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THE VALUE OF FORAGE MEASUREMENT INFORMATION IN RANGELAND MANAGEMENT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

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THE VALUE OF FORAGE MEASUREMENT INFORMATION IN RANGELAND MANAGEMENT

Prepared for

Office of Applications
National Aeronautics and Space Administration
Under Contract NASW-2558

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NOTE OF TRANSMITTAL

This report is prepared for the National Aeronautics and Space Administration, Office of Applications, under Contract NASW-2558. The data presented in this report are based upon the best information available at the time of preparation and within the resources of the study. Throughout this analysis, an objective viewpoint has been maintained in an attempt to model economic benefits in an unbiased manner. Nonetheless, there are many areas in this analysis where existing data were somewhat weak and where judgment had to be applied. These areas are clearly defined in the report and our rationale for the judgments exercised is stated. We believe that this work represents the most advanced analysis of rangeland management performed to date, significantly extending previous work and providing a basis for the implementation of satellite data in range management.

Principal Investigator for the study was Mr. Keith R. Lietzke. The computer programs used were developed and programmed by Mr. Philip Abram.

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ABSTRACT

In this study, we develop an economic model and simulation to estimate the potential social benefit arising from the use of alternative measurement systems in rangeland management. We present first the background for this study, including a review of previous work in this area. In order to estimate these benefits, it was necessary to model three separate systems: the range environment, the rangeland manager, and the information system which links the two. This has been accomplished using computer simulation. This study uses the most advanced work in modeling the rangeland environment available from the rangeland academic community as well as sophisticated mathematical and computer techniques for simulation. The rancher's decision-making behavior is modeled according to sound economic principles. Results of this study indicate substantial potential benefits, particularly when used in assisting management of government-operated ranges; possible annual benefits in this area range from $20 to $46 million, depending upon the system capabilities assumed. Possible annual benefit in privately-managed stocker operations range from $2.8 to $49.5 million, depending upon where actual rancher capabilities lie and what system capabilities are assumed.

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SUMMARY

In this study, ECON has undertaken the estimation of the value of information in the rangeland economy. This was achieved through the development of a three-part rangeland management simulation. The results of individual case studies were extrapolated to aggregated levels in an attempt to approximate gross benefits attributable to an information system.

The study was performed for the National Aeronautics and Space Administration in order to provide estimates of gross, potential benefits obtainable from an Earth Resource survey system. The analysis permits benefit estimation with satellite capabilities varying in (1) forage measurement accuracy, (2) measurement frequency, and (3) the lag in data availability. The results show that benefits are obtainable from improved information and that the constraining factor in deriving benefits from a satellite system is timeliness. Potential annual benefits of $20.5 million were found in assisting the management of public ranges from a system of estimated LANDSAT-like capabilities, while substantially better timeliness may be required to obtain significant benefits in the private sector. These results are summarized in Table i.

The forage resource in the United States yearly produces 213 million AUM's* with an annual value of between one and ten billion dollars, depending on the valuation methodology

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*AUM - Animal Unit Month. See footnote on page 1-1 for definition.

Table i. Estimated Potential Social Benefit from Use of Remote Sensing in Range Management:U.S.

Measurement System Parameters			Government Ranges		Private Ranges:Stocker Ranches	
Measurement Frequency (days)	Data Lag (days)	Measurement Accuracy (unit.lbs.per 1000 acres)	Percentage Increase in Output	Estimated Annual Value of Percentage Increase in Output ($,millions)	Percentage Increase in Output	Estimated Annual Value of Percentage Increase in Output ($,millions)
18	4	10,000	15.72	20.51	*	*
	1	10,000	23.90	31.18	*	*
	1	2,000	28.30	36.93	*	*
9	4	10,000	18.23	23.79	*	*
	1	10,000	27.04	35.28	*	*
	1	2,000	31.45	41.04	1.77-28.49	2.31-37.18
3	4	10,000	27.01	28.72	0.89-27.37	1.15-35.72
	1	10,000	30.82	40.21	5.53-33.24	7.22-43.37
	1	2,000	35.22	45.95	8.14-36.31	10.62-47.38

* Not clearly significant

Source: The Value of Forage Measurement Information in Rangeland Management, ECON, Inc., Report No. 75-127-4, 1975.

selected. However, forces from (1) increasing demands for beef and (2) increasing alternative demand for feed grains will place pressure on the rangeland resources for increased output. Figure i shows the estimated increased demands for forage to the year 2000.

There exist several avenues for increasing rangeland output which have been identified. It would be possible to divert land from other uses, e.g., agricultural or recreational, to permit grazing. In general, however, land owners will not find the switch from crops to grazing to be profitable, and public sentiment will constrain increased grazing in government lands now used for purposes of recreation. Another avenue for increasing the supply of forage, and one which will find frequent

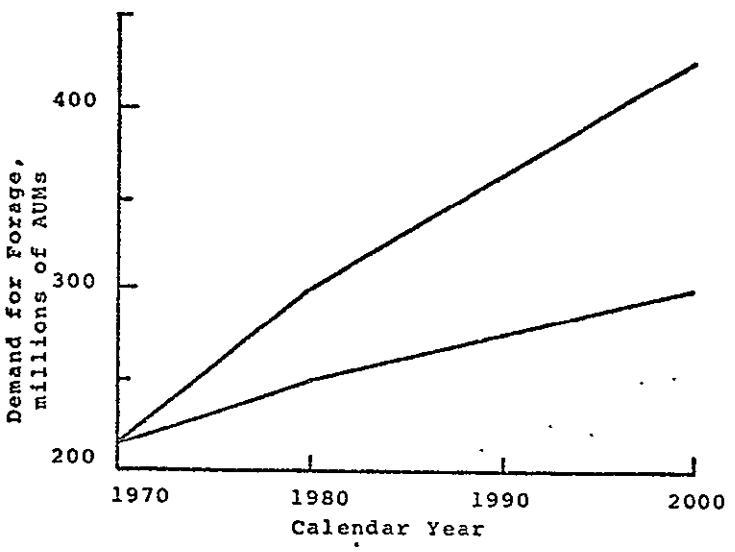

Figure i Estimated Limits of Demand for Forage to Year 2000

Source: USDA, Inter-Agency Work Group on Range and Production, "Opportunities to Increase Real Meat Production from Ranges of the U.S.A.," (non-research).

use, is that of range improvement investments. These activities are the subject of the FRES report,* a study performed by the U.S. Forest Service in which the costs and expected results of range investment are thoroughly documented. The FRES report finds that improved range investment management can significantly lower the cost per AUM and increase the supply.

The effects of uncertainty in forage supply and prices have been treated extensively in the rangeland management literature and it has been found that these uncertainties cause ranchers to intentionally undergraze. Thus, it is seen that improvement of the state-of-information is an additional avenue for increasing rangeland output. Two previous studies have looked at these phenomena: one by Halter and Dean,** and one by Hunter.*** Hunter's study, in particular, provides a good vehicle for assessing the economic effects of imperfect information in range management.

Hunter postulated that, in stocking a range in the face of a stochastic supply of forage (with the distribution assumed known), the rancher necessarily, but implicitly, tolerates a probability of overgrazing. Figure ii illustrates this phenomena.

---

*The Nation's Range Resources-, Forest-Range Environmental Study, USDA, Forest Service, Forest Resource Report No. 19, 1972.

**Halter, A.N. & G.W. Dean. Simulation of a California Range-Feedlot Operation, Gianinni Foundation Research Report No. 282. University of California, Berkeley, 1965.

***Hunter, D. Optimum Resource Allocation through Chance-Constrained Programming, Regional Analysis and Management of Environmental Systems Report No. 14, Colorado State University, 1974.

