (lb/ac)

F_i = biomass of forage type i (lb/ac)

EAT_i = biomass of forage type i eaten (lb/ac) by all cattle

R/F_i is essentially the instantaneous mortality rate of forage type i from cattle feeding and the terms inside the brackets represent the weekly mortality rate of forage from cattle feeding

(Fig. 5.4). The forage eaten (EAT_i) is then allocated back to daily realized intakes per animal for each cattle type. The forage consumed by each cattle group is assumed directly proportional to the forage requirements for that cattle group relative to the total herd requirement. Therefore if adult cows require, say, 63% of the total forage requirements, they receive 63% of the total forage consumed.

Residual requirements are calculated for each cattle type by subtracting the weekly intake of each forage type from the weekly intake requirements, and are used in equation 5.2 on the next preferred type as determined from the preference scheme outlined in Section 5.2.1.

Under hypothesis 3, the forage intake requirement from Fig. 5.1 is used to calculate h in equation 5.1 (e.g., if a cow requires 100 lb of forage per wk, it will take her, on average, 1/100, or 0.01 wk to consume 1 lb of forage). $E_{i,j}$ (equation 5.1) is then calculated for each forage type and each cattle type, given forage preferences and rates of effective search. EAT_i is then calculated using an analogue of equation 5.2:

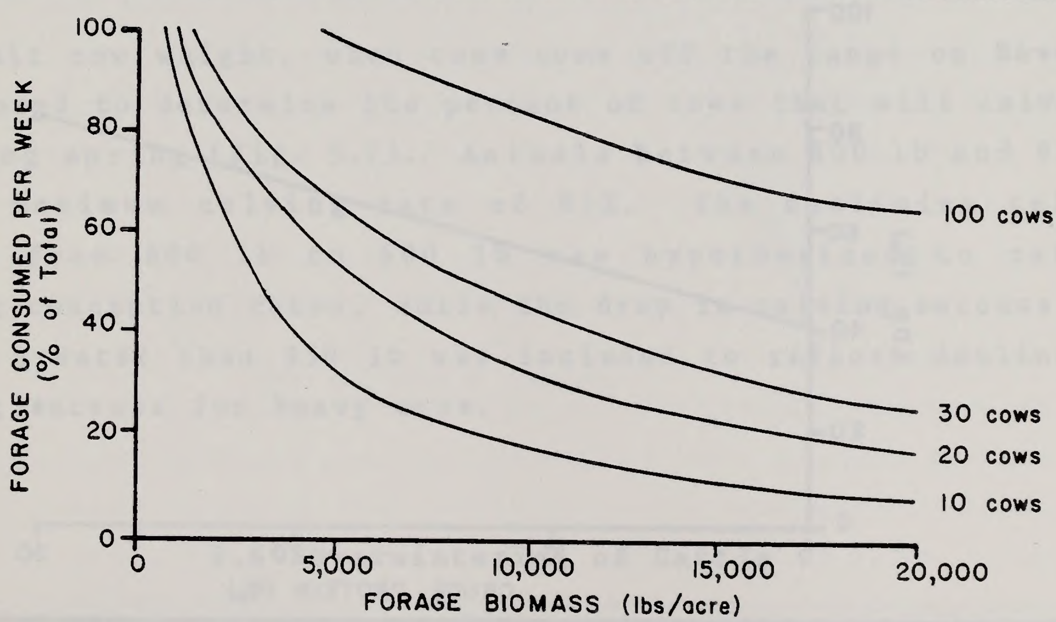

Fig. 5.4. Relationship between forage biomass available and percent utilization of forage. The equation assumes no waste, such that all the forage utilized is consumed by cattle.

$$EAT_i = F_i \left[1 - e^{-\left(\frac{\sum_{j=1}^{3} E_{i,j}}{F_i} \right)} \right] \qquad \text{(Equation 5.3)}$$

EAT_i is then allocated back to daily realized intakes per animal for each cattle type in the same manner as in hypothesis 1. Under hypothesis 3, equations 5.1 and 5.3 are used for each forage type to calculate forage lost by consumption and realized forage intake for each cattle type.

5.3 Cattle Growth

Forage biomass consumed by cattle is converted to total digestible nutrients (TDN) by assuming the relationship between protein content and TDN in Fig. 5.5. This function, which is assumed to be the same for all forage types, probably varies between different types of forage.

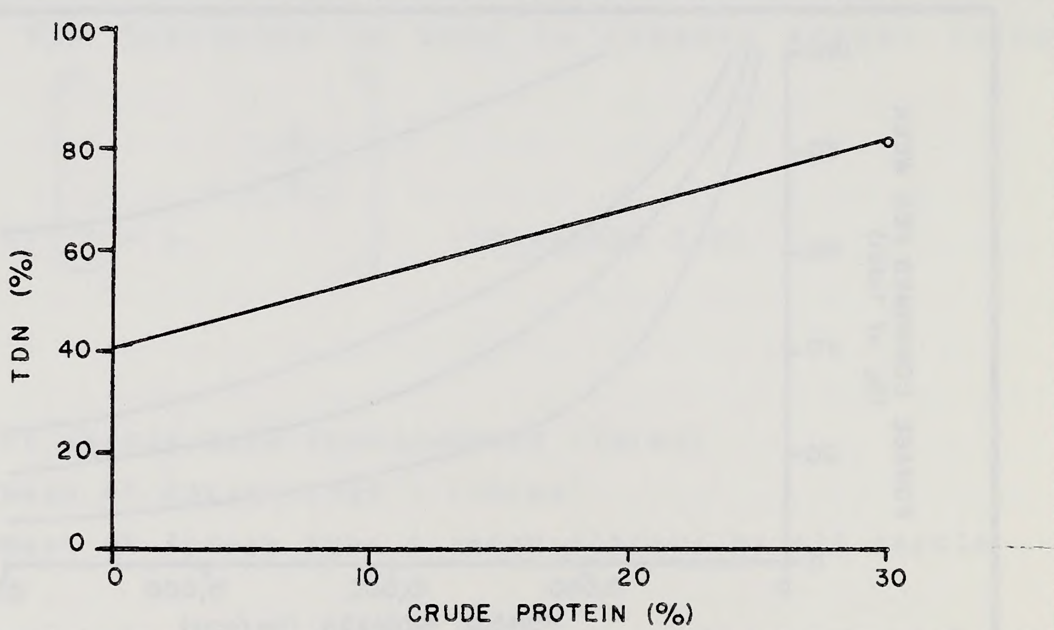

Fig. 5.5. Relationship between percent crude protein content of food and percent total digestible nutrient content. All seven food types were assumed to have the same relationship.

In the first workshop, the total weekly weight gain was calculated from the sum of the total weekly TDN consumption (Fig. 5.6). Note that cattle can lose weight with inadequate forage consumption. Also, a smaller animal needs to consume less TDN than a large animal to gain the same weight.

5.4 Fall Sales

In the fall, all yearlings and 80% of the calves are sold. The remaining calves are retained over the winter and become adult cows the following spring.

The sale of adult cows assumes the Saval Ranch has a fixed number of adult cattle it can graze on the range which is set by allowable animal unit months (AUMS). This number is maintained by buying or selling adult cows. Currently the ranch target is set to 1500. Therefore, if the number of adult cows plus calves retained exceeds the target then the excess cows will be sold.

5.5 Calving

Adult cow weight, when cows come off the range on November 30, is used to determine the percent of cows that will calve the following spring (Fig. 5.7). Animals between 800 lb and 950 lb have a maximum calving rate of 85%. The declining calving success from 800 lb to 600 lb was hypothesized to reflect changing conception rates, while the drop in calving success with weights greater than 950 lb was included to reflect declines in birthing success for heavy cows.

5.6 Overwintering of Cattle

The cattle the ranch keeps over winter are assumed to be maintained strictly on hay, either grown on the Saval hay

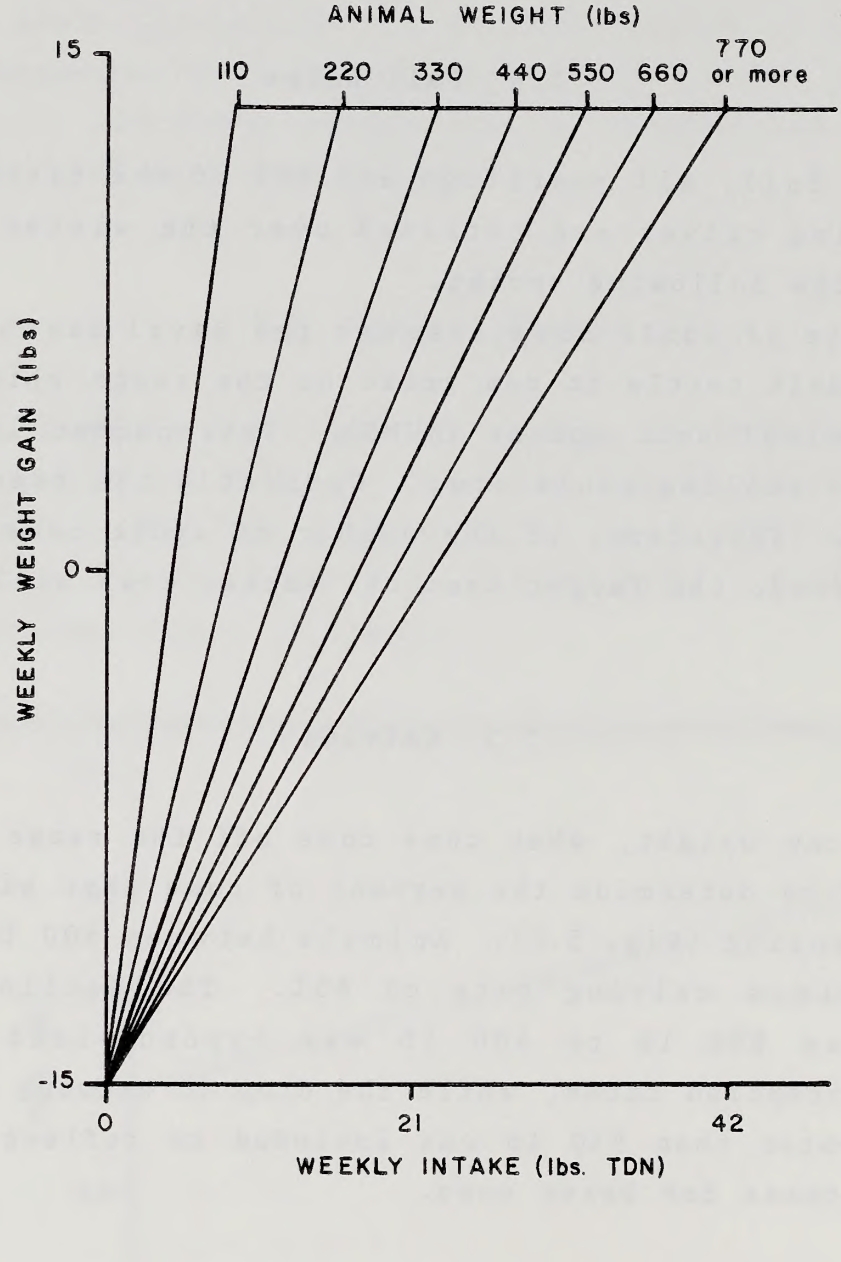

Fig. 5.6. Relationship between weekly consumption of total digestible nutrients and weekly weight gain by different weights of cattle.

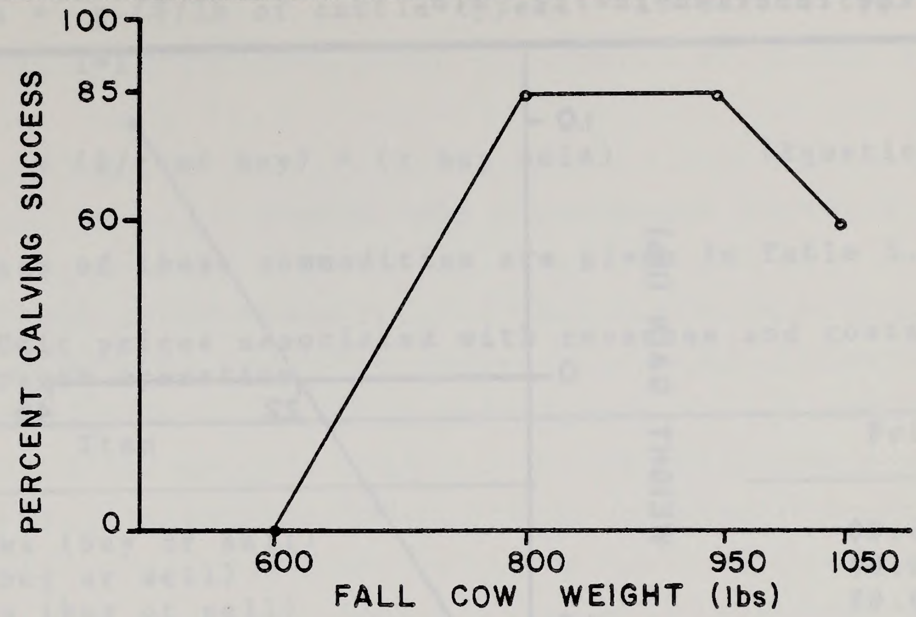

Fig. 5.7. Relationship between fall cow weight and calving success the following spring. Small cows have low conception rates; large cows have greater birthing problems.

meadows, or bought. (This is not what actually happens; more nutritious food, such as cottonseed cake, is often fed to pregnant and poorly-conditioned animals over the winter period.) The winter hay required by a cow for maintenance is calculated using the intake function described earlier (Fig. 5.3). It was assumed that the ranch operators would attempt to bring cattle weights over winter to a target weight (currently set to 700 lb for adult cows and unsold calves) in the spring when they were turned out to the range. It was further assumed that it would take 15 lb of hay over and above the maintenance ration (Fig. 5.3) to gain a lb of weight. The total winter hay required is therefore the maintenance ration plus any weight gain ration required. The user of the model has the option of buying all, part, or none of the deficit in hay supplies if ranch hay production is insufficient to meet total winter hay requirements. Any excess hay produced on the ranch is considered sold.

The growth of cattle over the winter period is calculated using the function in Fig. 5.8.

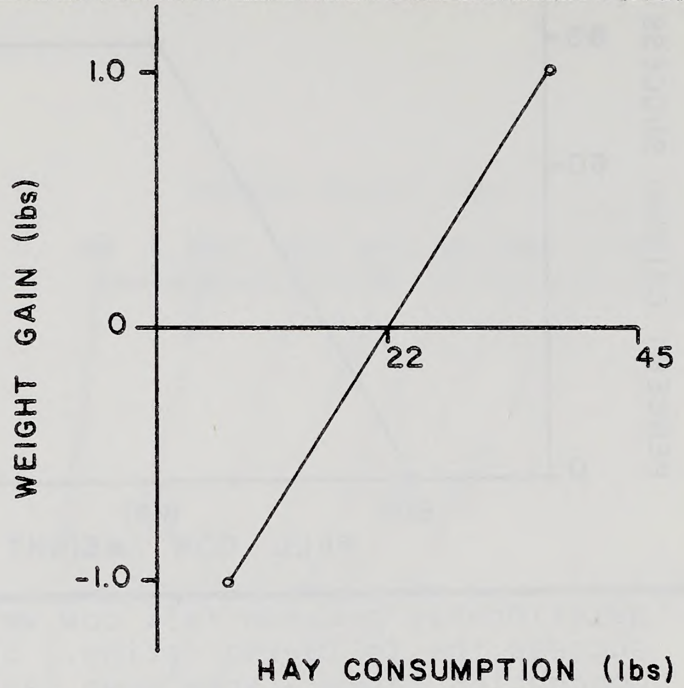

Fig. 5.8. Relationship between average daily hay consumption over the winter period and the average daily weight gain per cow over the winter period.

5.7 Economics

The subgroup used the dynamics of cattle production as a basis to simulate the economics of the ranch operation, and then used ranch revenues and costs to consider some aspects of the effect of the Saval Ranch operation on the economy of Elko County.

5.7.1 Ranch Revenues

Ranch revenues are assumed to come only from cattle and hay sales:

$$\text{Revenues} = \sum_{i=1}^{3} (\$/\text{lb of cattle type } i * \text{lb cattle type sold})$$

$$+ (\$/\text{t of hay}) * (\text{t hay sold}) \qquad \text{(Equation 5.4)}$$

The unit prices of these commodities are given in Table 5.6.

Table 5.6. Unit prices associated with revenues and costs of ranch operation.

Item	Price
A. Adult cows (buy or sell)	$0.40/lb
B. Calves (buy or sell)	$0.60/lb
C. Yearlings (buy or sell)	$0.63/lb
D. Hay sold	$60/t
E. Hay bought	$46/t
F. Growing hay	$30/t
G. Improving water availability to cattle	$5/ac
H. Plowing and seeding	$40/ac
I. Fertilizing	$12/ac
J. Fencing	$2500/mi
K. Chaining	$15/mi
L. Burning	$2/ac
M. Spraying and reseeding	$24/ac

5.7.2 Ranch Costs

Ranch costs were calculated using the following:

$$\text{Total Costs} = \text{fixed costs} + \left(\text{cost of keeping 1 head of cattle} * \text{\# head of cattle}\right)$$

$$+ \left(\text{unit costs for each management action} * \text{units of each management action taken}\right) \qquad \text{(Equation 5.5)}$$

The unit costs of management actions are given in Table 5.6. The fixed costs were assumed to be $250,000 and the cost of keeping one head of cattle was set at $60.

The net income for the ranch was therefore:

$$\text{Net Income} = \text{Revenues} - \text{Total Costs} \qquad \text{(Equation 5.6)}$$

5.7.3 Economic Benefits to Elko County

Three economic indicators were calculated from the economics of the ranch operation. The calculations were considerably simplified by the assumption that all commodities sold by the ranch are exported out of the country. The indicators are all a function of something called "ranch purchases", which is defined as those expenditures made by the ranch within Elko County. In the model:

$$\text{Ranch Purchases} = \text{Total Variable Costs} + \left(.05 * \text{Fixed Costs} \right) \qquad \text{(Equation 5.7)}$$

The three economic indicators were generated as follows:

$$\text{Gross Values of County Output} = 2.5 * \text{Ranch Purchases} \qquad \text{(Equation 5.8)}$$

$$\text{Ranch Value Added} = 0.15 * \text{Ranch Purchases} \qquad \text{(Equation 5.9)}$$

$$\text{County Value Added} = 0.4 * \text{Gross Value of County Output} \qquad \text{(Equation 5.10)}$$

The multipliers were estimated from economic input/output models of similar, but not identical, situations in eastern Oregon.