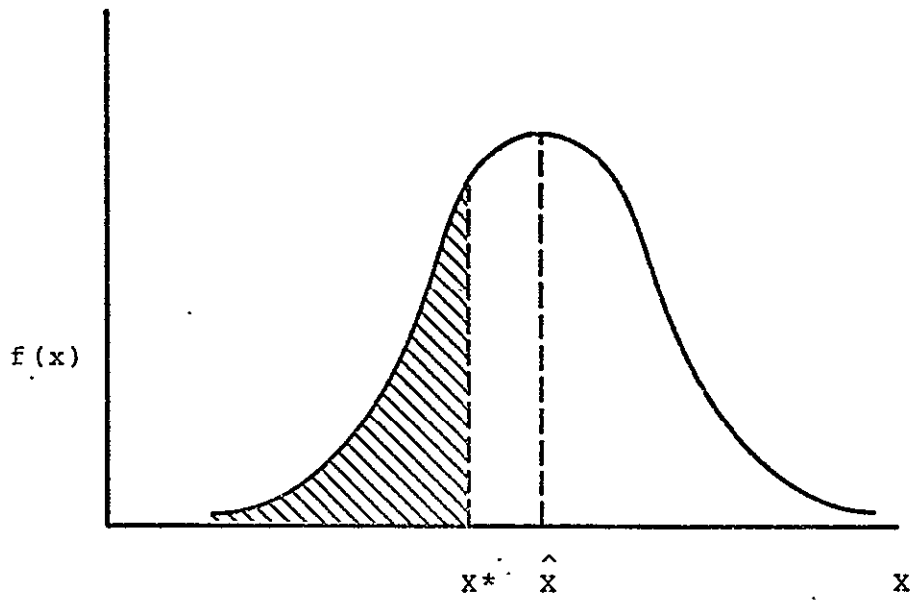

Figure ii Reducing the Probability of Overgrazing

X represents the amount of forage available for consumption during a fixed time interval; $\hat{X}$ represents the quantity of forage which the rancher chooses to graze and corresponds with a selected stocking rate. The shaded area is the probability of overgrazing ($P[X<X^*]$) that the rancher bears in his selection of X^*. This selected probability will be a function of the penalties due to overgrazing, the decision-maker's risk averseness and his time preference for income. In fact, Hunter's study concludes that the rancher will bear a 0.418 probability of overgrazing in any give season and that:

> Overestimating the carrying capacity of rangelands may result in such penalties as the necessity of having to buy supplemental feed or selling the livestock

> at a loss... Although these conclusions cannot be directly obtained from this study, the results indicate that the penalties a rancher must assume for overestimating his carrying capacity are greater than the penalties for underestimating the carrying capacity

and

> ... if the average forage production was normally distributed, the average net revenue was skewed downward (Hunter, p. 37).

The relation of X* to $\hat{X}$ in Figure ii is a function of two factors: the selected probability of overgrazing and the variance in the estimate of available forage, X, (or the standard deviation, σ, i.e., the square root of the second moment about the mean). Figure iii shows that, as long as the selected probability of overgrazing is less than .5, reduction in σ will increase X* holding $\hat{X}$ constant: that is, better information leads to increased rangeland output.

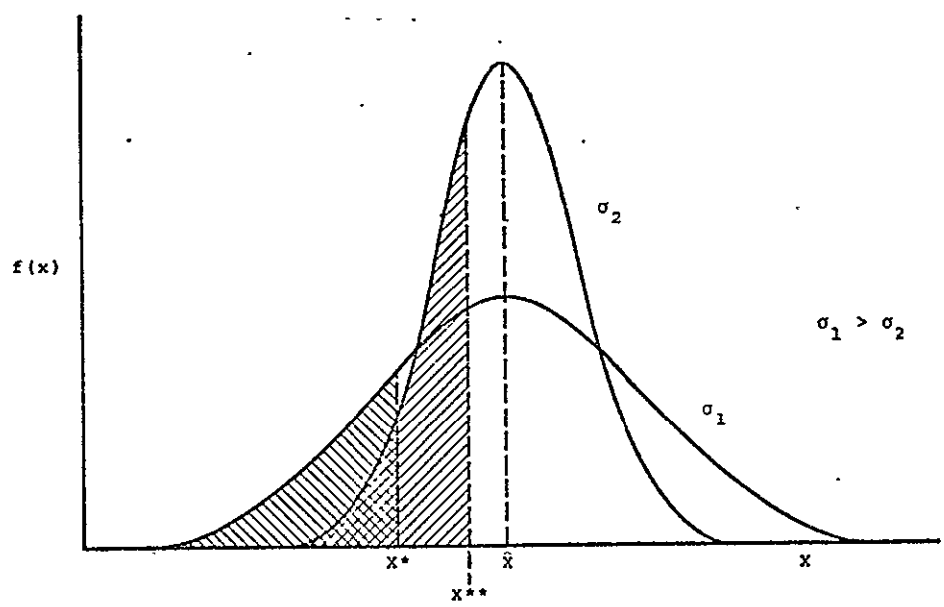

Figure iii Increased Forage Consumption As Measurement Error Decreases

Other range management studies, besides Hunter's, were reviewed for their applicability to this study's purpose. These included work by Westinghouse* and by Frank and Heiss.** Attention was paid to the most recent study by Earth Satellite Corporation.*** EarthSat used the Halter-Dean model and results from the FRES study to estimate the potential benefits from a LANDSAT-like earth observation satellite system. Their results are criticized in this report (Section 2.3) for inaccurate and arbitrary assumptions made about the way in which LANDSAT information would impact management decisions.

Having a methodology from the Hunter study that provides a relationship between rangeland output and the quality of information, the rangeland system is modeled to quantify this relationship. As shown in Figure iv, the rangeland system model is developed in three parts:

---

* EROS Applications Benefit Analysis. Westinghouse, Defense and Space Center, 1967.

** Frank, C.R., Jr. and K.P. Heiss. Cost Benefit Study of the Earth Resources Observation Satellite System, Grazing Land Management. RCA, Defense Electronics Products, Astro Electronics Division, 1968.

*** Earth Resources Survey Benefit-Cost Study, Rangeland Case Study. Earth Satellite Corporation and Booz-Allen Applied Research Corporation, 1974.

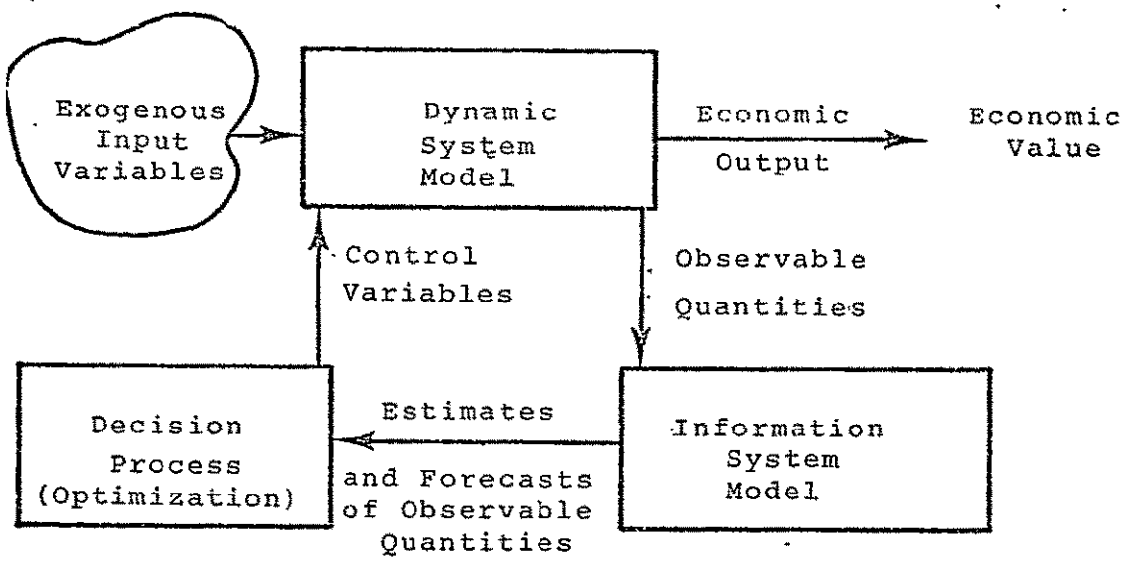

Figure iv Rangeland System Model

1. the dynamic system model (the range),
2. the information system which provides decision information on the state of the system, and
3. the decision process which manages the system (the rancher).

Attributes of the information system are then manipulated in the simulation process and the corresponding responses of the economic outputs measured. Figure v provides a more detailed overview of the modeling approach. Table ii provides a summary of the fixed inputs used in this modeling effort. Aspects of the range dynamic system were quantified using a detailed grassland simulation model called

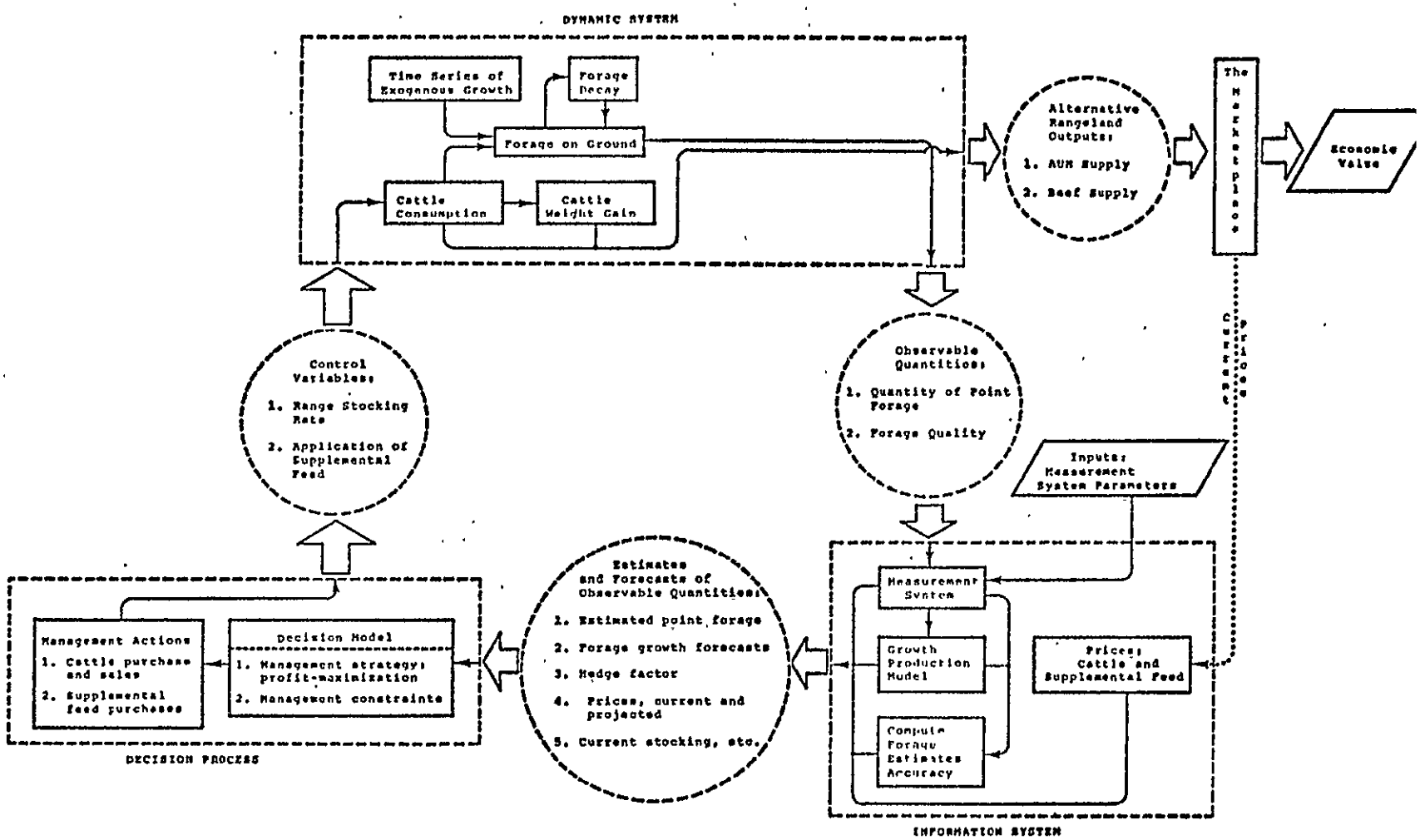

Figure v Flows in Range Management Simulation Model

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Table ii ECON Rangeland Benefit Model: Fixed Inputs

Input	Source of Data Used	Simulation Technique
Forage Growth	RANGES IV Grassland Simulation Model, Colorado State Univ.	Actual Data Used
Forage Decay Rate	RANGES IV	Regression to Estimate Coefficient
Cattle Forage Consumption	RUMEN used in RANGES IV environment, Univ. of Wyoming	Simple Averaging
Cattle Weight Gains	RUMEN	Simple Averaging
Cattle Prices	U.S.D.A., Cattle Auctions in Greeley, Colo. 1955-1962	Time Series Model
Supplemental Feed Prices	Colorado Crop and Livestock Reporting Service 1955-1962	Time Series Model
Transportation Costs	U.S.D.A. Publication	Actual Data Used
Overgrazing Threshold	R.E. Bement, U.S.D.A.	Actual Data Used
Slope of Demand Curve	U.S.D.A. Publication; Stoddard and Smith	Simple Econometric Model
Slope of Supply Curve	FRES Report; U.S.D.A. Forest Service	Simple Econometric Model
U.S. Total of Stocker AUM's Grazed	Earth Satellite Corporation	Actual Data Used
Probability and Cost of Overgrazing	R.E. Bement, U.S.D.A.; D. Hunter, Colorado State Univ.	Regression to Fit Postulated Forms; Optimization

RANGES IV.* Animal activity on the range was simulated using data from a model developed by R. Rice at the University of Wyoming and used in the environment produced by RANGES IV.

One component of the information system, and the primary one for this study is the forage measurement system. This system is inclusively defined by three attributes:

1. the accuracy of point measurement of standing biomass,
2. the frequency of measurement, and
3. the time lag between the point of measurement and the point of information availability to the decision-maker.

A time series forecast model of forage growth was developed, also using RANGES IV data; this is an autoregressive model of order one.

Following Hunter, chance-constrained linear programming was used to simulate the decision-maker; cost and revenue components and constraints were developed independently.

Costs due to overgrazing were estimated and the optimal probability of overgrazing was determined by maximizing the expected net rancher profits. It was found that increases in rangeland output were possible using better information; these increases were translated into social benefit (consumer plus producer surplus) via estimations of the market mechanism.

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*Gilbert, B. RANGES IV Grassland Simulation Model, Regional Analysis and Management of Environment Systems Report No. 17, Colorado State University, 1974.

Management of government ranges was simulated by suppressing decisions (stocking rate changes) in June and August. Gross social benefits* were then estimated for national levels by comparing alternative information systems to those already in existence, using aggregate data presented in the FRES report and by EarthSat. The results of these efforts are presented in Table i.

*The benefits given are gross benefits in that the costs of the information system and information dissemination are not subtracted from the given benefits.

1.0 THE RANGELAND MANAGEMENT SITUATION

1.1 Demand for Range Forage

1.1.1 Current Demand/Supply Situation

The United State supports a cattle and calf crop of approximately 131 million head. [41] These cattle are sustained by feed grains, silage and pasture feeding, but a very significant part of their consumption comes from rangeland grazing. In 1972, the USDA's Forest Range Environmental Survey reported that 1970's annual consumption of range-produced forage was 213 million AUM's. Table 1 presents a breakdown of this production. Cattle (and sheep), as ruminants, have the capacity for turning forage, unusable to man, into material of high protein value. Harvesting range vegetation production, through cattle, greatly increases the supply of protein available for human consumption.

Table 1 Production of Forage by Ownership and Ecogroup, 1970

Ecogroup	Annual Production, thousands of AUMs			
	National Forest System	Other Federal Lands	Non-Federal Lands	All Ownerships
Western Rangeland	5,696	15,551	34,834	56,081
Western Forest	3,334	594	6,801	10,729
Great Plains	1,161	2,465	89,140	92,767
Eastern Forest	1,064	147	52,314	53,525
Total	11,255	18,757	183,090	213,102
(Percent)	(5)	(9)	(86)	(100)

Source: USDA, Forest Service, Forest Resource Report No. 19

* An AUM (Animal Unit Month) is the amount of forage necessary to sustain a mature cow for one month. This is the common unit used in determining the capacity of a range. One AUM = 850 pounds of forage air dry (U.S. Forest Service figure [27]).

The two hundred million AUM's produced annually are used to sustain growth of cattle in the summer and to maintain calving cows and other grazing animals in the winter. Cattle grown in this environment are later sold to feedlots to be finished off on grains for consumer sale. As early as 1952, Sprague [28] estimated the value of this range resource at 10.6 billion dollars. Since that time, forage output and substitute feed grain prices have multiplied.