5.8 Analysis of Range Utilization Effects on Cattle Growth

The cattle feeding and growth equations are the core to the submodel, for they link forage production and range land management actions to beef production and range revenues. The interaction and consequences of the feeding and growth processes can be investigated by looking at "isoweights" for cattle as functions of forage availability or protein content (Figs. 5.9, 5.10). The model was used to calculate, for weights ranging from 440 lb to 800 lb, the level of either forage or protein required to keep cattle at that weight. These "isoweights" were calculated over a period of one day; forage dynamics can therefore be assumed constant.

Figure 5.9 shows these isoweights as a function of forage availability for different protein contents. As an example of how these graphs can be used, consider cattle weight gain on forage with a protein content of 9%. Cattle could never grow above about 680 lb with this diet. As the protein content of the food increases, less forage biomass is required to maintain or gain up to 770 lb.

Figure 5.10 is a series of isoweights as a function of protein content for a series of forage biomasses. The vegetation submodel assumed all forage types have a protein content of 15% in the spring; all shrubs decrease to 10% and all other forage types decrease to 3% in the fall. A diet of anything less than about 5% protein, irrespective of forage availability, is disastrous. This implies that without shrubs in the fall, cattle would lose weight because the quality of all other forage types is too low to sustain any weight. Also, as long as forage biomass remains relatively high and protein content remains above 5%, 70%-85% calving rates can be achieved. Over about 70 lb/ac, (and 9%-15% protein content), change in forage biomass is relatively unimportant in affecting calving rate. It is only when forage biomass decreases to low levels that changes in quality of the forage strongly influences calving.

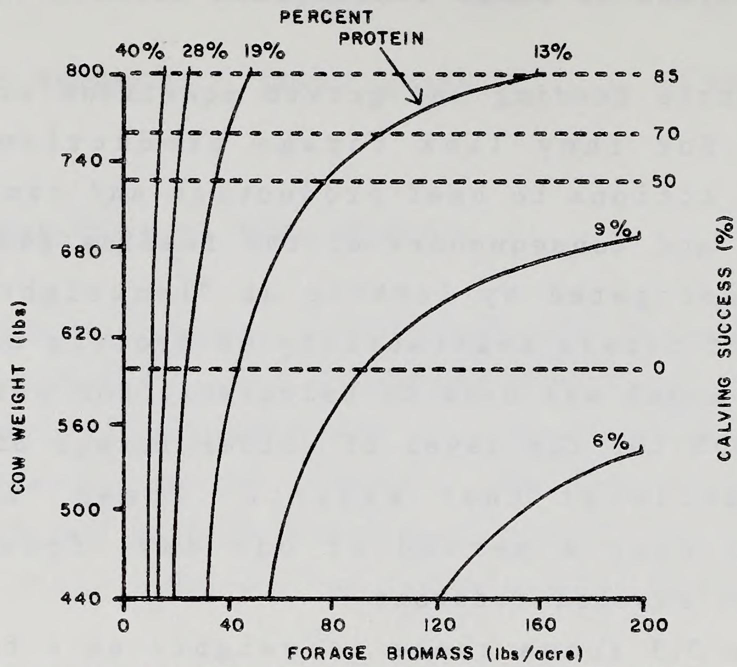

Fig. 5.9. Isoclines of constant cattle weight as a function of forage biomass for a series of protein contents. (Percent calving success at four cow weights are also shown.)

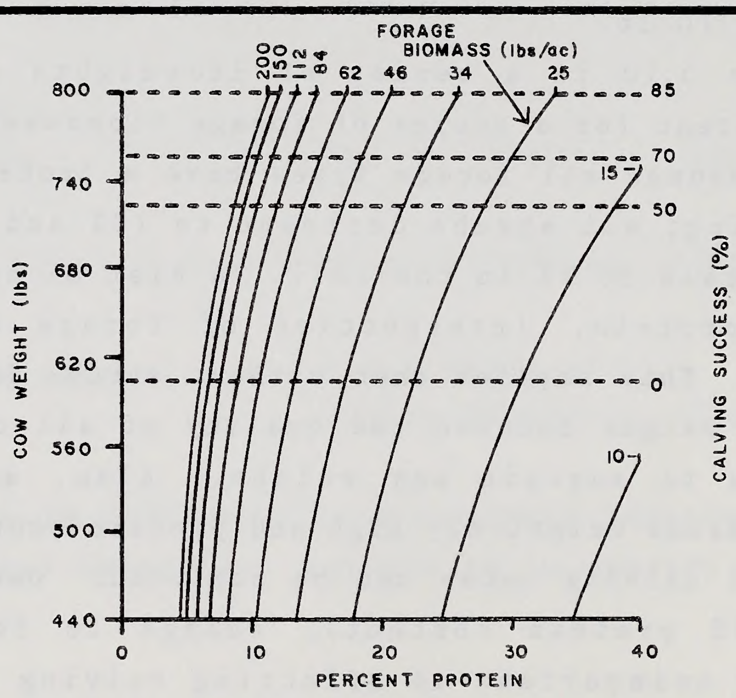

Fig. 5.10. Isoclines of constant cattle weight as a function of percent protein for a series of forage biomass levels in lbs/acre. (Percent calving success at four cow weights are also shown, as in Fig. 5.9.

These isoweights also point out a potential danger in attempting to maximize livestock production by stocking heavily on very high quality forage. This would be in the upper left region of Fig. 5.9. Any decrease in forage biomass, due to drought or some other uncontrollable process would be catastrophic; it would take very little decrease in forage biomass at 15% protein to drastically reduce beef weight. The alternate strategy, production of high biomasses of lower quality forage, allows for lower animal weights but slower declines in weight with decreasing biomass. This strategy would on average produce fewer pounds of beef but would also buffer against unpredictable circumstances, such as drought years. The range under the first strategy would, in some years, produce very high amounts of beef and other years, very low amounts of beef.

5.9 Review of Submodel Hypotheses

The preferences given in Table 5.5 *are correct.*

The consumption model developed between workshops is probably a more realistic representation of cattle feeding than the model developed at the first workshop. However, the parameters in Table 5.5 were derived independently of any input from range scientists. The feeding preferences in particular need to be better estimated. Existing literature could perhaps be used to estimate some of these preferences.

Total digestible nutrients (TDN) is a good predictor of forage quality.

Participants at the second workshop stated that acid detergent fiber (ADF) was a better index of forage quality. However, if crude protein, TDN and ADF can be quantitatively related to each other, any of the three can be used in the model.

Calves feed independently of their mothers from the beginning of spring.

This hypothesis is invalid but field research is likely not needed. The existing cattle feeding and growth functions could be used along with the assumption that calves consume no forage and gain a constant weight per week (from milk) until some time in the late spring or early summer. Adult cows' weight gain could then be adjusted according to food intake and the calf gain for which they have to consume food.

Forage preferences do not change from spring to fall and are independent of forage quality.

There is a confounding effect of preference and availability in the determination of what cattle (or other animals for that matter) eat. Apparent changes in preference, as measured by composition of diet, may in fact be due to changes in availability. Given the alternate hypothesis that forage preferences do change within the year, according to changing forage quality, the existing model could be modified to have the forage preferences changing weekly as a function of protein content.

Fall cow weight is the best predictor of calving success.

Cow condition through the winter period may also be important. It is conceivable that abortion rates would depend on how well the cows were maintained over the winter.

Maximum food intake is solely a function of animal weight.

Maximum fiber intake is probably solely a function of animal weight. Participants stated that animals could process fixed amounts of fiber per day; the actual quantity of forage consumed would depend on its fiber content.

All forage types exhibit the same relationship between % TDN and % crude protein.

A review of the appropriate literature would likely reveal if this hypothesis was invalid.

6. WILDLIFE SUBMODEL

The responsibilities assigned to the wildlife subgroup are summarized in Fig. 6.1. Due to the limited time available at the first workshop, the subgroup succeeded in conceptualizing the dynamics of only the mule deer and sage grouse populations. At the second workshop, there was some discussion on the inclusion of jackrabbits, grasshoppers, and ground squirrels. Although these discussions were productive they did not leave us at a level of refinement suitable for actual inclusion in the model at this time.

6.1 Mule Deer

Mule deer comprise one of the two important game species on the Saval project area. The entire project area lies within an area designated as mule deer key summer range in the Independence Mountains. Currently it is estimated that 350 deer summer on the project area.

The deer also use the central pastures (Upper and Middle Mahala; Upper Sheep) and eastern pastures (Lower Mahala, Lower Sheep) as fall and spring range as they migrate to and from their wintering range, off the project area.

6.1.1 Population Structure

To simulate the mule deer population, two age groups are represented; fawns (0-1 yr) and adults (older than 1 yr). Each of these is further divided into male and female. Although this structure is overly simplistic the participants felt two age classes would serve the purposes of the first workshop, noting however, a future refinement should be the introduction of a yearling class. Survival and reproduction for each of these age classes is described in the following sections.

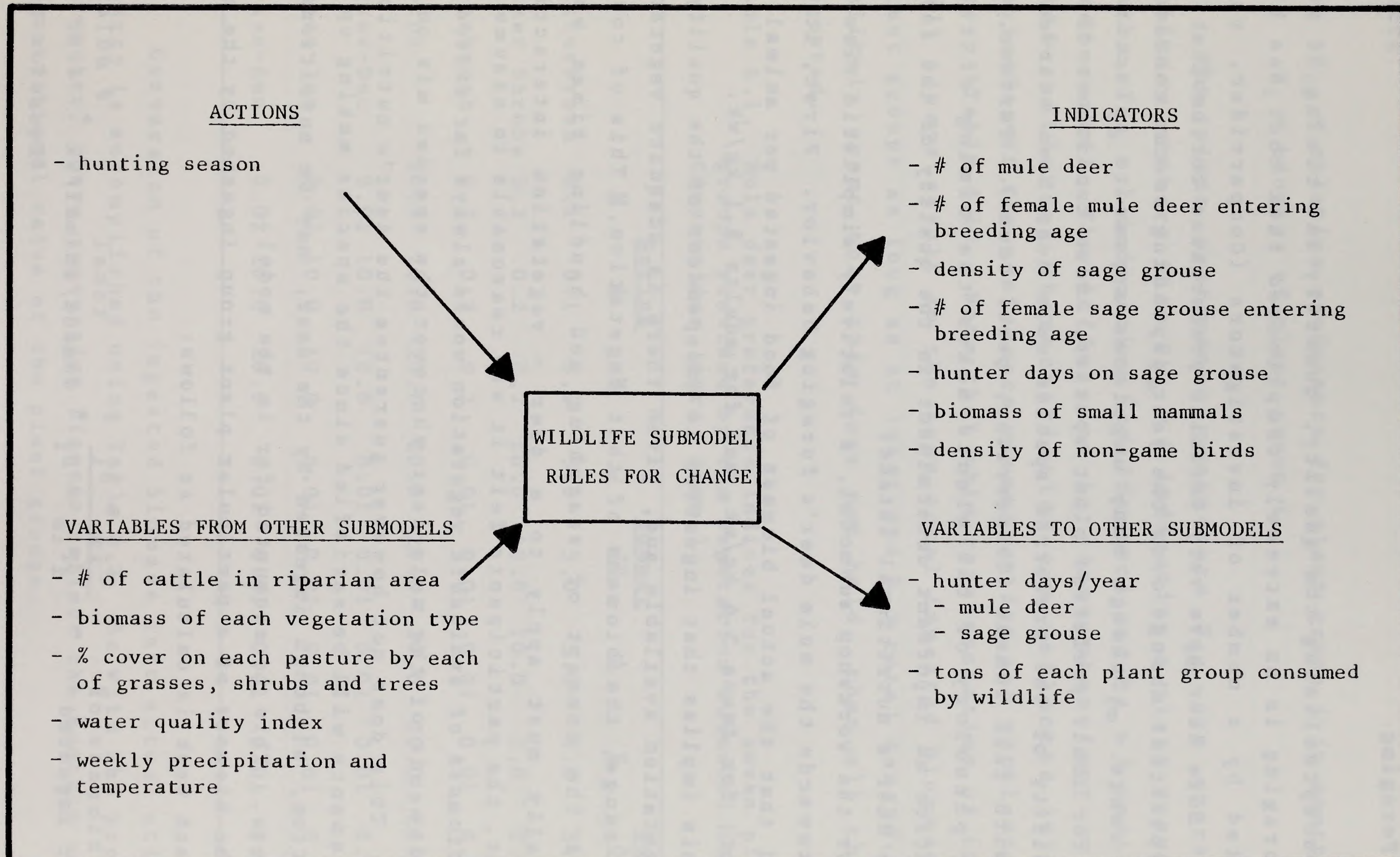

Fig. 6.1. Responsibilities assigned to the wildlife subgroup.

6.1.2 Foraging

Conceptualizing the quality, quantity and timing of mule deer foraging is an extremely complicated task that has been attempted by a number of investigators (Cooperrider, pers. comm.). Mule deer have very definite preferences for habitat and food types that change over the year depending on the condition of the range. Although many ungulates appear to selectively forage for their preferred plant species, under conditions of low availability of the preferred species mule deer have starved to death with full rumens (Cooperrider, pers. comm.). Further, the varied phenology of the plants makes the timing of range utilization an important determinant in the quality of the forage and the deer's nutritional intake.

For the workshop submodel, a relatively simplistic view was taken towards the mule deer's foraging behavior. First, it was assumed that the actual biomass of food ingested per animal was constant; for fawns 5.6 kg/wk, and for adults 9.1 kg/wk.

This implies that ingestion is independent of the quality of the vegetation available and, given there is adequate vegetation on the range, the biomass of that vegetation. This of course ignores the concept of searching and handling times which eventually must apply to a deer - vegetation interaction. However, the participants felt it was reasonable to assume the total biomass of available vegetation would always far exceed the total demands of the mule deer whatever the species mix on the range. This does not however guarantee the deer's nutritional requirements will be satisfied since the species making up the vegetation, although ingested by the deer, may be nutritionally worthless. This is accounted for in the model.

The biomass of a particular plant group ingested by the mule deer each week is calculated as follows:

$$\text{total biomass of group i ingested} = \frac{P_{im} * B_i}{\sum_i P_{im} * B_i} * \text{total demand/animal/wk} * \text{\# mule deer}$$

(Equation 6.1)

where:

P_{im} = relative preference for plant group i in month m

B_i = biomass of plant group i

The plant preference parameters P_{im} are expressed as positive numbers with $P_{im} = 0$ indicating a plant group is not eaten, $P_{im} = 1$ indicating indifference and $P_{im} > 1$ indicating a preference. The difference in plant phenology and other differentiating characteristics are reflected in monthly variation of the preference parameter for any particular plant group (Table 6.1). Note that this representation of ingestion will always result in the same total ingested biomass across plant groups as long as at least one $B_i >$ total demand. In the unlikely event that this does not hold, then all the B_i is ingested.

Table 6.1. Mule deer preference indices for the seven plant groups provided by the vegetation submodel (A. Cooperrider, pers. comm.).

	Spring			Summer			Fall		
	M	A	M	J	JU	A	S	O	N
Bitterbrush	0.1	0.1	0.1	5.0	5.0	5.0	5.0	5.0	5.0
Other Shrubs	0.2	0.2	0.2	10.0	10.0	10.0	2.0	2.0	2.0
Sagebrush	0.2	0.2	0.2	0.01	0.01	0.01	0.01	0.2	0.2
Forbs	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Grass-Dec	0.01	10.0	10.0	0.01	0.01	0.01	0.01	0.01	0.01
Grass-Inc	0.01	10.0	10.0	0.01	0.01	0.01	0.01	0.01	0.01
Grass-Ann	0.01	20.0	20.0	0.01	0.01	0.01	0.01	0.01	0.01

Conversion of the ingested biomass into actual utilizable energy is accomplished using Table 6.2. As with the preference parameter, these conversion figures reflect the monthly variation in nutritional value of the plant groups.

Table 6.2. Energetic Value of each plant group to mule deer by month (kcal/g ingested) (A. Cooperrider, pers. comm.).

	Spring			Summer			Fall		
	M	A	M	J	JU	A	S	O	N
Bitterbrush	1.2	1.45	1.6	1.9	1.9	1.9	1.9	1.9	1.9
Other Shrubs	1.9	2.3	2.4	2.6	2.6	2.6	2.4	2.3	1.9
Sagebrush	1.9	1.9	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Forbs	3.3	3.3	3.3	3.1	3.1	3.1	3.1	3.1	3.1
Grass-Dec	1.2	3.1	2.6	2.3	1.7	1.2	1.2	1.2	1.2
Grass-Inc	1.2	3.1	3.1	2.6	2.3	1.7	1.2	1.2	1.2
Grass-Ann	1.2	3.1	2.6	1.2	1.2	1.2	1.2	1.2	1.2

6.1.3 Health Index

Currently the model assumes that the health status of the deer is a cumulative function of the food ingested between March and November, the time period during which the deer are on the Saval range. The winter range was bounded out of the model and currently has no influence on the simulated dynamics. This was not done without some concern on the part of the participants and was immediately flagged as a questionable assumption that requires further attention.

The mule deer health index is simply the average weekly amount of "utilizable energy" ingested divided by a pre-specified requirement, (i.e., 18.34×10^3 kcal/wk for males; 26.92×10^3 kcal/wk for females) where the average is taken over the March to November period. An index value greater than 1, implies the deer is entering the winter range in excellent health; a value less than 1 implies a less than optimum condition which will have implications on winter survival and the following years reproduction success.

6.1.4 Overwinter Survival

Overwinter survival, a discrete event in the model, is represented as a function of the previous year's health index for each population group (Fig. 6.2). These survival rates are applied to the populations in the first week of each simulated year (i.e., March 15).