1.1.2 Anticipated Increases in Future Demand

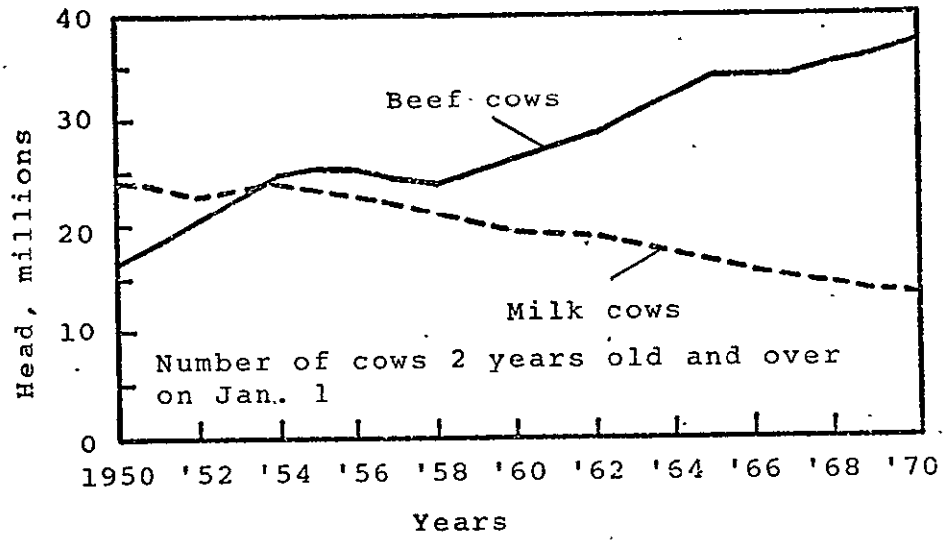
Near-term future demand for forage output can be expected to increase for several important reasons:

1. Increasing demand for beef --
Growing U.S. population, per capita income, and consumer preference for beef have all contributed to rapidly increasing beef cattle numbers. Figure 1 illustrates this trend. Consumer preferences and income increases have pushed 1970 per capita consumption of beef and veal 60% above its rate in 1950 (Figure 2). If this trend continues, as is expected, there will be increasing pressure on the range system to support more production.

2. Increasing export demand for grains --
Economically, it is important to maintain a strong balance of trade surplus in agricultural commodities. Particularly in the face of recent large payment deficits due to soaring oil prices, agricultural exports, most of which are grains, are an important means for getting some of that money back into the country; Figure 3 illustrates the important role agricultural products play in our balance of payments. For political and humanitarian reasons, it is one of the U.S.'s greatest advantages to produce more food than is consumed in our country and thus to help reduce the world food shortage. Annual U.S. coarse grain exports* have risen from 18.8 million metric tons in 1970-71 to 38.6 metric tons in 1973-74 [38]. As foreign demand for grains continues to increase, lands which produce roughage for harvesting will have increasing pressures to convert to grain production. Feed grains will become more expensive and it will be more profitable to fatten cattle longer on the range and less in the feedlot. These trends have already begun [40].

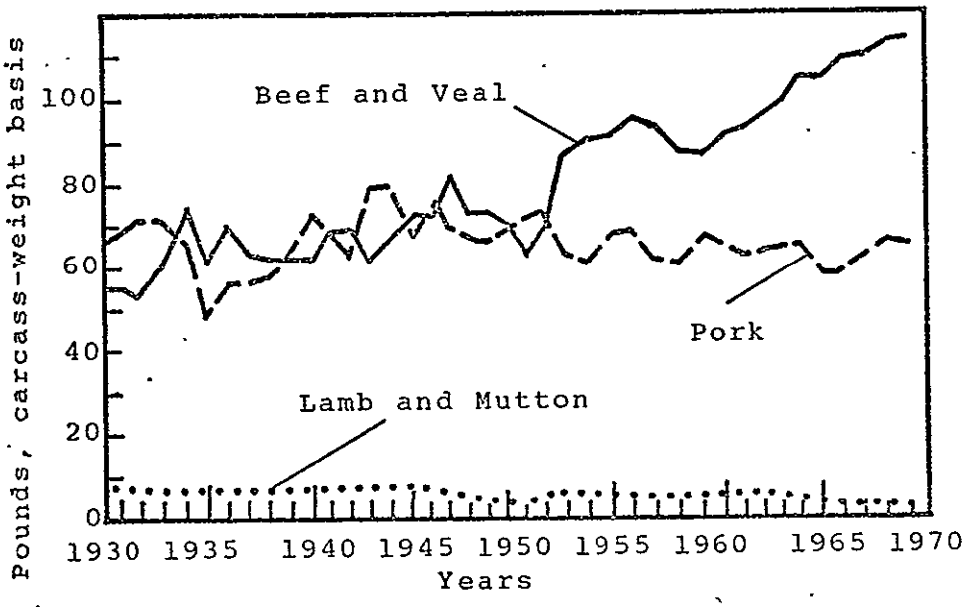
> Feeders who have been buying older, heavier cattle and feeding them for 60 to 90 days are realizing a more favorable return than those on longer feeding programs. USDA economists note that, with conditions of high feed costs, lower feeder cattle prices, and a fluctuating fed cattle market, feeders who start with heavier cattle may be in the best position in

* Total of rye, barley, oats, corn and sorghum.



Source: U.S. Department of Agriculture

Figure 1 Beef and Milk Cows on Farms, 48 States



Source: U.S. Department of Agriculture

Figure 2 Meat Consumption per Person

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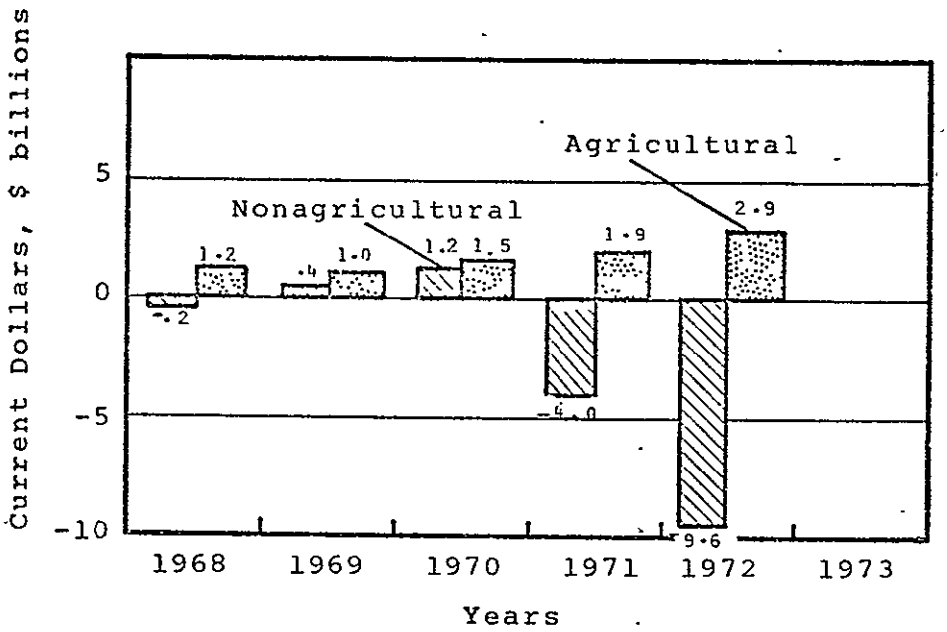

Source: U.S. Department of Agriculture

Figure 3 Net Exports over Imports

the months ahead. In the long-term, feeding of calves will probably continue to decline as high feed costs discourage this type of operation.

On the basis of these demand pressures, the USDA projects the necessary rangeland output increase at 50 to one hundred per cent over current production by the year 2000 (Figgure 4). A six agency report, "Opportunities to Increase Red Meat Production from Ranges of the United States," cites the need for procedures which will contribute toward the satisfaction of this supply objective, including [34]:

--eliminating the disparity in USDA policy emphasis between range and crop production

--more fully utilizing the Department's educational resources

--accelerating technical assistance to all range operators

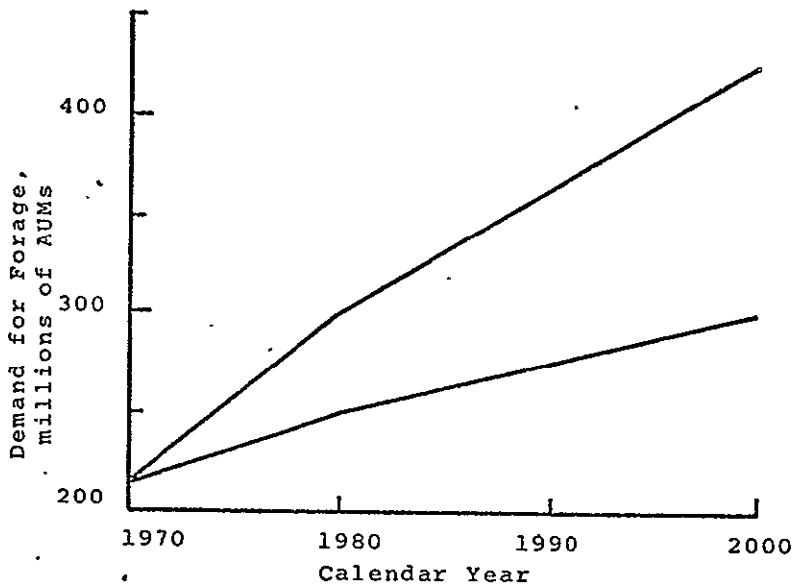

Figure 4 Estimated Limits of Demand for Forage to Year 2000

Source: USDA, Inter-Agency Work Group on Range and Production, "Opportunities to Increase Real Meat Production from Ranges of the U.S.A. (non-research)"

--demonstrating optimum range management systems on the National Forest System and associated private lands

--developing and managing the National Forest System to its full economic potential, and

--changing the USDA meat quality grades to reflect consumer preference and recognize the nutritional value of range-fed beef.