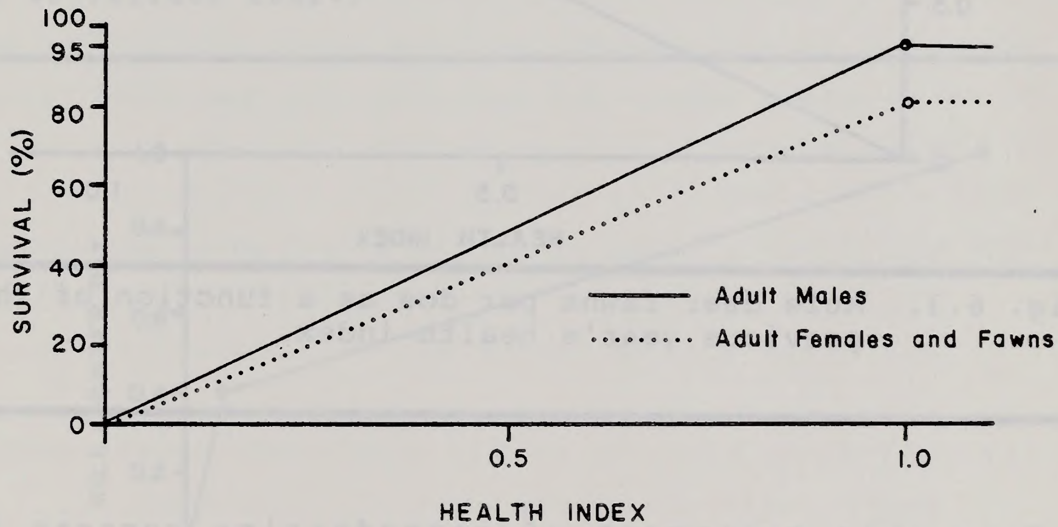

Fig. 6.2. Overwinter survival of the mule deer as a function of the previous year's health index.

6.1.5 Reproduction

Reproduction, a discrete event in the model that occurs on June 1 each simulated year, is represented as a function of the previous year's health index for the adult females (Fig. 6.3). Given the simple population age structure of this model, this would include the current yearlings (i.e., last year's fawns). The maximum number of fawns per adult female (i.e., 1.2) is the effective number in the fall after mortality due to predation and disease. The effective fawn + female to male ratio in the fall is set at 1.5:1.

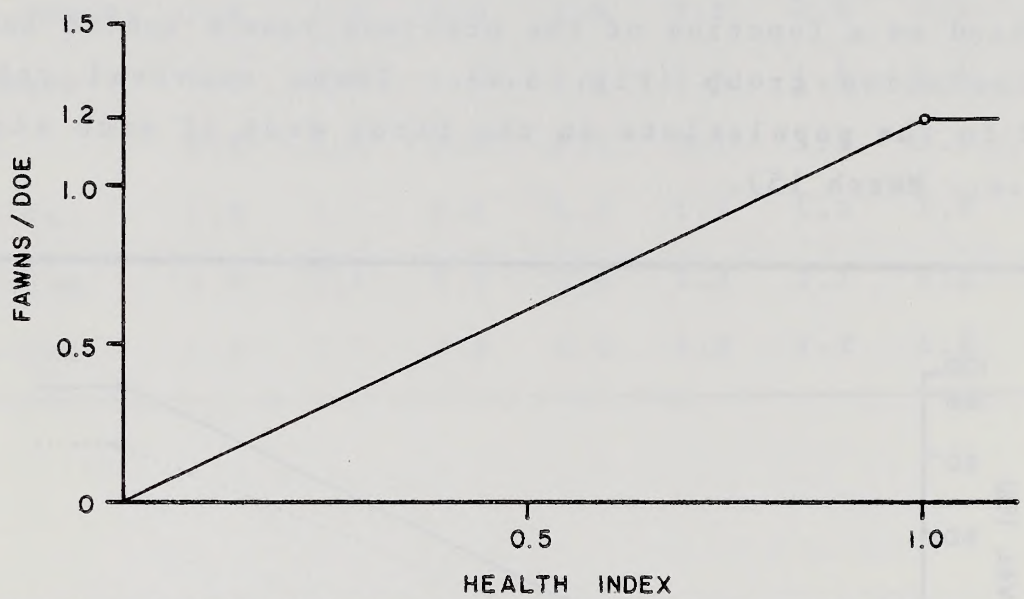

Fig. 6.3. Mule deer fawns per doe as a function of the previous year's health index.

Note this treatment of reproductive success includes predation (primarily from coyotes) as a fixed proportion of the actual births. The participants felt this was acceptable for the Saval Ranch area at this time but did not want to preclude it as an issue that may need further attention.

6.1.6 Hunter Mortality

Currently deer hunting in the Saval area is controlled using hunting permits issued on a regional basis (i.e., Game Management

Unit; GMU). Each permit allows the hunter one buck kill per year. The current number of permits for the GMU is 500/yr. Since the Saval area is a fraction of the GMU (approximately 25%), only that fraction of the permits are allowed to hunt the simulated deer population. The actual kill per effort (where effort is measured in hunter days) is represented as a function of the density of bucks on the Saval range (Fig. 6.4). Effort is the product of the number of hunters (i.e., .25 * # permits) which hunt in the Saval area and the average number of days each hunter spends hunting (i.e., 4 days/yr). Currently this effort is distributed evenly over the 37 weeks that the mule deer are actually on the Saval range (i.e., permitted hunters can hunt any time in the year). (The current hunting period is about 4 wk long, from early October to early November; the model can be changed to reflect that.)

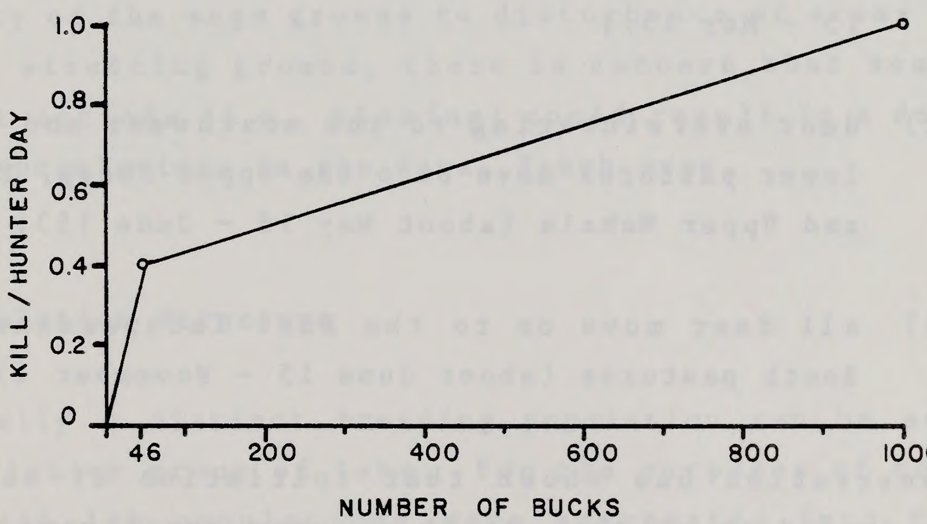

Fig. 6.4. Number of bucks killed per hunter effort as a function of the number of bucks in the Saval population.

At the second workshop, there was considerable discussion on how we might structure and parameterize a more realistic representation of hunting mortality. Unfortunately, the outcome was inconclusive and remains a refinement to be addressed at future meetings.

6.1.7 Deer Migration

Approximately 25% of the mule deer overwinter east of the Saval project area; the remainder to the southwest. Since the preferred summer range for deer are the higher pastures (i.e., East Independence North and South) the deer must pass through the lower pastures in the spring and fall. This passage can take as long as three months depending on the amount of snow and rate of spring melt. In the model this migration is described in three distinct phases, over time;

(1) deer overwintering east of the project area move onto the Lower Sheep and Lower Mahala pastures (about March 15 - May 15);

(2) deer overwintering to the southwest and those on the lower pastures move onto the Upper Sheep, Middle Mahala and Upper Mahala (about May 15 - June 15); and

(3) all deer move on to the East Independence North and South pastures (about June 15 - November 1).

Observation has shown that initiation of each phase is usually dependent on the amount of snow cover remaining and the start of "greenup". This is simulated by checking each week whether the forbs in selected pastures are in a positive growth stage. If so then the appropriate deer population is placed on the pastures indicated above.

During their passage across the lower and middle pastures, the deer are generally only found in the lower range sites (i.e., gullies, streambeds). Therefore in the model the mule deer browse only on vegetation on the loamy 8-10 and wet meadows during phase 1 and loamy 10-12 and wet meadows during phase 2. In phase 3 they browse all range types.

Currently the simulated movement of the deer back to their winter range occurs in the week after November 1. Any grazing which occurs during this week is not determined and has no effect on the deer's nutritional index. This simplification may require refinement if the return migration is thought to be a critical period for the mule deer.

6.2 Sage Grouse

Sage grouse comprise the other game species of concern on the Saval Project. A number of strutting grounds (leks) exist within and in close proximity to the project (Fig. 6.5). The minimum estimated adult breeding population of 670 sage grouse resides within or near the project area. Due to the apparent sensitivity of the sage grouse to disturbance of areas within 2 miles of a strutting ground, there is concern that some of the management options (i.e., plowing) could result in a decline in the grouse populations in the Saval Ranch area.

6.2.1 Population Structure

Generally a distinct breeding population can be associated with each lek or group of leks. For the purposes of the model, the observed lek populations were aggregated into five sage grouse populations (Fig. 6.5). The initial numbers associated with each are shown in Table 6.3.

Within each strutting ground population, three age classes are represented: chick, yearling and adult. These are further divided into male and female (i.e., cock and hen).

Unlike the deer model, the sage grouse populations are not simulated on a week to week basis. Instead survival and reproduction rates are estimated for critical periods over the

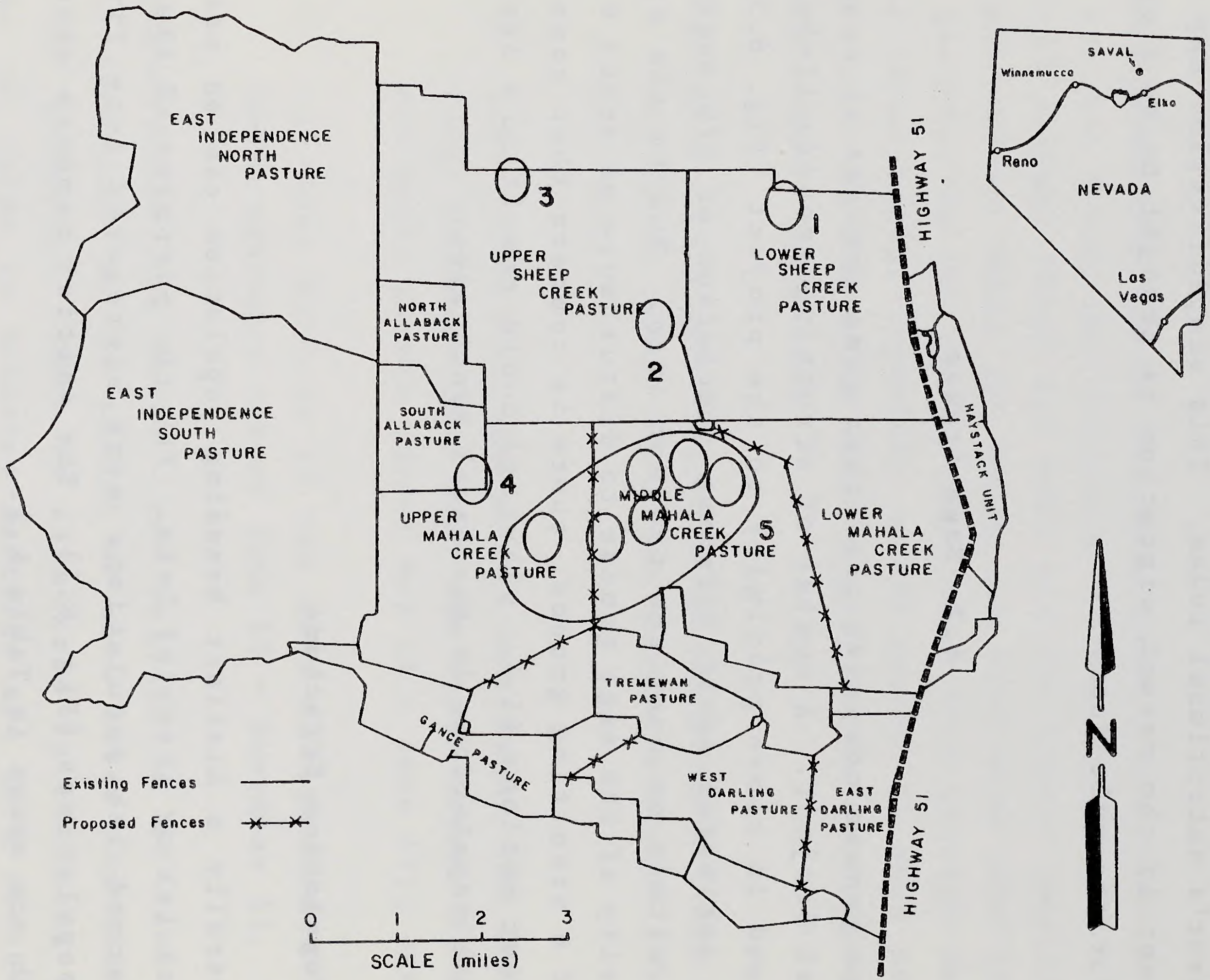

Fig. 6.5. Location of sage grouse strutting grounds on the Saval Ranch. Ellipses represent specific leks identified through field observation. Numbers indicate the population groupings represented in the model.

year and used to modify the populations at the end of the period. The populations currently displayed by the model are the number of sage grouse in the early spring (i.e., March 15) of each year.

Table 6.3. Number of sage grouse observed at each of the population sites indicated in Fig. 6.5.

Strutting area Lek Number	Sage Grouse Seen Males	Females
1	8	2
2	14	1
3	53	8
4	19	6
5	170	38

6.2.2 Reproduction

Both yearling and adult hens are sexually mature. The nesting period is usually from April 1 to June 15 each year with chick emergence occuring between June 1 and August 1. It is assumed that each hen nests during the April 1 to June 15 period and that some fraction of these nests successfully produce chicks (i.e., nesting success). This fraction is a function of the total average (over range sites and time) biomass of forbs plus grasses expressed in lb/ac on three range sites (loamy bottom, loamy 8-10, and claypan 10-12) between April 1 and June 15 (Fig. 6.6). Because the hens require some forbs during the nesting period the nesting success is reduced to zero if the ratio forbs: (forbs + grasses) is less than 0.1.

The number of chicks produced by each successful nest is a function of the total average (over range sites and time) forbs plus grasses on four range sites (claypan 10-12, loamy 8-10, claypan 12-16, loamy 10-12) in the period between June 1 and September 1 (Fig. 6.7). Since forbs are required by the sage grouse hens and chicks during this period the number of

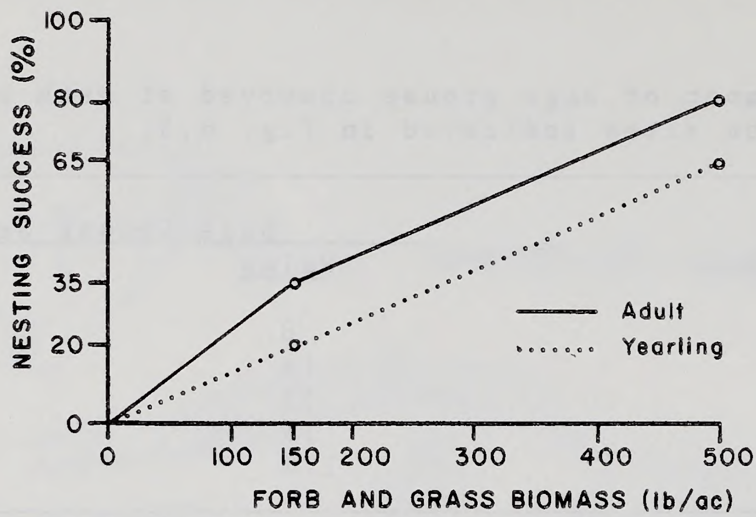

Fig. 6.6. Sage grouse nesting success as a function of the average biomass of forbs plus grasses. (The average is taken over range types and time.)

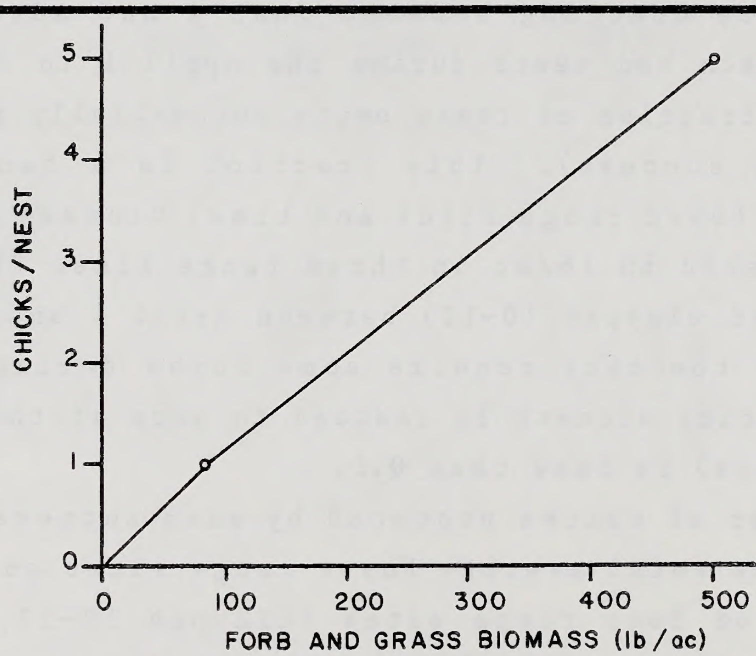

Fig. 6.7. Number of chicks per successful sage grouse nest that survive to the fall as a function of forb and grass biomass.

chicks/hen is reduced to zero if the ratio forbs: (forbs + grasses) is less than 0.1. Note the number of chicks estimated in this calculation is the number that survive to recruit into the fall population each year, not the actual number successfully emerging from the eggs.

6.2.3 Survival Rates

Survival rates for both male and female sage grouse are represented within two distinct periods--March 15 to September 30, and September 30 to March 15. This division was felt to be adequate to represent the dynamics of the grouse as a function of range condition. No attempt was made to directly represent the dynamics of predation on the grouse. Predation is implicitly represented by expressing survival as a function of the vegetation which provides cover from birds of prey and other predators.

6.2.3.1 Hens

Survival of the sage grouse hens between March 15 and September 30 is structured as a function of the quality and quantity of the vegetation during that period. Three plant groups are required--forbs, grasses, and shrubs (for cover). From the perspective of the sage grouse these plant groups are complementary and are all necessary to ensure optimal grouse survival.