1.2 The Rancher's Situation

The current and prospective macroeconomic environment in which the cattle rancher finds himself has been outlined above. But being a profit-maximizer, the rancher is not as interested in the trend in U.S. feed grain exports as in next month's beef prices. Accordingly, we will outline some of the important areas of the range manager's microeconomic situation, in which this rancher simulation has been developed.

1.2.1 Uncertainties

Whereas there are many aspects of the range manager's decision-making for which he has good knowledge -- e.g., given certain feed conditions, he can calculate cattle consumption and weight gains with good accuracy -- there are many conditions of great importance to rancher's decision-making for which his knowledge is inadequate, and correspondingly, profit loss can and does take place. Well recognized in this area are future price uncertainty and future forage growth uncertainty.

Because of future price uncertainty, ranchers tend to follow restrained (risk-averse) cattle buying patterns. This means that, even though forage feed conditions are very good, range managers do not fully stock because of the investment risk involved in the purchase of many cattle. Further, conservative (naive) price prediction models used by ranchers have been shown by Halter and Dean to result in lower profits and lower stocking rates [18] (See discussion in Section 2.3.3).

Future forage growth uncertainty is also an inhibiting factor on range stocking. Range managers, in trying to minimize costs, usually do not find frequent adjustment of range stocking rates to be a profitable activity, particularly when they have cattle grazing on leased land ten or fifty miles from home. Their goal in choosing a stocking rate is to find one which will be acceptable on the rangeland over a four to six month season. Since forage growth exhibits extreme variation, since growth prediction techniques are not accurate, and since overgrazing is very costly, the rancher tends to undergraze his range. D. Hunter has estimated that this type of restrained stocking activity results in 8% undergrazing on privately managed ranges [19] (See discussion in Section 2.4.).

A third type of uncertainty, although one which has not received as much attention, is the inaccuracy involved in assessing current forage condition (point forage estimates). The range manager sets and adjusts stocking rates usually by visually

sampling his ranch and relating his observations with past conditions. This process involves two types of errors: one, there is some measurement error in the rancher's viewing, say, an acre plot and recording, "There are about 200 more pounds of forage here now than there were at this time last year" -- we can assign a certain accuracy to this estimate; two, any sampling process inherently involves sampling error which comes, for example, from extrapolating from a one acre plot to a ten acre plot. Given the size of these two errors, one can determine the total accuracy the range manager has in assessing the current state of his forage resource.

This third type of uncertainty, although important in all areas of rangeland management, is particularly significant in two areas: government-administered grazing lands and regions with ephemeral forage. Federal administrators have large, extensive areas to manage and have been allocated precious little funds to do so. Monitoring range condition and range condition trends is done annualy on most federal lands. Allowable stocking rates are determined once a year and sometimes updated in mid-season according to general conditions. Broadly, the objective is to determine stocking rates which will be acceptable over many seasons and which will not promote range condition deterioration. As a result of these restrictions, there is much of the resource which is not being used, lest the incidence of overgrazing increase. More frequent monitoring of conditions on these lands could contribute much toward utilizing available resources without increased damage to the rangeland.

In the Southwestern United States, arid conditions interrupted by brief occurrences of rainfall cause sporadic growth of vegetation called ephemeral forage. This vegetation comes quickly and deteriorates rapidly after rainfall and is frequently ungrazed because its presence is unknown. Timely information about this growth, gathered by a system with greater measurement frequency than is presently used, would permit harvesting of this resource.

1.2.2 Dealing with Uncertain Forage Availability

As stated in the previous section, the rancher cannot know the exact amount of forage which will be available for consumption by cattle which he places on the range. Consequently, he faces the possibilities of (1) understocking the range and letting some forage go ungrazed, thus losing profit potential or (2) overstocking the range and

a) if overstocking is recognized, cattle may be sold at an earlier date

b) if overstocking is recognized, forage may be supplemented with purchased feed grains and roughage

c) if overstocking is not recognized, overgrazing occurs and the range is damaged.

Put simply, overgrazing is that activity which violates the principle of sustained yield. Overgrazing occurs when foraging animals consume vegetation so as to harm the reproductive capabilities of the plants. This results in a loss of forage resource in the following year or years and, generally, the overgrazed range must be left ungrazed for some recovery period, six months to one or two years. Any more than minimal plant damage can also contribute to severe soil erosion which can damage the range for periods of several years.

A hypothetical rancher's choice can be constructed. If a rancher chooses to overgraze during a season at a rate of 85 pounds of forage per acre for a 4-6 month season, on a 100 acre range he could consume about 10 AUM's (1 AUM=850 pounds of forage) over rates which would promise no plant damage. If his cattle gain about one pound per day and can be sold at $22.00 per hundred pounds, the rancher could realize a $10 \times 30 \times \frac{\$22.00}{100}$ = $66 profit increase on those one hundred acres over and above his profits if he chose not to overgraze. However, that is only this year's situation. Next year he will (hypothetically) have to rest the range in order for it to produce normal forage in the future. If the range produces 250 pounds of growth per acre, his loss the following year will be 25 AUM's or $25 \times 30 \times \frac{\$22.00}{100}$ = $165. The rancher will make this choice according to his time preference in revenue. It is possible that the manager may be planning to sell the range or employ it in some alternative use. In this situation, it could be to his advantage to overgraze. However, this is not generally the case.

The cost of overgrazing would be expected to have a shape similar to that shown in Figure 5. One would expect this convex shape for three reasons:

1. Moderate overgrazing injures the reproductive capabilities of the plants. A small amount of overgrazing means that the range must be rested for a short period of time; more overgrazing requires resting for a longer period of time. Costs here are associated with the discounted value the range would have otherwise had while it is being rested.

2. More severe overgrazing does more permanent damage to the range. It may kill the plants and cause erosion so that regrowth is no longer possible. Severe overgrazing decreases the value of the range as a forage-producing asset for a long period of time.

3. At some point there is simply not enough forage for sustaining the grazing animals. If a rancher stocks his range just prior to a severe drought and leaves the country for six months, he would return to find not only damaged rangeland but also a total loss in his cattle investment! This is a further cost of overgrazing. Even before the situation becomes extreme, cattle competition for the resource results in decreased consumption and weight gains.

Estimates of actual costs of overgrazing are delinated in the Section 4.4.1.

In determining optimal stocking rates, the rancher must weigh the advantages and disadvantages of his options. In particular, he must consider the effects of overgrazing and their implicit costs versus the profits foregone when understocking takes place.

Since there are costs associated with both options, the rancher of course would prefer to graze optimally, (neither overgrazing, nor undergrazing) but since he has imperfect knowledge of the forage resource available to him (and assuming an error with a continuous distribution), the probability of his chosing the "optimal" stocking rate is zero. Rather, the rancher will almost always bear some probability of overgrazing (P_o) and, correspondingly, some probability of undergrazing ($P_u = 1-P_o$). From observations, the range manager has available to him some estimate of optimum consumption during the season, $\hat{X}$, and he knows the distribution of error in his estimate, $E = N(0,\sigma_x)$. He can thus calculate the probability distribtuion of actual forage, as shown in Figure 6.

If he were to choose a stocking rate such that $\hat{X}$ amount of forage were consumed, he would be bearing a 50% chance of overgrazing. Where the rancher chooses to graze will depend upon several factors: the relative costs of overgrazing and undergrazing, the rancher's time preference for income, his risk averseness, and the size of the error in estimating forage availability.