For the purposes of the model, hen survival is calculated in two steps. First, survival under optimal cover conditions is calculated as a function of the total average density of forbs plus grasses between March 15 and September 30 (Fig. 6.8). Then, to reflect deviations from optimal cover, the survival is modified as a function of the average percent shrub cover on the pasture (Fig. 6.9). Therefore, the effective hen survival rate

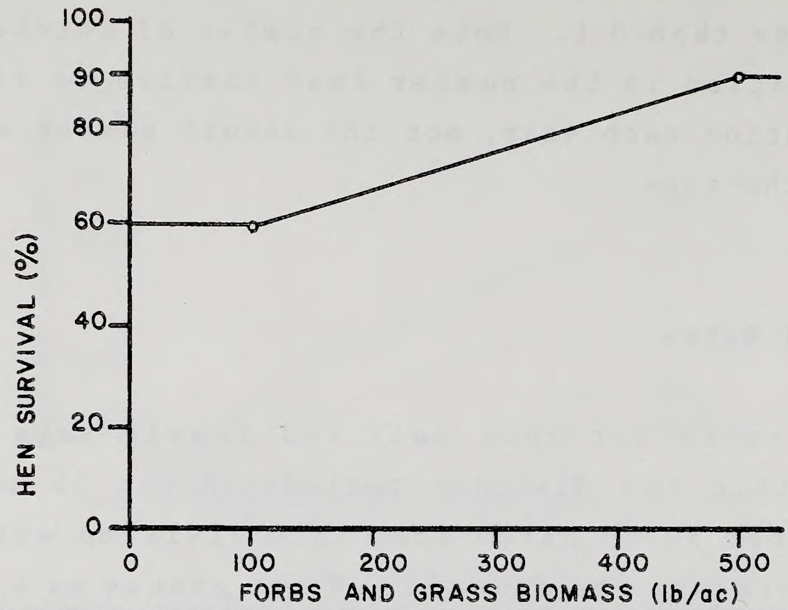

Fig. 6.8. Sage grouse hen survival rate over the March 15 to September 30 period, as a function of forb and grass biomass, under optimal cover conditions.

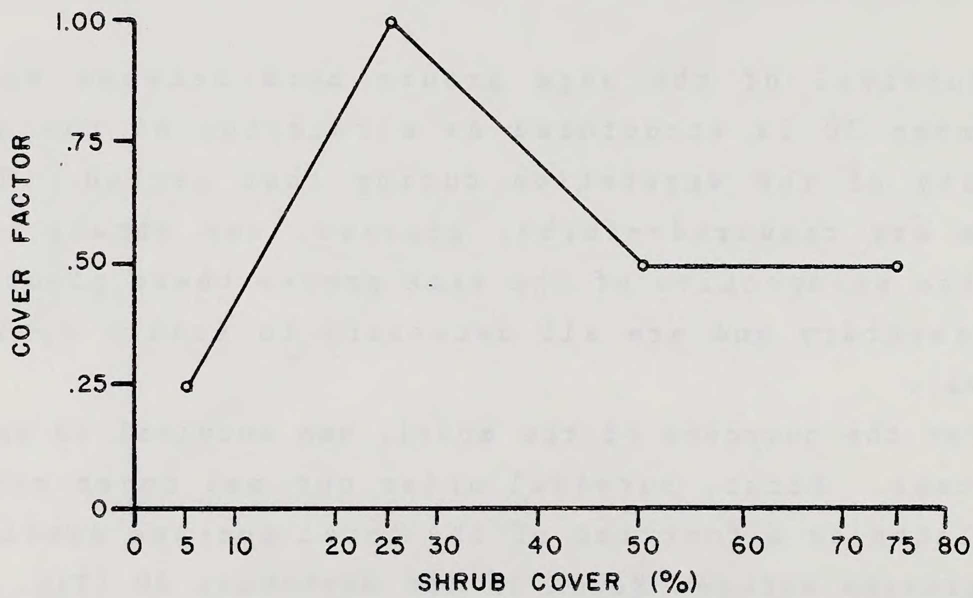

Fig. 6.9. Cover factor for sage grouse as a function of average percent shrub cover during the March 15 - September 30 period. (Optimal cover has a factor of 1.)

between March 15 - September 30 is the optimal survival rate times the determined cover factor.

Over the winter period the hen survival rate is fixed at 0.9.

6.2.3.2 Males

The most vulnerable period for the male sage grouse is during the breeding season, March 15 - May 31. During this period the male stays on or near the lek and exercises little caution in avoiding predators and little care in maintaining his health. It was felt by the participants that most of the male mortality occurs during this period and that this mortality could be expressed as a function of percent cover alone. Therefore the March 15 to September 30 male survival rate is expressed as a function of the percent shrub cover on the pasture containing the strutting ground, averaged over the March 15 - May 31 period (Fig. 6.10).

Over the winter period the male survival rate is fixed at 0.8.

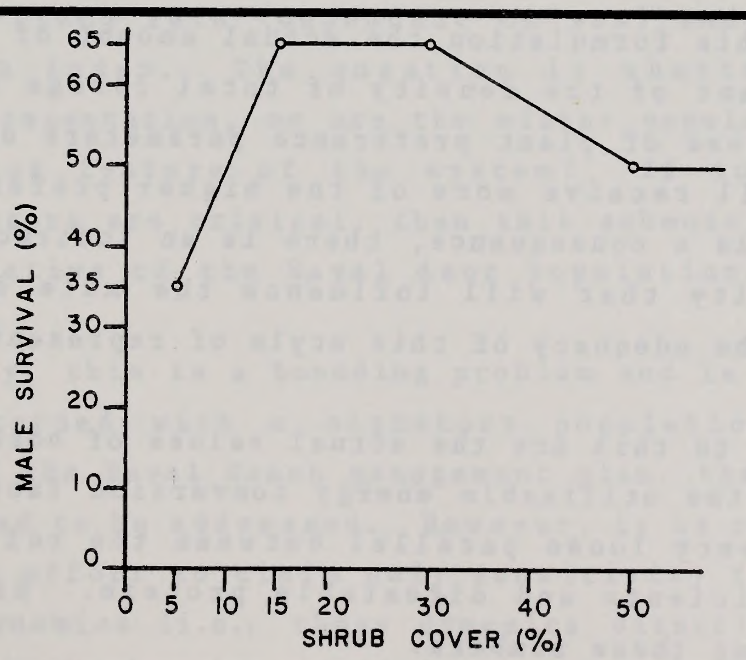

Fig. 6.10. Male sage grouse survival rate over the March 15 to September 30 period as a function of average percent shrub cover during the critical breeding period (March 15 to May 31).

6.2.4 Hunting

Sage grouse are one of the main game species on the Saval Project. During the workshop there was insufficient time to adequately represent the relationships between the number of hunters, the density of grouse, and the actual grouse kill. For the time being, hunting mortality is held fixed at 10% of the fall population. Since sage grouse hunting is of recreational value, this aspect of the model should certainly receive further refinement in the future.

6.3 Review of Submodel Hypotheses

6.3.1 Mule Deer

The total biomass of vegetation ingested weekly by each mule deer is constant, independent of the density of available forage.

Under this formulation the actual amount of forage ingested is independent of the density of total forage on the pasture. However the use of plant preference parameters does ensure that the deer will receive more of the higher preference forage if available. As a consequence, there is an indirect dependence on forage density that will influence the mule deer population dynamics. The adequacy of this style of representation should be tested.

Related to this are the actual values of both the preference factors and the utilizable energy conversion factors. Currently there is a very loose parallel between the relative values of these coefficients and digestable protein. Effort should be spent refining these numbers.

The concept of a mule deer health index is an effective means of representing the feedback between vegetation and mule deer survival.

The disadvantage of this approach is that it is sensitive only to the average forage conditions over each simulated year. Any extreme conditions that could result in short or medium term starvation of the deer would most likely be lost. This is especially critical from the perspective of fawn survival, primarily in spring and early summer.

Related to this is the need for herbaceous cover during the fawning period to ensure protection from the weather and predators.

The dynamics of the winter habitat is not critical in the determination of deer survival and reproduction.

Currently the model assumes that all the determinants of deer survival and reproduction are a function of deer foraging success while on the Saval range. Overwinter survival is the product of a fixed rate (dependent on sex) and the previous year's health index. The question is whether this is a reasonable representation, or are the winter population dynamics the controlling feature of the system? If in reality the overwinter factors are critical, then this submodel is currently not representative of the Saval deer population and could be misleading.

Ultimately, this is a bounding problem and is common to any analysis concerned with a migratory population. From the perspective of the Saval Ranch management plan, the problem will eventually need to be addressed. However, it is reasonable for the modelling effort to claim only sensitivity to the spring-summer-fall dynamics (i.e., those dynamics directly affected by the management plan) under conditions of fixed winter survival (i.e., given winter conditions are held constant, what are the effects on the deer population?).

6.3.2 Sage Grouse

Grouse nesting success and number of chicks per successful nest are primarily a function of the abundance (i.e., relative and actual) of forbs and grasses near the nest and in brood use areas.

Currently chick production is a function of only the combined density of forbs and grasses during two critical periods (April 1 - June 15; June 15 - September 1). Forbs and grasses serve as a source of both food and cover. What is ignored is the possible effects of shrub cover in both quantity and spatial layout especially in the spring.

This representation assumes no depression in chick survival because of heavy snows in the spring.

The key factor determining the summer survival rate of the male grouse is percent shrub (sagebrush) cover during the mating season.

This formulation is in effect a surrogate way of representing the effects of predation and low nutritional input on the male grouse during the period they are on the strutting grounds. Although a more dynamic representation of predation (i.e., functional and numerical response) would be more precise, the information to build such a model was not available. The appropriateness of this structure should be tested.

The key factors determining the summer survival rate of the female grouse are percent shrub (sagebrush) cover and the total biomass of forbs and grasses averaged over the summer period.

As with the male grouse this is a "short" way to represent the effects of predation and feeding success on the grouse. Since it is looking only at seasonal averages it may be lacking sensitivity to short-term events.

Hunting mortality is a fixed proportional removal (i.e., 10%) of the fall population.

It may be an inadequate representation of hunting mortality to assume that it is fixed. Since sage grouse are an important game species in the Saval area (which is ultimately the major reason they are of concern to the study) effort should be put into changing this formulation of loss due to hunting, perhaps one that evaluates

(1) the number of grouse killed per unit of effort as a function of grouse density; and

(2) the change in effort as a function of the kill per effort in the previous season.

7. THE INTEGRATED MODEL

Sections 2 - 6 of this report have provided a detailed description of the development of the Saval Ranch simulation model. Once the four submodels had been programmed and debugged they were linked together at the first workshop to form a complete system model. Refinements of the model were carried out prior to and during the second workshop in January 1982. This chapter discusses the current model's output.

7.1 The Question of Model Validation

The Saval Ranch model, like any model of a complex biological/physical/economic system, is necessarily incomplete. It is a highly simplified representation of a real system, undoubtedly containing some conceptual biases and incorrect data. However, it does represent a synthesis of the knowledge of a diverse group of scientists and managers who work with the system on a day to day basis. It is very much their model and the assumptions and simplifications applied in building the model represents the state of knowledge of the system given the constraints of time and the objective to build an integrated model capable of exploring the implications of a wide range of management options.

Traditionally the accepted form of model evaluation involves extensive validation during which, if the model passes various rigorous statistical tests, it is classified as "valid". In AEAM this task is approached from the opposite direction; invalidation. In truth no bio-physical model is valid since it is by necessity simple in comparison to the real world. Further, a model is a hypothesis describing how the modellers think the world behaves and if one wishes to remain true to the scientific method the objective of evaluation should be to disprove the hypothesis (i.e., the model). If one fails, this doesn't necessarily mean the hypothesis is true, it could mean the right test has not yet been developed. In any case the more tests the model survives, the greater one's confidence in its predictions. But one must be careful not to believe the model, but rather use its output to suggest ideas and issues that require action (i.e., monitoring, research analysis, etc.). One cannot, a priori, identify the limits of predictive power or robustness, no matter how much effort goes into testing the model. There is invariably a real world process not included in the model that will eventually cause a divergence between model and observation. However, it is within this world of uncertainty that management decisions must be made. Models have proven to be useful in helping deal with this uncertainty.

Evaluating the model in this fashion is partially intended to de-emphasize the quantitative nature of the model output and concentrate more on the qualitative aspects. We are not so interested in the projected numbers over the next 15 years but more in qualitatively how the system responds given the various perturbations imposed (i.e., management actions, natural perturbations, etc.). In other words we want to

(1) develop an understanding of how robust the system is to stress,

(2) determine if there are management actions that can partially or completely mitigate an adverse impact, and

(3) come to some agreement on the quantity, quality and kinds of data we need to both improve our understanding of the system and help us monitor its "health".

7.2 Model Output

7.2.1 Three Year Scenario

Figures 7.1 and 7.2 are results of a three-year simulation of the full model with a stocking of 1,000 cows. The indicators in these figures are graphed weekly over the three years. The sharp declines in plant biomasses at the end of each year reflect the single large time step over the winter period from November 30 to March 15 (Section 2.4).

Figure 7.1a shows the above-ground and below-ground biomass and cattle consumption of "other shrubs" on the Darling West pasture. There is an increase in above-ground biomass and a corresponding decrease in below-ground biomass in the beginning of all years. Some time after seed set, below-ground biomass begins to increase up to a peak in late fall. Cattle consumption is very low and has no effect on growth.

The dynamics of perennial grass decreasers follow essentially the same pattern (Fig. 7.1b). Cattle consumption is greater on this plant type, however, reflecting the higher preference of cattle for this plant type over "other shrubs" (Table 5.4). The greater cattle consumption influences the grass dynamics slightly, especially in the fall of the second and spring of the third years.

Cow weights (Fig. 7.2a) remain relatively constant at about 750 lb. Forage availability is not restricted (Figs. 7.1a,b); the inability of cows to grow to more than about 750 lb is likely due to the weight gain vs. TDN intake (Fig. 5.6). Large animals, in the model, may simply not be able to consume sufficient amounts of TDN to grow past 750 lb; the calculations of percent crude protein (Section 3.2.4) may be improper as well.

Calf weights (Fig. 7.2a) show a similar pattern among all years, with a constant increase through spring and summer and a leveling off in late summer and fall at about 350 lb. The high

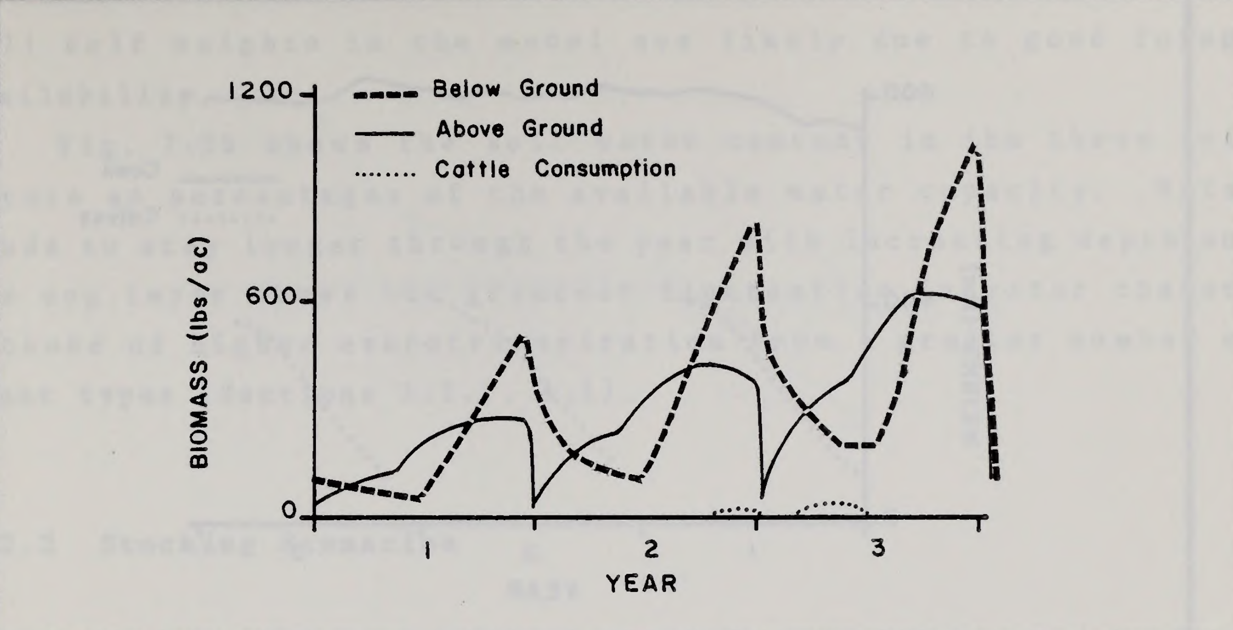

Fig. 7.1a. Weekly above- and below-ground biomass of "other shrubs", and cattle consumption, on Darling West pasture, clay range site, with ranch stocking level of 1000 cows.

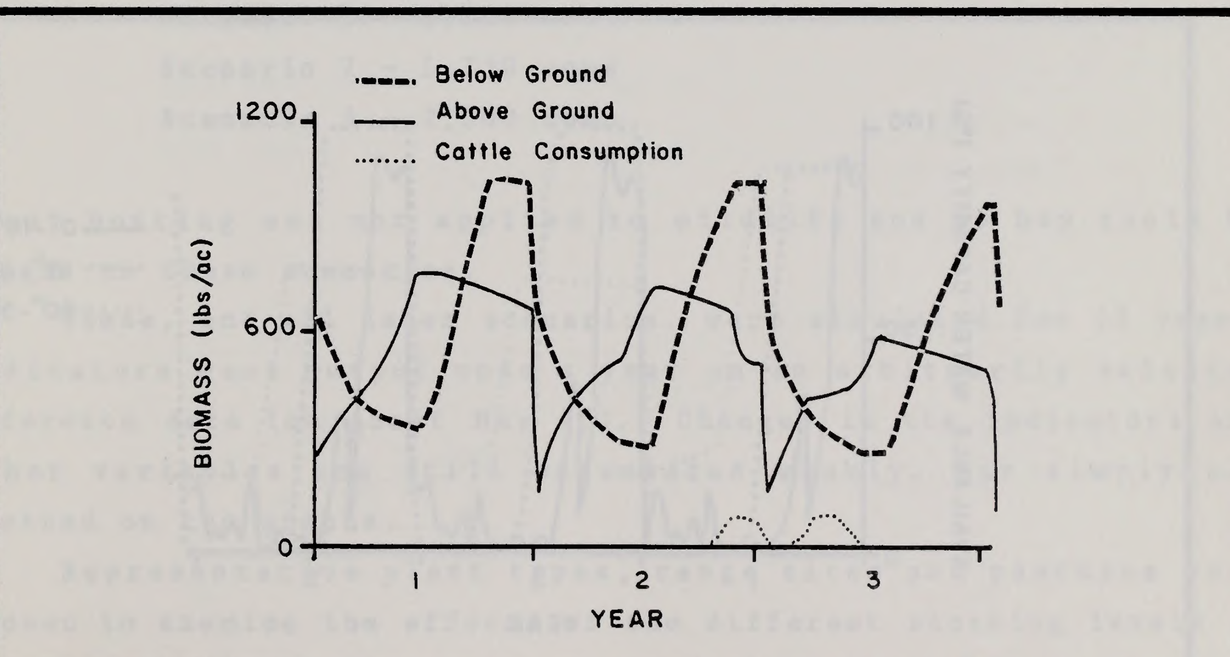

Fig. 7.1b. Weekly above- and below-ground biomass of perennial grass decreasers, and cattle consumption, on Darling West pasture, clay range site, with ranch stocking level of 1000 cows.

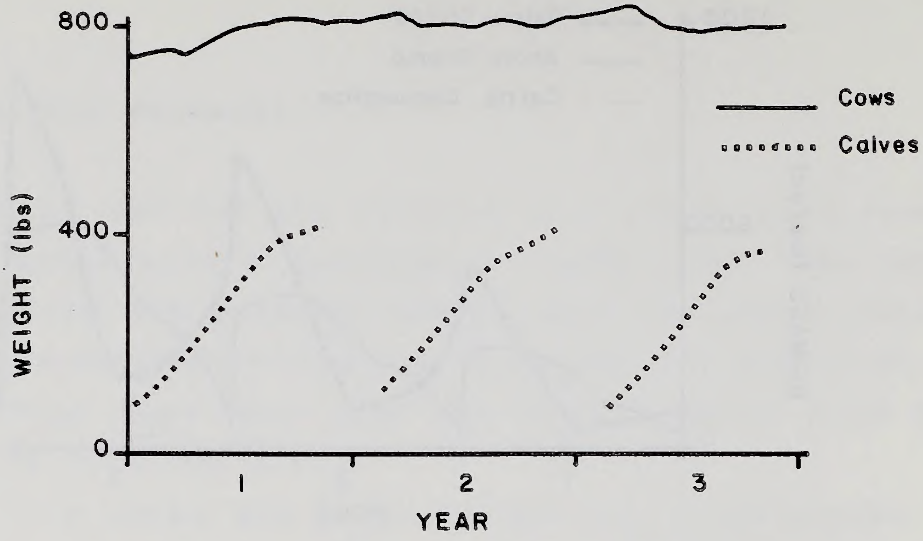

Fig. 7.2a. Weekly cow and calf weights on the Saval Ranch, with ranch stocking level of 1000 cows.

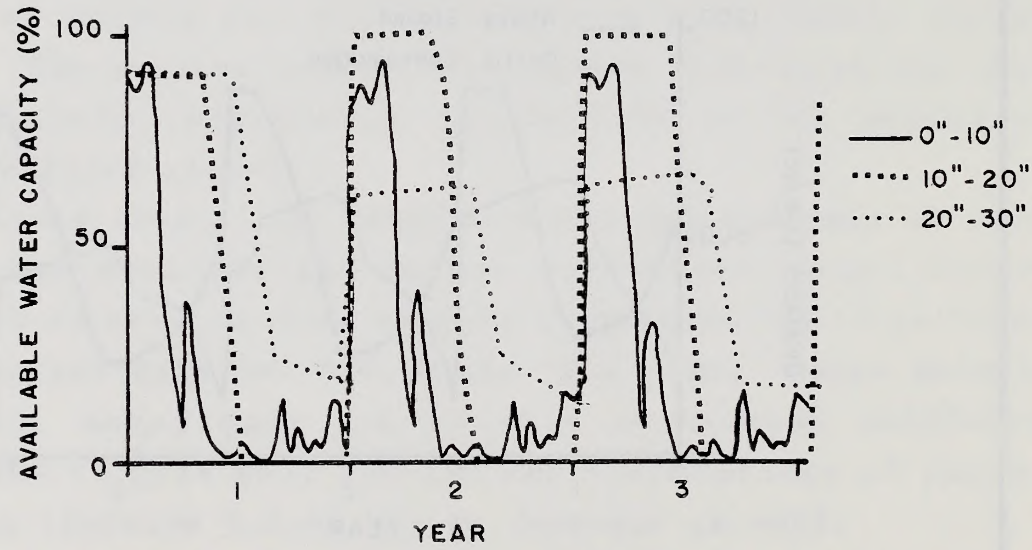

Fig. 7.2b. Weekly soil water expressed as percent of available water capacity for three soil depths on Darling West pasture, clay range site, with ranch stocking level of 1000 cows.

fall calf weights in the model are likely due to good forage availability.

Fig. 7.2b shows the soil water content in the three soil layers as percentages of the available water capacity. Water tends to stay longer through the year with increasing depth and the top layer shows the greatest fluctuation in water content because of higher evapotranspiration from a greater number of plant types (Sections 3.2.1, 4.1).

7.2.2 Stocking Scenarios

Stocking levels used in the model ranged from unrealistically low to unrealistically high; this range was included simply to test model extremes. Consequences of intermediate levels can be interpolated. Four scenarios were run, each with different stocking levels:

NC - no cattle
Scenario 1 - 1,000 cows
Scenario 2 - 1,750 cows
Scenario 3 - 2,500 cows

Also, hunting was not applied to wildlife and no hay could be bought in these scenarios.

These, and all later scenarios, were simulated for 12 years. Indicators were output once a year on an arbitrarily selected reference date (on about May 15). Changes in the indicators and other variables are still calculated weekly, but simply not plotted on the graphs.

Representative plant types, range sites and pastures were chosen to examine the effects of the different stocking levels on range condition. Figure 7.3 shows "other shrubs" and perennial grass decreasers on clay sites in the Darling West pasture. Figure 7.4 shows "other shrubs" and forb biomass on riparian sites in the Middle Mahala pasture and Fig. 7.5 shows sagebrush

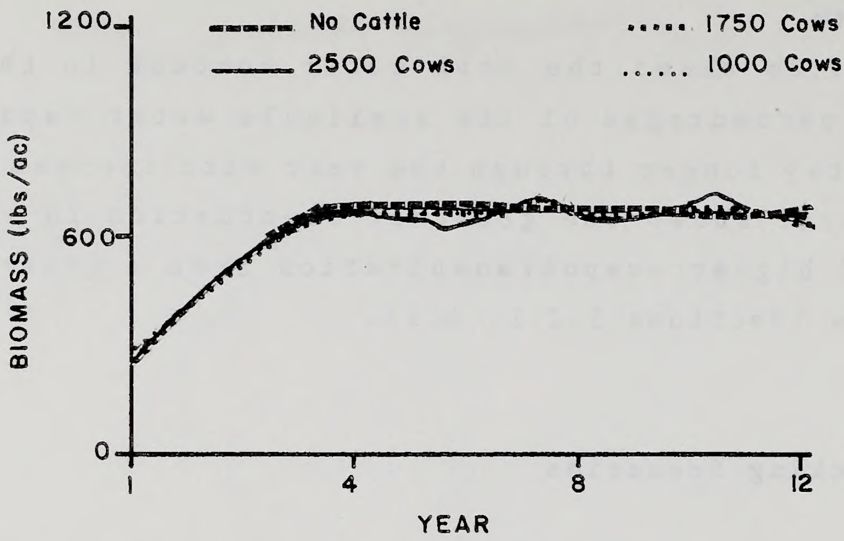

Fig. 7.3a. Annual "other shrub" biomass dynamics on Darling West pasture, clay range site for four cattle stocking levels on Saval Ranch.

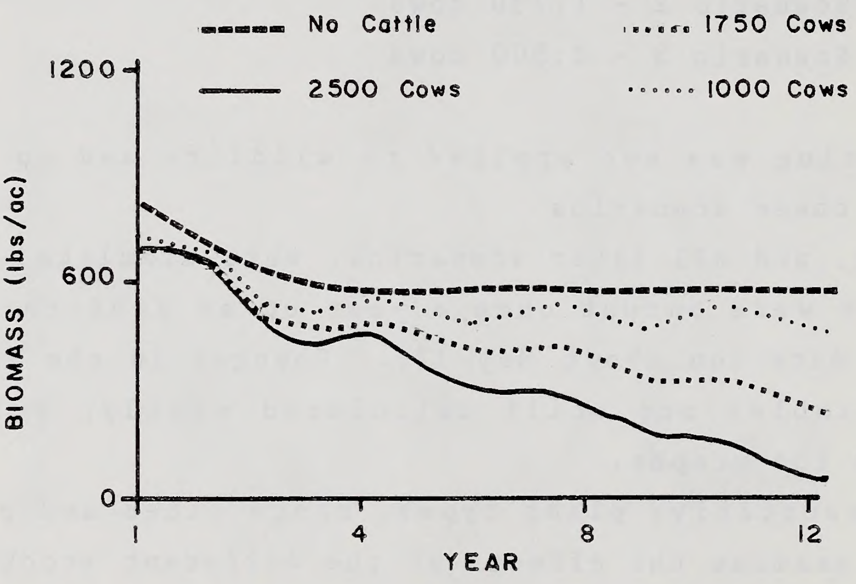

Fig. 7.3b. Annual perennial grass decreaser biomass dynamics on Darling West pasture, clay range site for four cattle stocking levels on Saval Ranch.

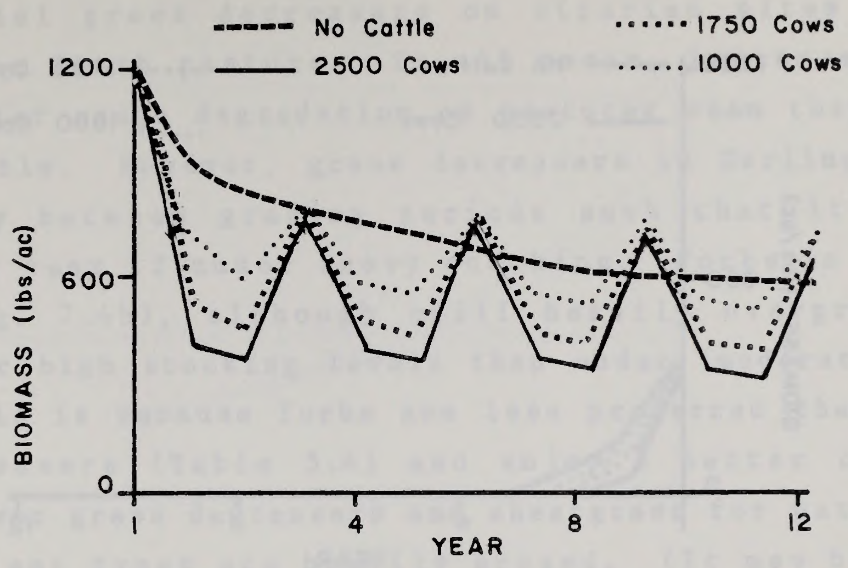

Fig. 7.4a. Annual "other shrub" biomass dynamics on Middle Mahala pasture, riparian range site, for four cattle stocking levels on Saval Ranch.

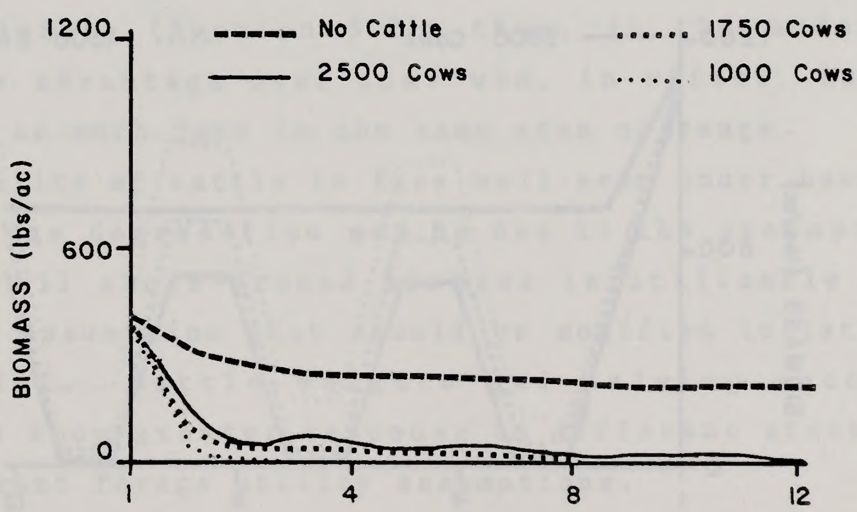

Fig. 7.4b. Annual forb biomass dynamics on Middle Mahala pasture, riparian range site, for four cattle stocking levels on Saval Ranch.

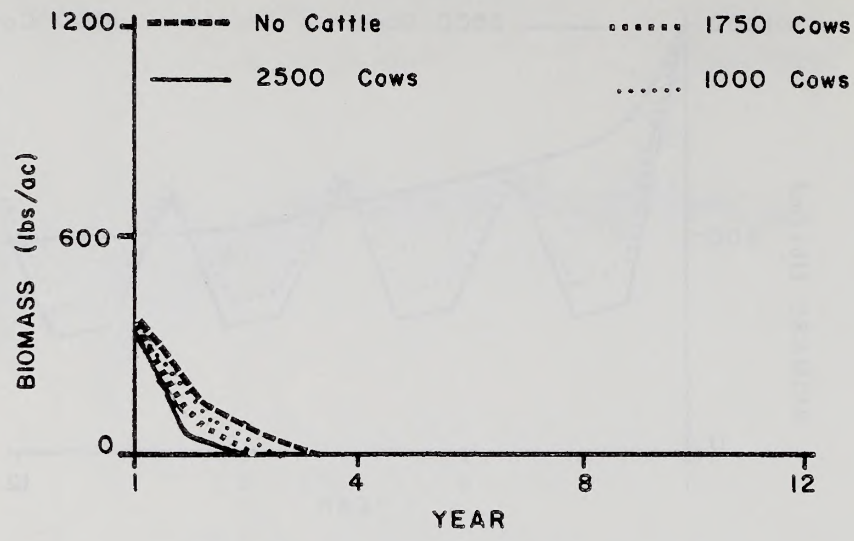

Fig. 7.5a. Annual sagebrush biomass dynamics on E. Independence South pasture, riparian range site, for four cattle stocking levels on Saval Ranch.

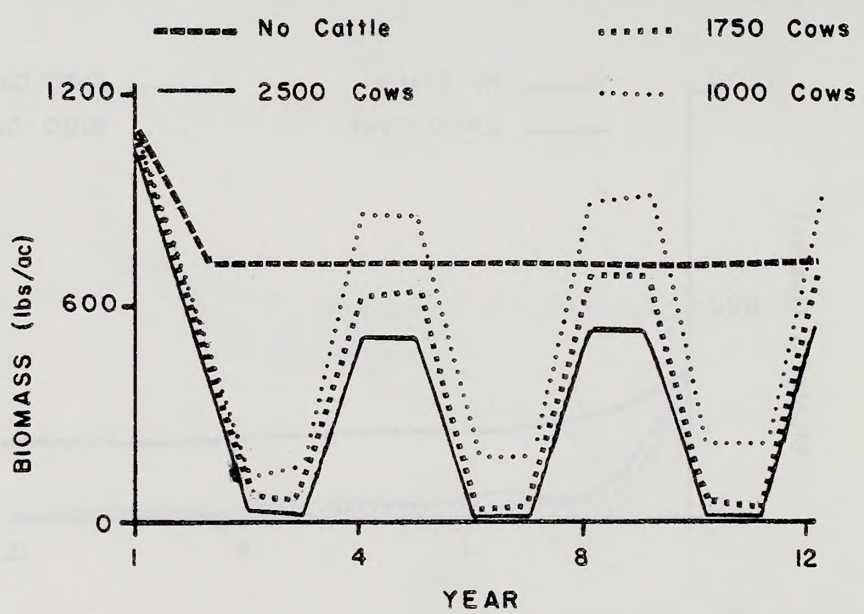

Fig. 7.5b. Annual perennial grass decreaser biomass dynamics on E. Independence South pasture, riparian range site, for four cattle stocking levels on Saval Ranch.

and perennial grass decreasers on riparian sites in the E. Independence South pasture. In all cases, increased stocking causes greater range degradation on pastures when they are occupied by cattle. However, grass decreasers in Darling West show no recovery between grazing periods such that it is highly degraded by year 12 under heavy stocking. Forbs in the Middle Mahala (Fig. 7.4b), although still heavily overgrazed, fare better under high stocking levels than under "moderate" stocking levels. This is because forbs are less preferred than perennial grass decreasers (Table 5.4) and enjoy a better competitive advantage over grass decreasers and cheatgrass for water when the last two plant types are heavily grazed. (It may be that this model prediction is unrealistic; some workshop participants suspect that there would be little or no forb growth under heavy stocking levels. The model may need more work in this area.)

Cattle fare well in spite of the heavy range degradation (Fig. 7.6). Cow weights decrease only under very heavy stocking, while calving success remains near 75% and calf weight near 300 pounds under all stocking levels. The ability of calves to maintain a good weight even under heavy stocking is because they are assumed to search as large an area as cows but to require less food intake (Section 5.2); they, in the model, enjoy a competitive advantage over cows who, in effect, have to find about twice as much food in the same area of range.

The ability of cattle to fare well even under heavy stocking and high range degradation may be due to the assumption in the model that all above-ground biomass is utilizable by cattle, which is an assumption that should be modified in later versions of the model. Cattle weights and calving success would undoubtedly show greater response to different stocking levels under different forage utility assumptions.