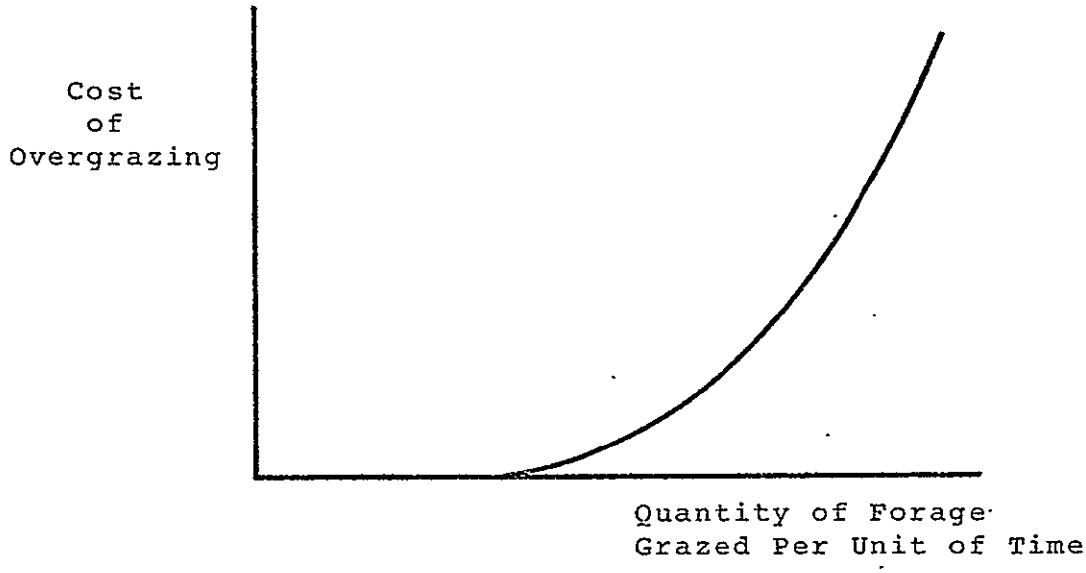

Figure 5 Cost of Overgrazing

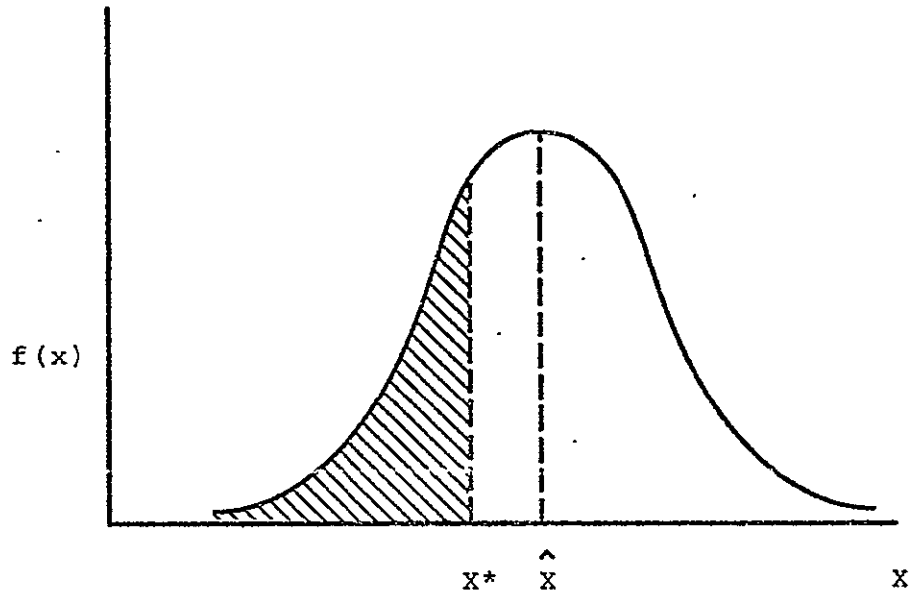

Figure 6 Error Distribution in Knowing Available Forage (X), and Probability of Overgrazing

It is generally accepted that overgrazing is very costly in the long run and is to be avoided. Thus, one would not expect the rancher to tolerate a probability of overgrazing greater than 0.5. Figure 6 illustrates this situation. Where $\hat{X}$ is the optimal grazing rate for a deterministic system, X* is the optimal rate in the stochastic system, with the shaded area representing the probability of overgrazing. The rancher manipulates the probability of overgrazing which he tolerates by "hedging" on his best guess of available forage (i.e., grazing less than $\hat{X}$). Hunter has documented that it is to the rancher's benefit to undergraze in the face of uncertain forage availability: "...if the average forage production was normally distributed, the average net revenue was skewed downward [8a]." These results are shown in Figure 7. Hunter found that expected profits would be maximized when $P_o = 42\%$ and that this resulted in about 8% underutilization of the range resources given the forage variability used in the simulation. Referring back to Figure 6, the 42% refers to the shaded area under the curve and 8% refers to the distance $\frac{\hat{X} - X^*}{\hat{X}}$.

1.2.3 Benefits Due to Increasing Accuracy in Estimation of Forage Availability

Clearly, by improving his knowledge of forage availability, the rancher could profit. This is shown in Figure 8. By improving his knowledge of X (decreasing the variance in his error, ε) and still holding P_o constant, the rancher can graze at a higher rate. He thus can realize additional profits by grazing more cattle, or the same cattle for a longer time.

It may be to the rancher's advantage to expend resources to improve his state of information: he may hire more workers to more frequently watch changing range condition; he may rent a light aircraft to take pictures of forage conditions; or he may invest in equipment which will measure soil moisture and thus improve his forage growth prediction capabilities. Presumably the individual rancher will divert resources toward this activity until the marginal revenue from improving his forage availability knowledge is equal to the marginal cost of such improvement so long as he is aware of the benefits obtainable. Since ranchers do survey their range conditions occasionally, at some expense to themselves, it can be assumed that the marginal revenue afforded by this improvement in forage availability estimation accuracy is at least equal to the cost of such an improvement. This study will attempt to document the gross monetary benefits of improved accuracy in estimating forage availability, resulting from better knowledge of present conditions or of future growth, in order to assist range manager's and government policy-maker's decisions on investments in this type of activity.

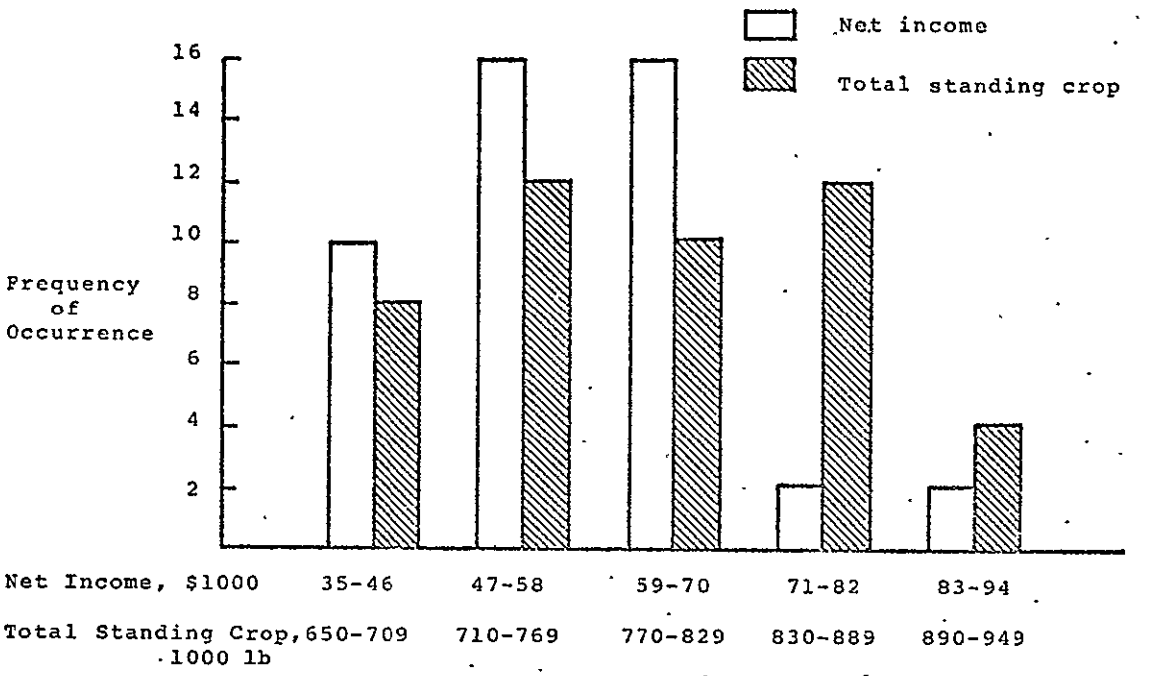

Figure 7 Frequency Distributions of Available Forage and Net Income from Hunter Simulation Results.

Source: Optimum Resource Allocation Through Chance - Constrained Programming, RANGES Report #14, p. 38.