Deer show exponential growth in the absence of hunting (Fig. 7.7a). The absence of any density-dependent processes on deer populations means the model is unstable, with deer numbers either going to infinity or to 0. Final deer numbers at the end of 12 years decrease with increasing cattle stocking. This occurs

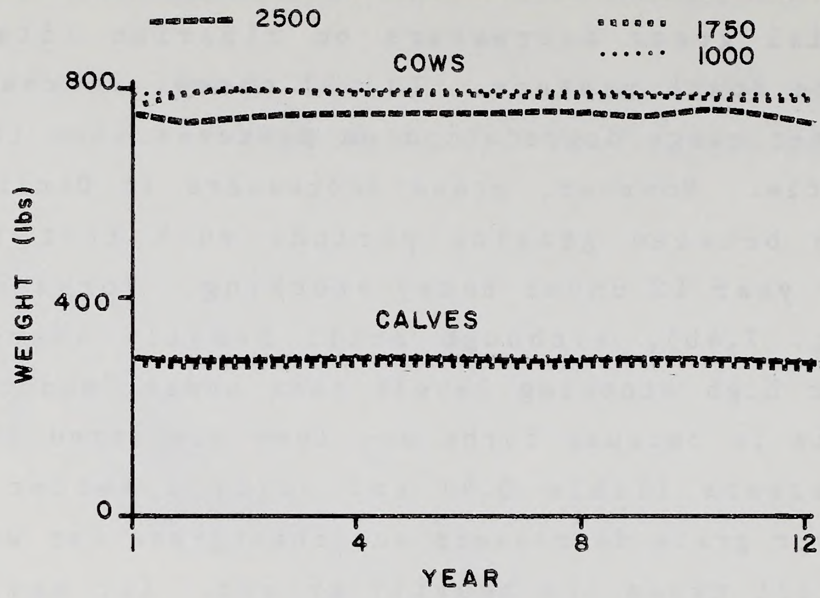

Fig. 7.6a. Cow and calf weights under three different stocking levels on Saval Ranch.

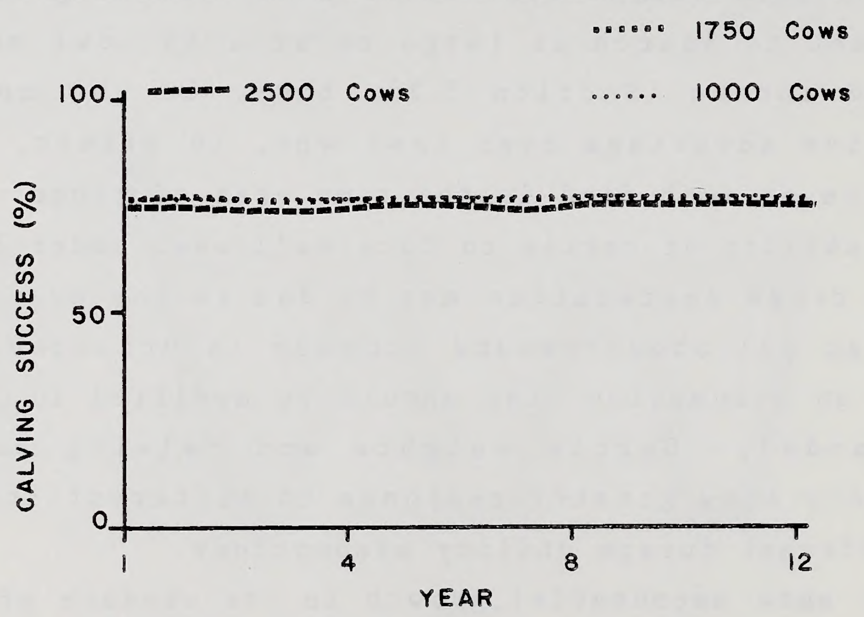

Fig. 7.6b. Calving success under three different stocking levels on Saval Ranch.

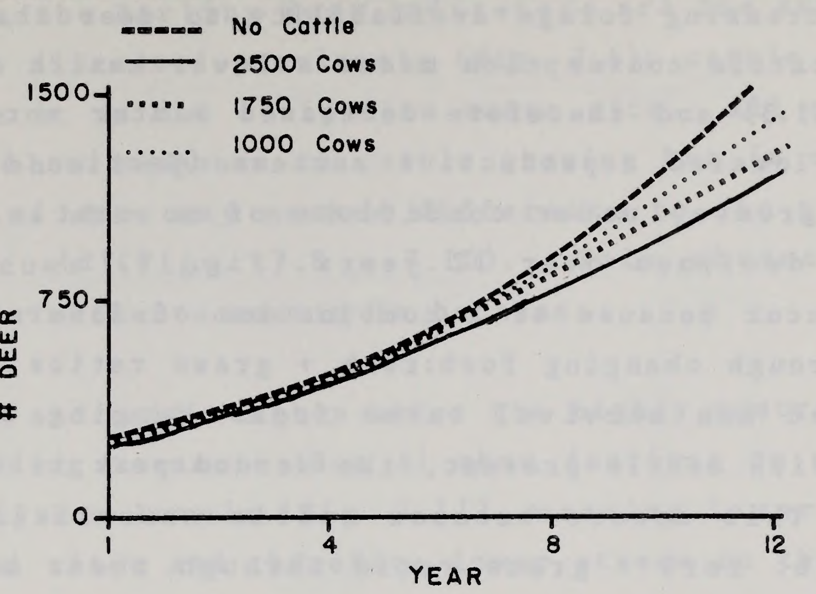

Fig. 7.7a. Total mule deer numbers under four cattle stocking levels on Saval Ranch.

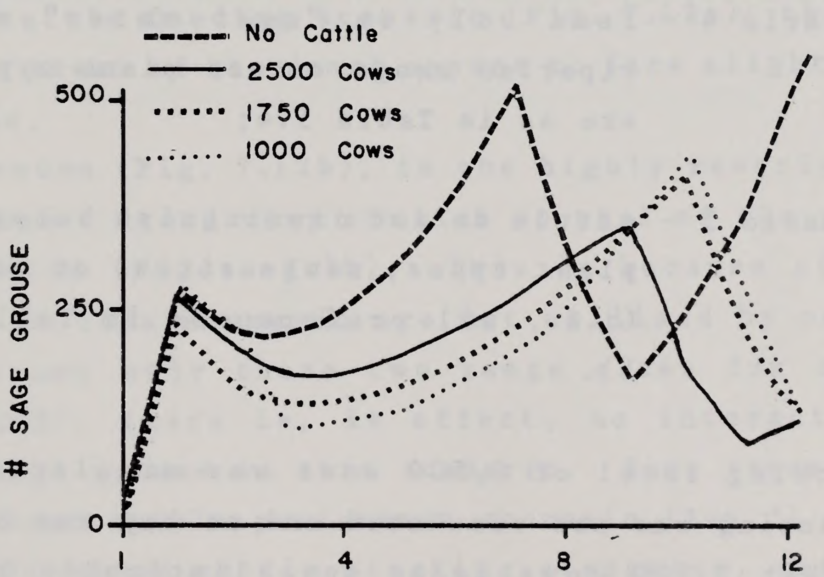

Fig. 7.7b. Total sage grouse numbers under four cattle stocking levels on Saval Ranch.

because decreasing forage availability to deer that arises from increased cattle consumption means a lower health index for deer (Section 6.1.3) and therefore decreased winter survival (Section 6.1.4) and lowered reproductive success (Section 6.1.5).

Sage grouse, under conditions of no cattle, exhibit two peaks and declines over 12 years (Fig. 7.7b). The declines probably occur because of a combination of lowered reproductive success through changing forb:forb + grass ratios (Section 6.2.2) and lowered hen survival rates from changing cover (Section 6.2.3.1). With cattle present, the second peak is delayed by 2 - 3 years. This occurs because cattle essentially maintain a higher forb: forb + grass ratio through their higher feeding preference for grass decreasers over forbs.

7.2.3 Feeding Preference Scenarios

Two scenarios were run with cattle feeding preferences different from those in Table 5.4:

Scenario 4 - feed only on "near water" sites and on riparian range sites; plant type preferences are as in Table 5.4;

Scenario 5 - cattle do not distinguish between different plant types, range sites, or water nearness (i.e., all preferences in Table 5.4 set to 1).

A stocking level of 2,500 cows was simulated, and again, wildlife hunting was not simulated and no hay was bought. It is realized that 2,500 cows is an unrealistically high stocking level, but experience has shown that modeling extremes of the expected is a useful process for understanding functional relationships.

In Run 4, the Darling West indicators are the same as in the no cattle run discussed previously (Fig. 7.4); cattle do not feed there because it is not a riparian range site. All other forage indictors do show response to cattle grazing but in no case does forage biomass show any marked difference to the previous run with 2,500 cows (Figs. 7.8 - 7.10). This absence of range degradation in either scenario is because:

(1) cow and calf weights under the highly restricted cattle feeding scenario (Run 4) show declines to unrealistically low levels (Fig. 7.11), meaning lowered consumption rates and therefore lower stress on the range; and

(2) under the unrestricted feeding scenario, feeding pressure is distributed over the entire pasture instead of being concentrated on particular range sites with the result that all areas of the pastures are fed upon but all are fed upon very little.

Deer have a slightly higher final density in the highly restricted cattle feeding scenario (Fig. 7.12a); this is likely because most areas of the ranch appear to fare slightly better in this scenario.

Sage grouse (Fig. 7.12b), in the highly restricted feeding scenario, show a trend very similar to that of the previous no-cattle scenario (Figure 7.7b). This is because clay and loam range sites in this scenario are not utilized by cattle. Sage grouse hens use only these two range sites for reproduction (Section 6.2.2); there is, in effect, no interaction between cattle and sage grouse in this scenario. Sage grouse numbers in the unrestricted cattle preference scenario (Run 5) have a trend similar to previous cattle stocking scenarios, reflecting the interaction between changing forb:forb + grass ratios by cattle consumption and sage grouse reproductive success.

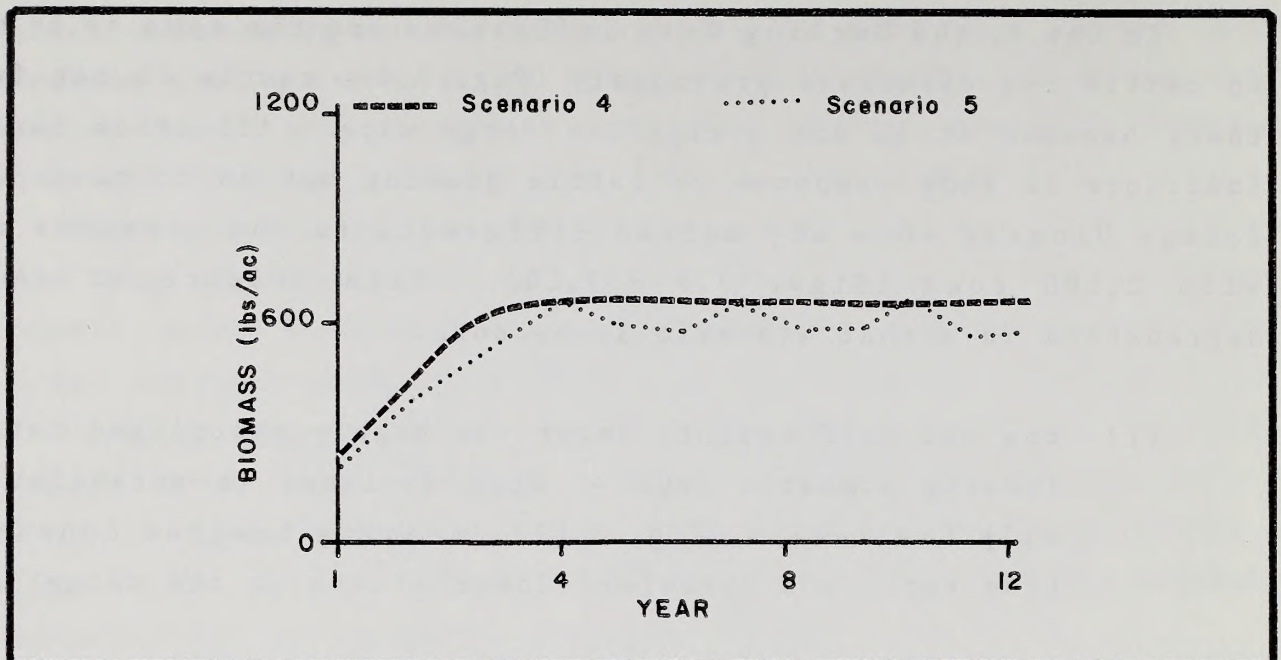

Fig. 7.8a. Annual "other shrub" biomass dynamics on Darling West pasture, clay range site under two cattle food preference scenarios. (See text this section for description of preference scenarios.)

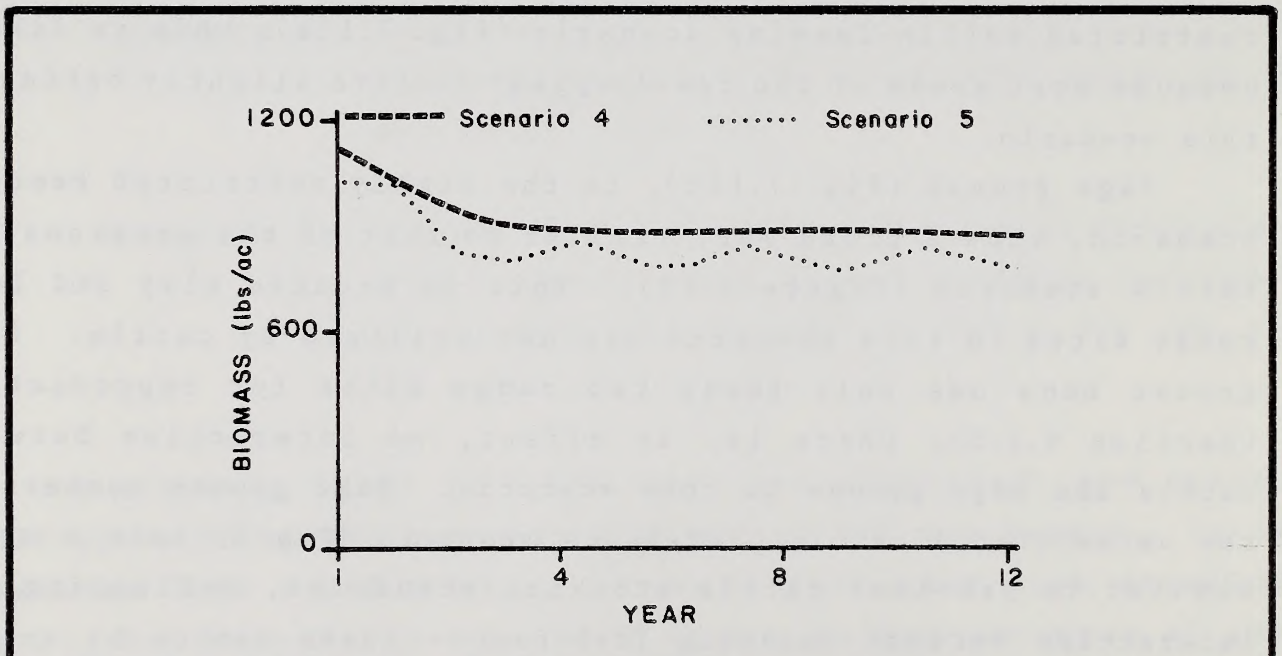

Fig. 7.8b. Annual perennial grass increaser biomass dynamics on Darling West pasture, clay range site under two cattle food preference scenarios. (See text this section.)

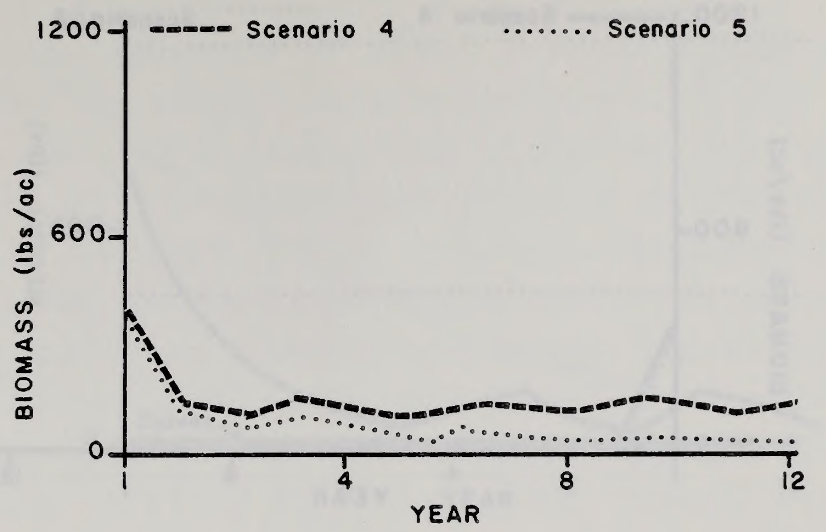

Fig. 7.9a. Annual "other shrub" biomass dynamics on Middle Mahala pasture, riparian range site, under two cattle food preference scenarios. (See text for scenarios.)

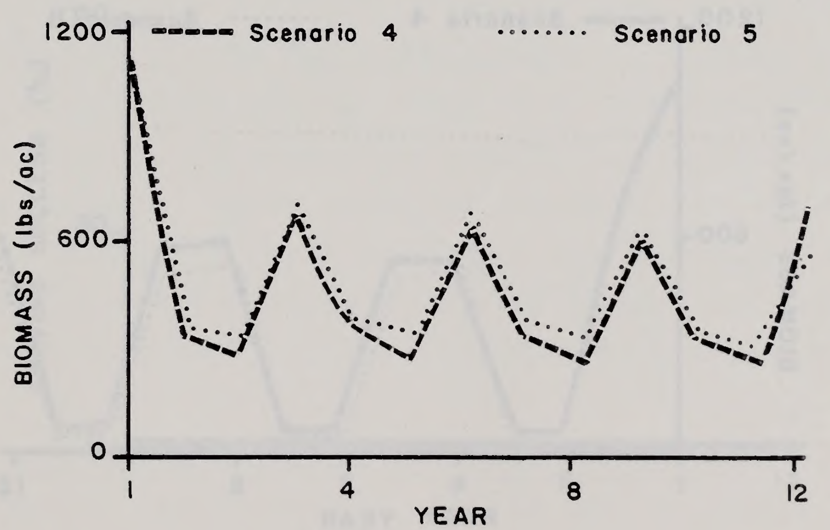

Fig. 7.9b. Annual forb biomass dynamics on Middle Mahala pasture, riparian range site, under two cattle food preference scenarios. (See text for scenarios.)