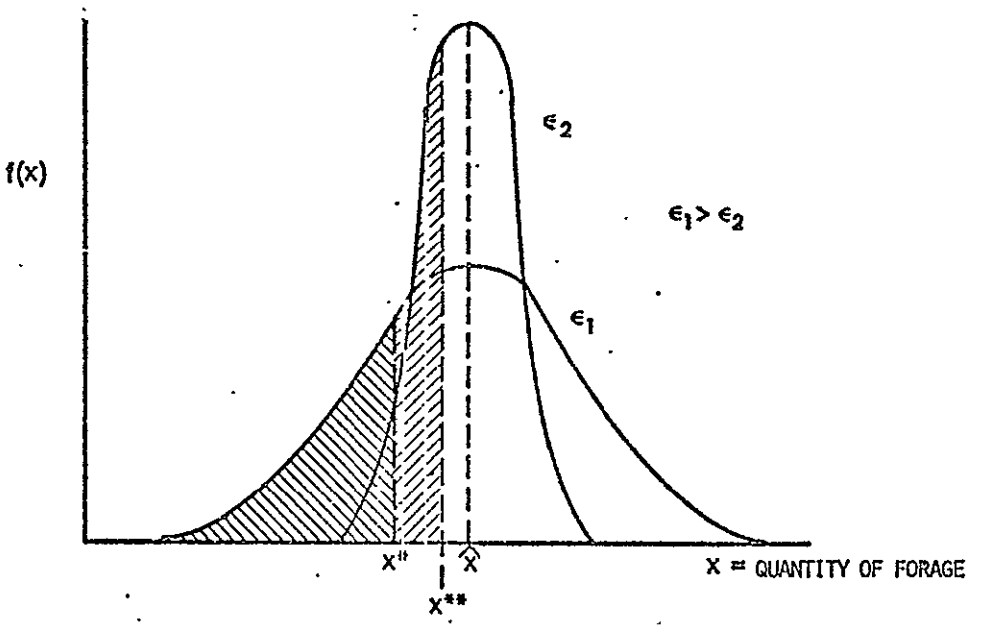

Figure 8 Increased Forage Consumption As Measurement Error Decreases

1.3 Opportunities for Increasing Forage Supply

Returning to a macroeconomic view of the situation, we have already mentioned the need for increasing the supply of forage for cattle consumption over the next thirty years. The Federal government has significant control over the aggregate supply of AUM's. One option available is to open Federally-owned rangeland for intenstive or even exploitative grazing. This solution, however, is not very attractive if carried too far, for exploitative grazing damages the range and inhibits future forage production. Further, Federally-owned rangeland is a multi-use resource with output including wood, water, environmental beauty, rare and endangered animal species, hunting, and other outdoor recreation. Increased pressure for forage output restricts these other competing outputs and, while some forage increase on Government lands is likely, consideration must be given to the other uses of rangeland.

Range investment practices also will contribute to increased AUM supply. Forage output increases here can be effected by any of several activities including [39a]:

- Fertilization
- Irrigation
- Drainage
- Brush control - mechanical
- Brush control - chemical
- Brush control - biological
- Brush control - fire
- Debris disposal
- Undesirable forb control
- Mechanical soil treatments
- Seeding
- Prescribed burn for forage improvement
- Rodent control
- Insect and disease control
- Small water developments
- Large water developments
- Fences
- Timber thinning

These investments all have their costs and it is expected that range owners will engage in them where they feel it is profitable to do so. Federal policy-makers can aid AUM supply by making investments on public lands and/or by encouraging ranchers to do so on their own land or on Federal land which they graze. However, in spite of the recently acknowledged need for increasing range outputs, no increased funding for range management exists in the primary Federal agencies, the Forest Service and the Bureau of Land Management [33a, b].

The emphasis of this study, however, is not meeting forage demand through range investments, but rather what possible technical support could be offered by the Federal government, particularly in the area of improving knowledge of forage at the time of stocking decisions and improving predictions of future forage growth over the stocking seasons.

1.3.1 Improved Measurement Accuracy

As has been demonstrated, in the face of uncertain forage conditions, the rancher maximizes expected profits by grazing at less than rates which would be optimal under deterministic systems. The complementary situation holds on Federal lands grazed by lease by private ranchers. The range-managing government agencies have tremendous areas to cover with little manpower allocated to do so. They are unable to maintain a high accuracy in knowing range conditions and, as a result, they can only allow relatively small herds to graze leased areas in order to avoid overgrazing. Measurement systems which allow for superior knowledge in assessing current forage availability will allow for increased animal output from grazed land without increasing the risk of overgrazing. Systems such as NASA's Earth Resources Survey (ERS) could contribute such information on both private and Federal lands with minimal cost to the user.

1.3.2 Improved Forage Growth Prediction Accuracy

In the rangeland science literature one can find studies designed to facilitate forage growth prediction. Much research funding has been devoted to clipping studies and the effects of weather, soil, soil moisture, grazing intensity, etc. on forage growth; however, generally, these relationships are not well quantified. Predicting next month's forage growth remains altogether not much more accurate than predicting next month's weather, for the two are highly correlated. However, there are some measurable parameters which can improve growth prediction and, as mentioned, one of these is ground soil wetness. Measurements and superior measurements of these parameters can contribute to improved growth prediction and, as before, can permit higher grazing rates.

Measurement systems which can record these parameters (current forage and growth-dependent factors) will thus expand rangeland output and will be of benefit to those affected by the industry: beef producers and consumers. A preliminary (very rough) estimate of the trade-off here is that a one percent improvement in forage availability estimating accuracy will yield about a 0.8 percent increase in the supply of AUM's. This preliminary estimate is based on the results of the simulation by Hunter [19], which said that, if there was approximately a 10% error in forage availability estimates, rangelands would be undergrazed at about 8%.

2.0 RANGELAND MANAGEMENT STUDIES - A REVIEW

The rangeland management literature and funding in support of NASA's ERS program have produced several simulations which deal with the effects that imperfect information have on range managers. Some of these studies have been reviewed during this project and summary descriptions of them are found below.

2.1 Westinghouse - EROS Applications Benefit Analysis

On the basis of several interviews with the Bureau of Land Management, Westinghouse [44] estimated in 1967 that earth resource information could contribute a 10% increase in the efficiency of the BLM. They then multiplied the BLM's budget by 10% to arrive at a $5.4 million estimated benefit.

2.2 Frank, Heiss - Cost Benefit Study of the Earth Resources Observation Satellite System, Grazing Land Management

In a study performed in 1968 for RCA [15], Frank and Heiss estimated benefits from an ERS system in three categories:

1. cost reduction in substituting satellite photography for aerial photography
2. benefits from forecasting range conditions
3. benefits from forecasting forage growth

Frank and Heiss found that the Bureau of Land Management and the Forest Service of the USDA together spend about $175,000 annually in aerial photographs of grazing lands. They further estimated that the total value of complete annual coverage of all grazing land would be about $1 million, if they were able to be provided at about one-half the cost of current aerial photographs. Since aerial photographs currently are capable of resolution superior to that envisioned in an ERS system, satellite pictures would not be perfect substitutes for the next ten years. Thus, Frank and Heiss estimated that satellite photography could currently replace 10% of aerial photographs at a gross annual benefit of $100,000.

Frank and Heiss felt that identification of plant vigor and density early in the season could contribute to early identification of range condition trends. Such monitoring could identify areas of insect or disease infestation and assist procedures to protect the resource. This would be particularly important where improvements have been recently made. They estimated that at least a one-half of one percent increase in the total value of all forage resources could be affected by this type of monitoring, thus arriving at an annual gross benefit of $8.75 million, assuming total annual forage value of $1.75 billion.

Knowledge of variables such as plant vigor and soil moisture content have been shown to improve later forage growth forecasts. Frank and Heiss felt that these forage growth forecasts could be made by central agencies using ERS information and distributed to individual ranchers, resulting in prediction accuracy presently unavailable. Using the results of a study performed by Dean [10], which estimated that a "perfect predictor" could increase ranch income by about 12 percent, they estimated that the improved forage growth prediction capabilities available through an ERS system could also increase total forage value by one-half of one percent. This amounted to an annual gross benefit of $8.75 million.

2.3 Earth Satellite Corporation - Earth Resource Survey Benefit - Cost Study, Rangeland Case Study

In this study [14], contracted by the Department of the Interior in 1974, EarthSat made use of two previous studies in an attempt to arrive at the monetary benefit possible using ERTS*-type information in rangeland management. EarthSat concluded that ERS benefits could be found in three areas of rangeland management. Benefits from inventorying range resources for reallocation and from monitoring range resource for improved range productivity were estimated using results found in the FRES report, performed by the Forest Service. The Halter-Dean Range-Feedlot Model was used to estimate benefits in range feed condition reports for livestock inventory decisions.