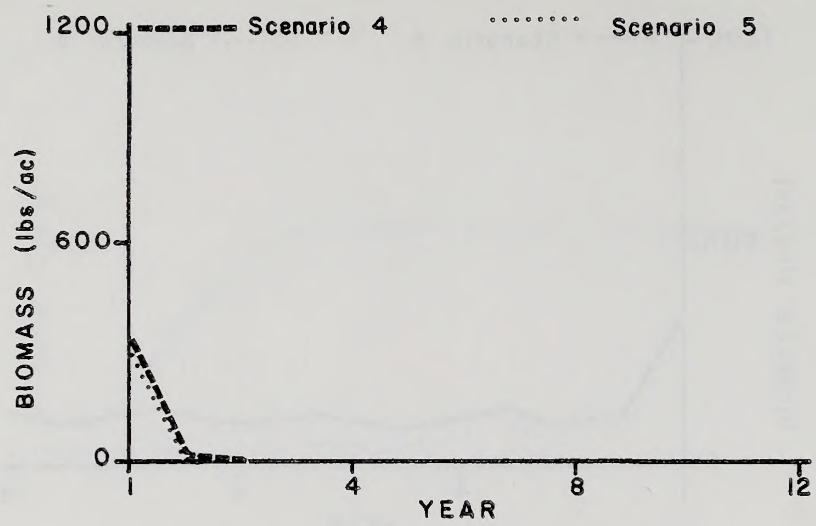

Fig. 7.10a. Annual sagebrush biomass dynamics on E. Independence South pasture, riparian range site, under two cattle food preference scenarios. (See text for scenarios.)

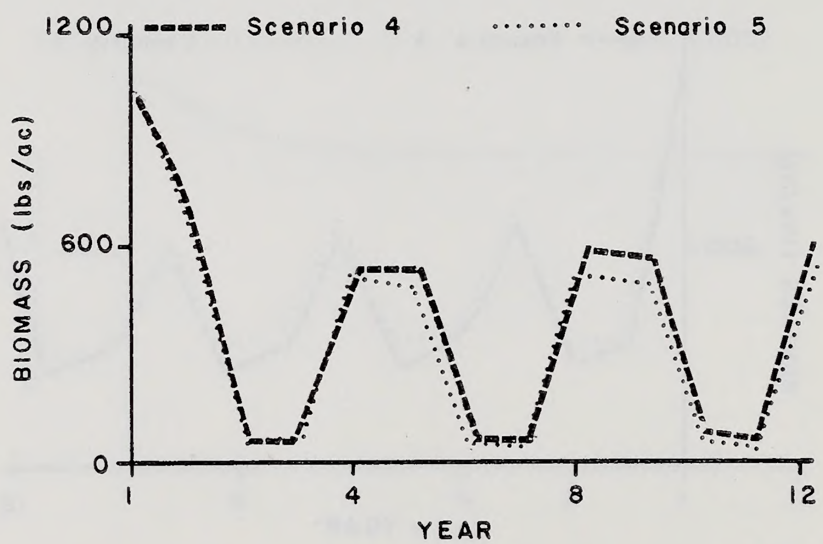

Fig. 7.10b. Annual perennial grass increaser biomass dynamics on E. Independence South pasture, riparian range site, under two cattle food preference scenarios. (See text for scenarios.)

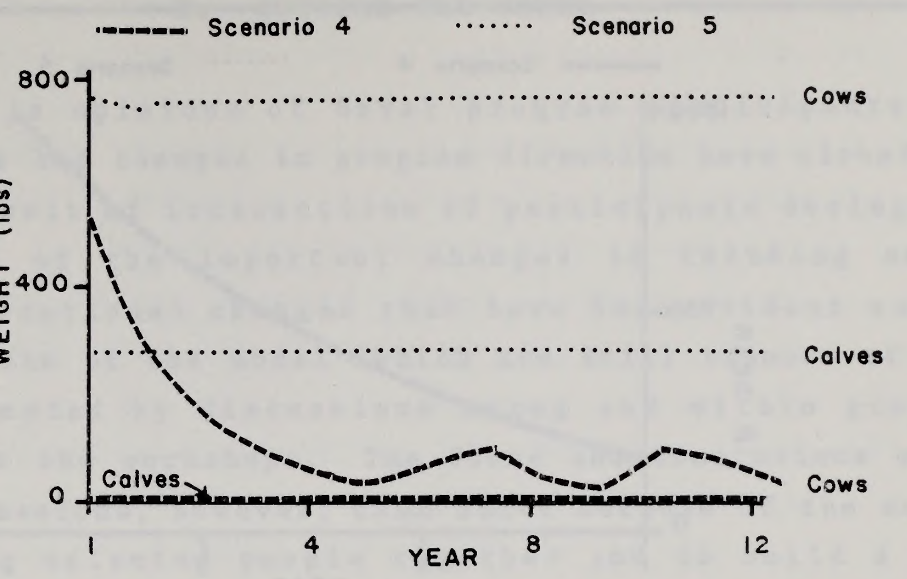

Fig. 7.11a. Annual cow and calf weights under two cattle food preference scenarios. (See text this section for a description of preference scenarios.)

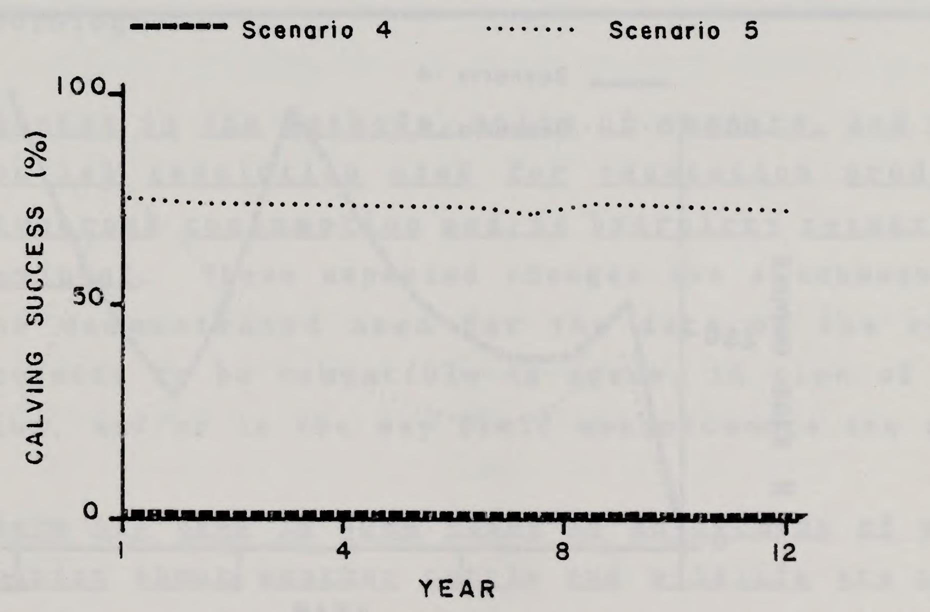

Fig. 7.11b. Annual calving success under two cattle food preference scenarios. (See text this section for a description of preference scenarios.)

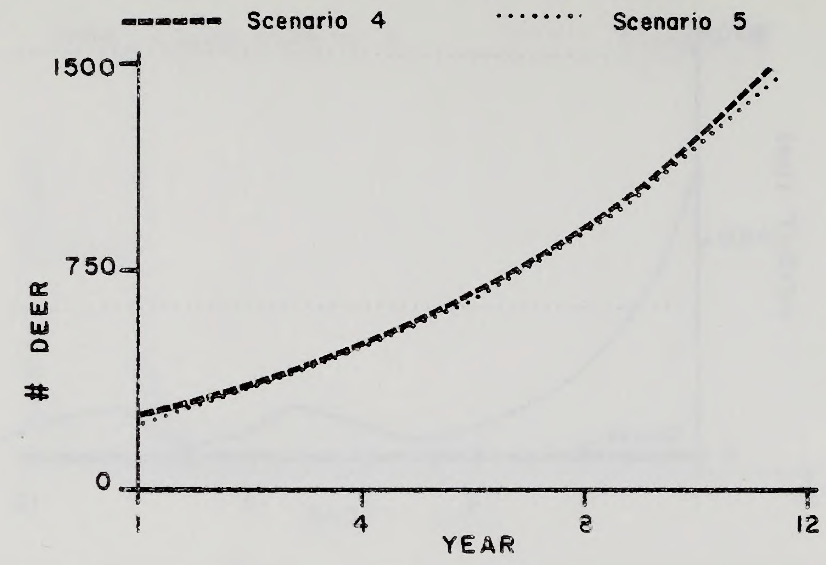

Fig. 7.12a. Total mule deer numbers under two cattle food preference scenarios. (See text this section for a description of preference scenarios.)

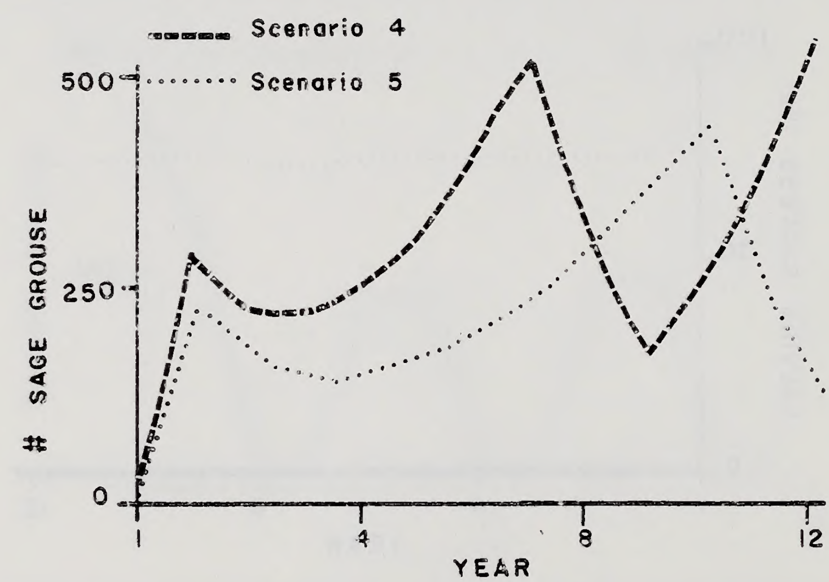

Fig. 7.12b. Total sage grouse numbers under two cattle food preference scenarios. (See text this section for a description of preference scenarios.)

8. OUTSIDE THE MODEL

Changes in opinions of Saval program participants about research needs and changes in program direction have already come about as a result of interactions of participants during workshops. Most of the important changes in thinking and the immediate operational changes that have been evident were not based on outputs of the model (which are still tenuous at best), but were prompted by discussions among and within groups of individuals at the workshops. The focus and conclusions of many of these discussions, however, came about because of the requirement to bring selected people together and to build a model. Examples of changes in attitudes and direction that seem to have evolved independently of model output are noted below.

(1) Major changes in the plans for hydrological research appear to have taken place. These changes seem to have resulted from the apparent differences between the information needs of the vegetation researchers for hydrological data, and the data being generated by the hydrologists.

(2) Changes in the methods, units of measure, and perhaps spatial resolution used for vegetation production, livestock consumption and/or hydrology research seem imminent. These expected changes are a consequence of the demonstrated need for the data of the research projects to be compatible in space, in time of collection, and/or in the way field measurements are made.

(3) There has been in some cases an adjustment of existing opinion about whether cattle and wildlife are compatible. At project outset, consensus seemed to hold that management for cattle and management for wildlife were generally incompatible, and that determining compromise management options was the prime purpose of the Saval

project. But conclusions reached during the workshops strongly suggested that selected range management options could benefit cattle, mule deer, sage grouse, and perhaps other wildlife species simultaneously. As an example, increases in habitat interspersion and herbaceous plant production caused by judicious sagebrush control might increase cattle production, songbird diversity, and grouse and deer production.

(4) The importance of understanding population regulating factors for wildlife species became obvious as a consequence of building the model. As a result of this realization it is anticipated that future research will change to focus more sharply on population regulating mechanisms, and on how the Saval grazing program affects them.

(5) Building the model has made it clear that economics analysis, as it currently exists, cannot accomodate values measured in units other than dollars. To develop an analysis that can comment on values in terms other than dollars (as is needed in the case of many of the wildlife species, for example), the economists need dollar equivalents of values that are currently perceived in other ways.

(6) During the course of building the model, it became clear that environmental changes resulting from the implementation of the Saval Management Plan might be readily overshadowed by the expected annual or seasonal variability caused by weather and other factors; this will make it extremely difficult to separate the consequences of the Saval Management Plan from "normal" change. This points out a major weakness of the program: the lack of control data. Because the program is new, good controls in time are lacking. Moreover,

nearby off-site areas potentially available as controls in space probably differ sufficiently from Saval that the comparability of data from the two would be limited. Innovative methods will be needed to provide useful experimental control.

(7) The need for a more sophisticated data-management scheme than currently exists has become obvious. Building the model has emphasized that the relatively informal methods of data storage and management that currently exist will hinder effective interdisciplinary transfer and use of the data.

(8) The need to more clearly define "quality" in some of the indicators has become evident. For example, it was agreed that songbirds and rodents were important wildlife groups, and that impacts on them caused by the Saval grazing plan should be measured. But a definition of quality in bird and rodent populations that would enable decision-makers to decide if the observed impacts were "good" or "bad" needs to be finalized so research can be appropriately focused.

9. FUTURE DIRECTIONS

9.1 Model Improvements

A simulation model should be simple enough that the output can be logically deduced as the consequence of basic hypotheses. The existing model cannot easily perform this task, because of the expense and complexity of performing multiple simulation runs (the usual method of tracking down the causes of events).

Some suggestions for submodel improvements and simplification are presented within the submodel reports and will not be repeated here. However the major recommendation that does warrant more discussion is a longer time step. Both the vegetation and hydrology submodels could be adapted to function adequately on a longer time step. Although some detail would be lost, we feel the overall trends of the indicators would be very similar and certainly adequate to evaluate the effectiveness of the Coordinated Management Plan. One suggestion is that the model be structured to operate as an event driven model rather than a fixed time step. The events would be the movement of the cattle from pasture to pasture and the timing between these events could be determined or set internally in the model as a function of one or more state variables (for example when the cattle have grazed 50% of the available forage they move to the next pasture). Such a change with the "full" model is probably not warranted at this time. However it does present a reasonable alternative that may facilitate easier development of a reduced version of the model for operation on a micro-computer system.

There is great potential value in simplifying the model down to a micro-computer scale, particularly for educational and evaluative objectives. For a relatively small investment, the Elko offices or other group could make use of the model, as well as the statistical, plotting and other packages available for mini-computers. This is especially relevant to the ultimate objective of the Saval project, namely to provide a transferable product (i.e., the model) that can be used in other locations. The low cost and ease of operation of micro-computers makes it feasible to transfer not only the modeling insights, but also the model itself.

Once a micro-computer model is behaving credibly it should be possible for ranchers themselves to invest in a micro-computer and actually start using the model first hand. This could ultimately meet many of the educational and communications objectives of the Saval Project.

Some of the submodels are presently incomplete in terms of scope of Saval Ranch research, because there was not enough time in the workshops to include all items of interest. This is particularly true of the wildlife submodel, which now includes detail on only mule deer and sage grouse. In addition to these there is significant concern about (and on-going Saval research to investigate) songbirds, small mammals (rodents, rabbits), fish, and others.

Water quality (in terms of sediment delivered to streams) in the model is currently a crude index to fish habitat quality, but substantial refinements need to be made. It was suggested in the second workshop that macrobenthos species composition, abundance, and/or diversity would be better measures of habitat quality for fish, and easier to document in the field than sediment delivery. This needs to be evaluated further.

Environmental variables that regulate populations of grasshoppers, passerine birds, jackrabbits, Belding's ground squirrels, and rodent species diversity were discussed in the second workshop, but there was not time to enter the animal/habitat relationships into the model. Crude representations of important functional relationships between some of these (grasshoppers, jackrabbits, ground squirrels) and their habitats were developed (Fig. 9.1). These need to be refined and entered into the model, and relationships for songbirds and other rodents need to be developed.

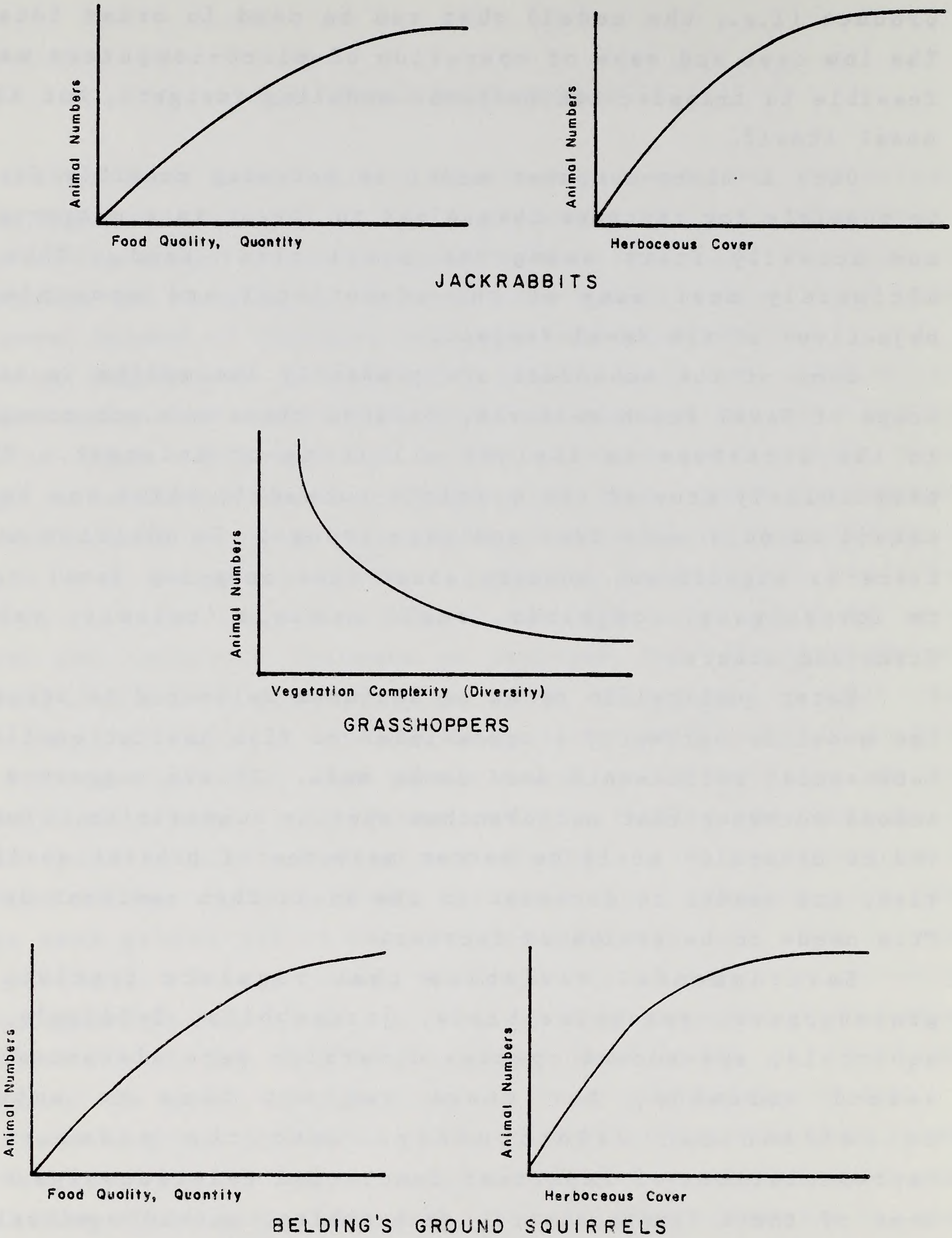

Fig. 9.1. Suspected functional relationships between habitat variables and jackrabbits, grasshoppers, and Belding's ground squirrels. (These have not been quantified or included in the Saval model.)

9.2 Data Management

Much information is being collected in the Saval Project. The total data "bank" can be thought of as existing in three dimensions: subject area, space, and time. That is, information is being generated about different subjects (e.g., range science, wildlife biology, economics, etc.), at different spatial levels of resolution (from the whole ranch down to plant quadrats), and at different time intervals (daily, monthly, annually, etc.) (Fig. 9.2). Furthermore, the data needs to be comparable within and among the subject disciplines (Fig. 9.3).

There are several advantages to a computerized, cross-referenced system of data storage (a "data base") for the Saval Project:

(1) all data can be accessed from one location;

(2) analysis of data across subject areas, between spatial areas, or through time is greatly facilitated;

(3) tabulation or graphical display of results can be performed quickly.

Data base systems consist of at least two components (Martin 1977):

(1) a collection of interrelated data stored together with "controlled redundancy" (e.g., all data might be labelled with a date of collection, pasture number and/or range site number) to serve multiple applications; and

(2) a language and set of programs for adding new data and modifying and retrieving existing data.

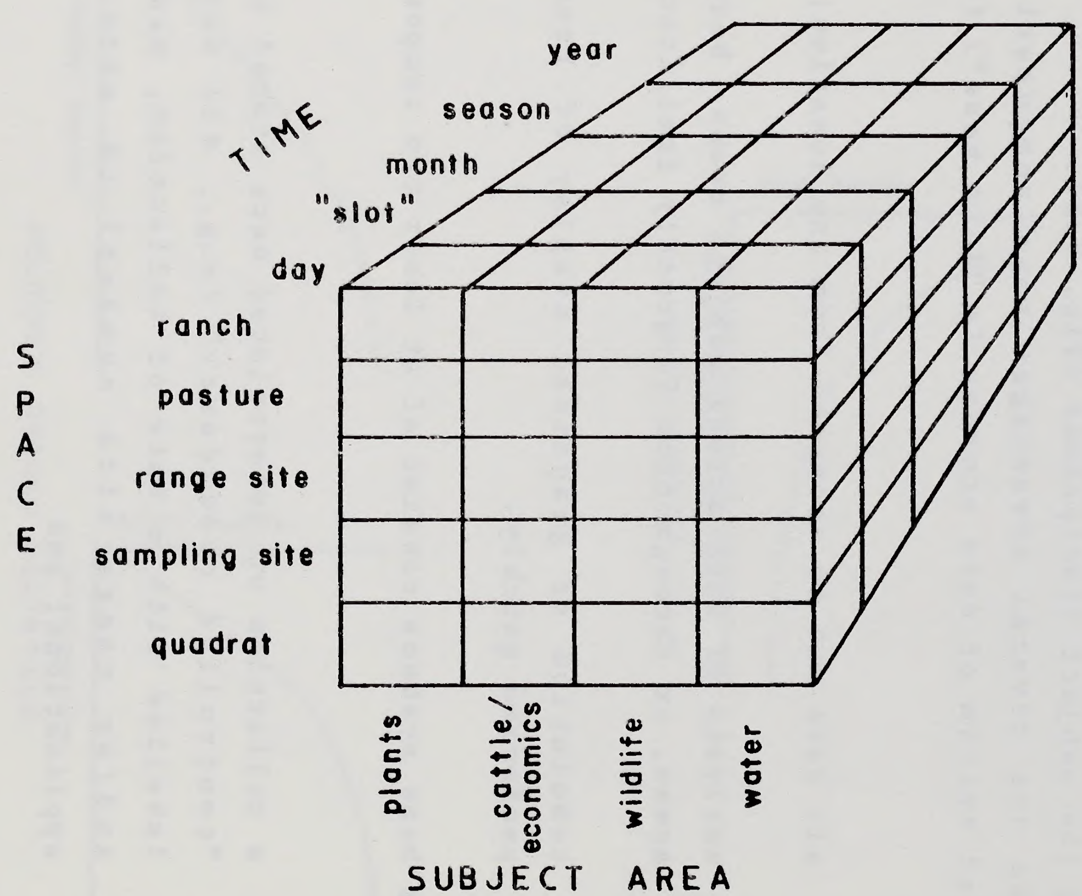

Fig. 9.2. The three dimensions of data being collected on the Saval Ranch.

SPATIAL LEVEL	DISCIPLINE: VEGETATION	CATTLE/ECONOMICS	WILDLIFE	WATER
• multiple pastures to whole ranch	• hay production • total forage production • % veg. cover	• net ranch revenue • non-market values • direct/indirect market values • hay sold • livestock production • cattle weight	• hunter-days • non-consumptive user-days • # sage grouse & deer	• precipitation stations • stream flows
• single pasture or hay meadow	• hay production • total forage production • % veg. cover	• cattle weight gain • cattle diet (fistulated cows)	• # sage grouse • # deer	• bank stability • benthic macro-invertebrates
• single range site	• total forage production • % veg. cover • composition (biomass)	• cattle utilization	• wildlife utilization • # sage grouse • # deer	• soil moisture content • infiltration
• sampling site • soil moisture block • strutting ground • trapping grid	• % cover (two types) • % composition • % occurrence		• # sage grouse • # deer	
• plant quadrat • wildlife transect • individual trap	• vegetative cover • % composition • % occurrence • presence/absence • # of species		• sage grouse nesting sites • mule deer utilization • biomass of small mammals • diversity/#'s songbirds	

Fig. 9.3. Hierarchical nature of data gathered for the Saval project. Arrows indicate that linkage and cross-referencing capability is essential among both spatial levels and disciplines.

Data should be stored so that they are independent of application programs which use the data (i.e., statistical packages, programs for graphing or spatial display, etc.). The storage scheme must represent the associations inherent in the data (i.e., not force awkward restructuring), and must be flexible to allow new data types, cross-references and applications to be added in the future. In addition, the basic structure of the data base should be easily understood by users with no training in programming.

There are many data base systems currently available, which fulfill the above objectives to varying degrees and have widely varying computer hardware requirements. If the Saval Project decides to seriously examine the potential benefits and costs of alternative data base systems, detailed consultations with application and systems programmers are essential. Much time will be saved in the future if it is decided now what cataloging information needs to be recorded by all investigators. For example, data sheets used in the field or laboratory could be formatted for direct keypunching, saving both time and copying errors.

It is probably not worthwhile for the Saval Project to pursue the development of cartographic data bases which, although allowing automated production of maps, require major investments of time and money in digitizing, storage, error correction and programming (Harvard Library of Computer Graphics 1979).

Finally, it should be stressed that data bases are constructed incrementally. A detailed inventory of data being collected either now or in the future (specifying the frequency of collection, spatial resolution, variables being measured, and units of measurement) should be completed as soon as possible. (Terry Dailey has already accomplished much of this.) The next step should be the compilation of a list of all intended future data analyses (across subject areas, spatial areas and time periods), and the assignment of priorities to this list. Construction of a small "prototype" data base on a subset of the whole project's data would permit examination of the potential benefits and costs of a larger system, without major investments of time or money. The prototype should be designed in such a way that pieces could be added to it incrementally.

9.3 Research Design

Emphasis in the workshops and in this report has been on building a simulation model, but the prime objective of research done on the Saval Ranch is not to build a model. It is to help evaluate the consequences of ranch management activities (actions). What the model-building does is help Saval Project scientists perceive what kinds of information are needed to best understand the consequences of activities. It is then up to the scientists to design and conduct research to best supply this information.

9.3.1 General Approaches

There are two kinds of approach for trying to measure the consequences of an operation such as the Saval Ranch management scheme. One, which we will call the 'monitoring' approach, is to select the components of concern (indicators) and try to measure how each changes over time as the range management plan is carried out. In theory this approach documents the cumulative effects of range management actions. The other approach, which we will call 'hypothesis-testing', is to focus on how each indicator responds to a specific action at a specific time and place, and to eventually try to sum the results of each action to evaluate their cumulative effect. It is imperative that the weaknesses and benefits of each approach be evaluated, and the future research for the Saval planned accordingly.

The 'monitoring' approach has two major problems. First, it is usually impossible to validate whether observed changes in the indicators were caused by the actions or by unrelated phenomena, because the variables that might affect the indicators are too many to measure. (A related problem is finding a control area that matches the treatment area in all respects except the treatment.) Second, the results of the monitoring approach are nearly impossible to extrapolate elsewhere, for essentially the same reasons: even should one be able to demonstrate a response to the treatment (action), what combination of factors caused the response will not be clear, and seldom or ever will the same precise combination of factors exist elsewhere. Experience suggests that these problems override most advantages the monitoring approach offers.

The 'hypothesis-testing' approach likewise has two apparent disadvantages. First, the effects of each action must be added in some way to determine the overall effects of the ranch management operation. Second, the results may (as with the monitoring approach) have limited applicability elsewhere. But these problems are more apparent than real. In the first place, one can usually examine (as has been done in the Saval workshops) the mechanisms that normally regulate each indicator, and find that very few of the planned actions are likely to significantly affect the indicator. Research can then focus on these few actions, and adding their effects is simple. And in terms of the transferability of site-specific data, as long as the information collected describes major functional relationships, it is usually broadly applicable (see Reichle 1975, Kerr and Neal 1976, Odum and Cooley 1976, Truett 1980). Moreover, because most actions are localized in time and space, suitable control areas (always required for rigorous design in impact analysis research) are frequently available nearby.

The research plans that currently exist for the Saval Ranch seem to incorporate both research approaches. For example, the stated needs to conduct ranch-wide surveys (of vegetation trend, deer numbers, etc.), to study the effects of the ranching operation as a whole, and to find a control area outside the ranch suggest that researchers are proposing a monitoring approach. Other proposed studies (relationships between birds and vegetation structure, and between cattle diet and forage composition, etc.) are hypothesis-testing types of inquiries and attempt to document functional relationships at selected sites.

We suggest that, to respond to the stated project needs, research on the Saval Ranch emphasize hypothesis-testing studies that investigate functional relationships at selected sites. Only in this way can the research (1) go beyond measuring how the indicators changed, to suggest what caused the change, and (2) provide results that are readily applicable in other places and times. Moreover, evaluating impacts on an action-specific basis makes gaming with the computer model easier (most single-action scenarios can be handled by an APPLE micro-computer) and makes the computer output more understandable.

9.3.2 Cross-Disciplinary Communication

For research to be effective and efficient, there must be a consistent view among managers and research disciplines of what constitutes the problem. Briefly, the problem in the Saval ranch project appears to be:

> Ranch managers desire to make more money by maximizing the annual net production of grazing animals--cattle. They think the new management plan will promote this. Public resource managers (Bureau of Land Management, Forest Service, Nevada Department of Wildlife) want to be sure that other renewable resources (e.g., soil productivity, selected fish and wildlife populations) do not suffer as a consequence. It appears desirable to conduct research to evaluate the plan's financial rewards, and its conflicts with other resources in such a way that both the research strategy and the results can be applied to the same kind of problem elsewhere.

Not only must the view of the problem be consistent, but strong emphasis should be placed on:

(1) Promoting frequent dialogue among field researchers and between field researchers and project management. Suggestions include (1) frequent meetings of all researchers to discuss their current efforts, new findings, and new proposed research plans, and (2) meetings between the field personnel and steering committee (during the regular steering committee seasons?).

(2) Coordinating field research (data collecting) activities among the disciplines. For example, the proposed one-month observation to be made of cattle movement in North Independence Pasture could coincide with before-after measures of vegetation biomass at selected sites in the same pasture.

(3) Insuring compatibility among researchers in the way that components are measured and in the units of measure, if cross-disciplinary use of the data is anticipated. Examples are: (1) If hydrologists need to know total canopy cover of vegetation regardless of the vegetative class, it is difficult for them to use data gathered by vegetation studies that measure only canopy cover of shrubs and basal cover of grasses, and that segregate the data by plant class. (2) Unless wildlife people can convert grouse and deer to dollars, and it is unlikely they will be able to, the value of the wildlife will have to be judged outside the economics analysis.

(4) Making efforts to minimize interdisciplinary communication problems caused by semantic difficulties. For example, much of the terminology describing range

quality has evolved where cattle grazing has been the dominant use of rangeland. It describes how useful the range is to grazers, but not necessarily to anything else. Thus, practices currently called "range improvements" may or may not "improve" the range for animals other than livestock, and wildlife biologists and ranchers may have different perceptions of what such terms mean.

9.3.3 Disciplinary Research

The recommendations for disciplinary research that follow are based on several premises:

(1) The purpose of the research is to evaluate effects of ranch management actions on selected indicators identified during the workshops.

(2) The research design and output should have utility beyond the Saval to the extent possible.

(3) Interdisciplinary coordination of research should be maximized.

As suggested earlier, we believe that hypothesis-testing kinds of research, specific to actions and sites, should be instituted in all disciplines as soon as possible. In this and all impact analysis research, the smaller the spatial scale, and the fewer the variables of interest, the easier it will be to isolate causes for observed changes. Ranch-wide inventories or monitoring programs are perhaps necessary for developing a baseline characterization, for tracking range condition changes, or for formulating important hypotheses, but monitoring-type programs will almost certainly fail to provide statistically valid and defensible answers about causes of changes (i.e., to determine whether observed changes can be attributed to operation of the Saval management plan).

If these kinds of hypothesis-testing programs are adopted, there will probably be little need for "control" areas outside the ranch--they can be found (or created as exclosures, etc.) within the ranch. It is extremely doubtful if an adequate "control" ranch could be located anyway; there would be too many differences in unmeasured variables between it and the Saval that might affect the responses observed.

Additionally we recommend that, as soon as possible, each disciplinary scientist review the literature in his field <u>related to the kinds of functional relationships that emerged as important during the workshops</u>. Certainly each person has already reviewed the general literature about his or her subject, but we are suggesting that each look in depth at <u>a different kind of information, that which discusses how the indicators identified in the workshops are regulated</u>. As noted earlier, these kinds of functional relationships are generally much more conservative from place to place than are data describing levels of populations or other components, implying that literature from many other places and times are relevant. The importance of evaluating these kinds of literature to help researchers formulate important hypotheses and evaluate research results cannot be overstated.

In a practical sense, we recommend that research focus in space on representative actions planned or already implemented on the Saval (e.g., improving irrigation systems in hay meadows, plowing sagebrush and seeding with crested wheatgrass, grazing pastures at given times and with given stocking rates, etc.). At the site of each action, the disciplines to be involved in research would be those that, judged by current knowledge, would hypothesize there to be a measurable effect of the action. For example, based on workshop discussions, it seems that a plowing and seeding operation might affect (1) vegetation production; (2) weight gain by calves; (3) numbers and/or diversities of grouse, deer, songbirds, and small mammals; and (4) water infiltration and evapotranspiration regimes. In this example, a research effort that involves these disciplines might then proceed to test, at appropriate sites, hypotheses about the impacts of plowing and seeding.

A first step in the planning procedure would perhaps be to develop hypotheses about how expected actions would importantly affect each indicator. This would let each scientist determine which actions he might be interested in investigating. Examples of the <u>kinds</u> of hypotheses the workshop exercises suggested were important follow (some of these may have already been tested, and certainly there are others that need testing):

<u>Vegetation</u>

Hay production can be doubled (or tripled, etc.) by improving the irrigation system without changing the annual amount of irrigation water used.

Plowing sagebrush areas and seeding them to crested wheatgrass increases average annual biomass of forbs and cheatgrass produced.

Formulas can be developed to predict (by season?) changing level of cattle use of each plant type (increaser, decreaser, etc.) with distance from water and slope of terrain.

<u>Hydrology</u>

Plowing sagebrush areas and seeding them to crested wheatgrass increases average soil water availability in the top ten inches.

Water infiltration into the soil is significantly diminished when cattle graze pastures at current stocking rates in spring (or summer, or fall).

Water infiltration into the soil is increased and total evapotranspiration is decreased when sagebrush stands are replaced with crested wheatgrass plantings.

Cattle and Economics

Weaning weights of calves (or, alternatively, calving success) are affected more by cow weights the preceding fall than by cow weights in early spring.

Calf daily weight gain on a pasture is significantly increased when the total area of pasture more distant from water than 0.5 mi is reduced from 50% (or any given percent) to 0.

Irrigation improvement (on given hay meadows) is a cheaper way (amortized over 15 yr) of acquiring winter hay than is buying hay from outside the ranch.

Wildlife

Plowing sagebrush areas and seeding them to crested wheatgrass decreases the amount of time deer/sage grouse use the areas during critical periods.

Deer and cattle diet overlap, in pastures used simultaneously by both, is such that competition for food between deer and cattle is minimal regardless of the time of year the pasture is grazed.

Grazing selected pastures in spring (early summer) decreases the amount of time deer/sage grouse use them in spring and summer.

Change in bird/small mammal species diversity as a consequence of a given management action is predictable on the basis of change in vegetation structure caused by the action.

In summary, for results of research on the Saval Ranch to reliably evaluate the consequences of the Management Plan and be readily applicable elsewhere, the research scientists should

(1) Test hypotheses related to impacts of specific actions at specific sites on selected indicators,

(2) Shift away from approaches that attempt to monitor how indicators respond ranch-wide to the sum of management actions,

(3) Clarify functional relationships that strongly influence the behavior of (i.e., 'regulate') the indicators, and that are sensitive to expected actions, and

(4) Require a level of communication among disciplines that promotes interdisciplinary compatability in research goals, field methods, and data collected.

Ideally, research design will continue to evolve as some hypotheses are tested and new hypotheses are developed. The model should guide this evolution and, as new data surface, become more realistic and hence more useful as a management tool.

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