2.3.1 Forest-Range Environmental Study (FRES)

In 1970, the Forest Service of the USDA completed a comprehensive survey of the Forest-Range resource based in the United States [39]. This study categorized the entire rangeland environment by ecogroup and ecosystem. The study then documented 22 outputs of each of these ecosystems and rated their values. Some of these outputs are listed on page 1-15 of this report. The FRES report outlined the possible rangeland management strategies and objectives available to the Federal range managers:

A. Environmental management without livestock: Livestock are excluded by fencing, riding, public education, and by incentive payments. The environment is protected from natural or other disasters, such as wildfires or pest epidemics. Resource damage is corrected to maintain a stewardship base. Costs for this strategy are charged to other benefiting resource areas (watershed management and timber management) and

*NASA's Earth Resource Technology Satellite-1, now LANDSAT-1.

to stewardship resources areas (fire protection, pest control, and lands). That is, no cost is charged to range under this strategy.

B. Environmental management with livestock: Livestock use is within the apparent present capacity of the range environment. Investments for range management are applied only to the extent required to maintain the environment at a stewardship level in the presence of grazing. Investments for implementation may be very low for some resource classes. Resource damage resulting from past use is charged to benefiting or stewardship functions. The goal for the strategy is to attain livestock control. No attempt is made to achieve livestock distribution.

C. Extensive management of environment and livestock: Management systems and techniques, including fencing and water developments, are applied as needed to obtain relatively uniform livestock distribution and plant use, and to maintain plant vigor. Management seeks full utilization of the animal unit months available for livestock grazing. No attempt is made to maximize livestock forage production by cultural practices such as seeding.

D. Intensive management of environment and livestock: All available technology for range and livestock management is considered. Management seeks to maximize livestock forage production consistent with constraints of maintaining the environment and providing for multiple use. Existing vegetation may be replaced through improvement in growing conditions. Structures may be installed to accommodate complex livestock management systems and practices. Advanced livestock management practices are commonplace.

E. Environmental management with livestock production maximized: Stewardship of soil and water are required. Timber may be completely removed. Multiple use is not a constraint.

Exploitative management, a strategy which violated the principle of substained yield, was also considered an option. Additionally, the FRES report documented how present grazing lands, public and private, are being managed. Table 2 shows how these management strategies were employed by ownership and by ecogroup. Table 3 shows how AUM productivity is affected by management strategy.

Table 2 Management Strategies by Ownership and Ecogroup, 1970
[Totals may not add due to rounding]

Ownership by ecogroup	No livestock (A)	Some livestock (B)	Extensive management (C)	Intensive management (D)	Maximize livestock (E)	Exploitative (X)	Total
	Thousand Acres						
National Forest System:							
Eastern Forest	19,734	3,004	443	5	----------	129	23,318
Western Forest	30,135	35,864	20,718	327	----------	20	87,066
Western Range	15,009	16,596	16,524	2,576	----------	881	51,588
Great Plains	543	2,001	1,216	122	----------	19	3,903
Total	65,421	57,466	38,903	3,032	----------	1,051	165,875
Other Federal:							
Eastern Forest	8,690	156	54	2	----------	128	9,030
Western Forest	7,740	1,911	2,094	97	----------	13	11,855
Western Range	24,342	60,960	76,665	12,591	----------	4,260	178,819
Great Plains	1,355	2,494	3,102	145	----------	8	7,105
Total	42,127	65,521	81,915	12,836	----------	4,409	206,809
Non-Federal:							
Eastern Forest	205,224	40,184	31,355	9,861	2,370	72,141	361,135
Western Forest	25,529	14,444	17,519	700	1,312	2,202	61,708
Western Range	18,449	39,675	97,236	12,330	15,531	4,996	188,218
Great Plains	9,861	18,883	138,109	19,137	30,983	877	217,851
Total	259,063	113,186	284,220	42,029	50,196	80,216	828,912
All ownerships:							
Eastern Forest	233,648	43,344	31,852	9,868	2,370	72,398	393,483
Western Forest	63,404	52,220	40,331	1,125	1,312	2,235	160,629
Western Range	57,800	117,231	199,427	27,497	15,531	10,137	418,625
Great Plains	11,759	23,378	142,427	19,406	30,983	904	228,859
Total	366,611	236,174	405,039	57,897	50,196	85,676	1,201,596

Source: USDA, Forest Service Report No. 19

Table 3 Average Animal Unit Month Production by Strategy and Ecosystem, 1970

Ecogroup by ecosystem	Production by Strategy, AUM's per year					1970 average
	Some livestock (B)	Extensive management (C)	Intensive management (D)	Maximize livestock (E)	Exploitative (X)	
Western Range:						
Sagebrush	0.03	0.13	0.28	0.28	0.05	0.12
Desert shrub	.01	.05	.11	----	.01	.03
Southwestern shrubsteppe	.03	.09	.17	.08	.05	.06
Chaparral-mountain shrub	.02	.12	.21	.16	.01	.07
Pinyon-juniper	.02	.05	.14	.16	.01	.05
Mountain grasslands	.10	.28	.33	.49	.11	.29
Mountain meadows	.60	.93	2.50	2.70	.45	1.14
Desert grasslands	.03	.22	.25	.25	.01	.19
Annual grasslands	.32	.92	1.52	2.49	.46	1.05
Alpine[1]	.21	.21	.20	----	----	.21
Western Forest:						
Douglas-fir	.04	.05	.23	----	.43	.04
Ponderosa pine	.04	.09	.27	----	.08	.07
Western white pine	----	----	----	----	----	----
Fir-spruce	----	----	----	----	----	----
Hemlock-Sitka spruce	----	----	----	----	----	----
Larch	.01	.02	----	----	----	.01
Lodgepole pine	.01	.02	----	----	----	.01
Redwood	----	----	----	----	----	----
Hardwoods	.06	.34	.64	1.00	.10	.33
Great Plains:						
Shinnery	.07	.19	.26	.33	.08	.23
Texas savanna	.13	.22	.44	.61	.09	.31
Plains grasslands	.22	.31	.35	.50	.61	.31
Prairie	.40	.75	.84	1.28	----	1.01
Eastern Forest:						
White-red-jack pine	----	----	----	----	----	----
Spruce-fir	----	----	----	----	----	----
Longleaf-slash pine	.64	.64	1.56	----	.78	.77
Loblolly-shortleaf pine	.17	.21	----	7.69	.04	.22
Oak-pine	.16	.24	----	1.21	.07	.21
Oak-hickory	.26	.24	.46	----	.06	.23
Oak-gum-cypress	.14	----	----	----	.08	.08
Elm-ash-cottonwood	.20	.35	1.13	----	.23	.36
Maple-beech-birch	.84	.98	----	----	.43	.62
Aspen-birch	1.43	2.01	2.60	----	.71	.99
Wet grasslands	.92	1.54	3.93	----	1.12	2.61
Weighted average	0.11	0.25	0.44	0.90	0.22	0.26

[1] Includes barren areas above treeline.

Source: USDA, Forest Service Report No. 19.

Having completed a projection of the demand for AUM's over the next thirty years, a linear optimization computer simulation (FREPAS) was then developed to determine how AUM output could best be expanded to meet the anticipated demand under various sets of constraint policy alternatives.

> The system not only permits assessment of demands, but also measurement of resource productive capacity and trade-offs between outputs. It contains accounting systems to handle the mass of resource and cost data and a linear programming code capable of accepting a variety of external constraints [39c].

Figure 9 illustrates how various alternatives were developed to constrain the results of policies. One strategy alternative was selected as best on the basis of maintaining environmental quality and limiting the rate of change in the rural sector (i.e., restricted change from extensive to more intensive forms of management). This strategy, Alternative 19, "established that identification of the most efficient lands for grazing for added development can ensure that the cost of grazing does not increase to the point that grazing becomes non-competitive with other feed sources [39d]".

2.3.2 EarthSat's Use of the FRES Report

On the basis of reviewing ERTS-1 Principal Investigators' reports [25, 13, 22], EarthSat concluded that [14a]:

> Many of the potential capabilities of an ERS system, e.g., a synoptic view of 10,000 square miles and repetitive coverage, offer unique possibilities for rangeland inventories. Reports of ERTS-1 investigators indicate that inventories using ERS-data may be better than conventional inventories.

Using the results of the FRES report, EarthSat found that a shift in management strategies of the nation's rangeland could result in an annual benefit of $114.3 million by the following comparison:

$4.11/AUM	under continued misallocation
-$3.66/AUM	under optimal alternative
$ .45/AUM	saved
X254	million AUM's annual average projected for 1977-86
$114.3	million as the value associated with efficient reallocation.

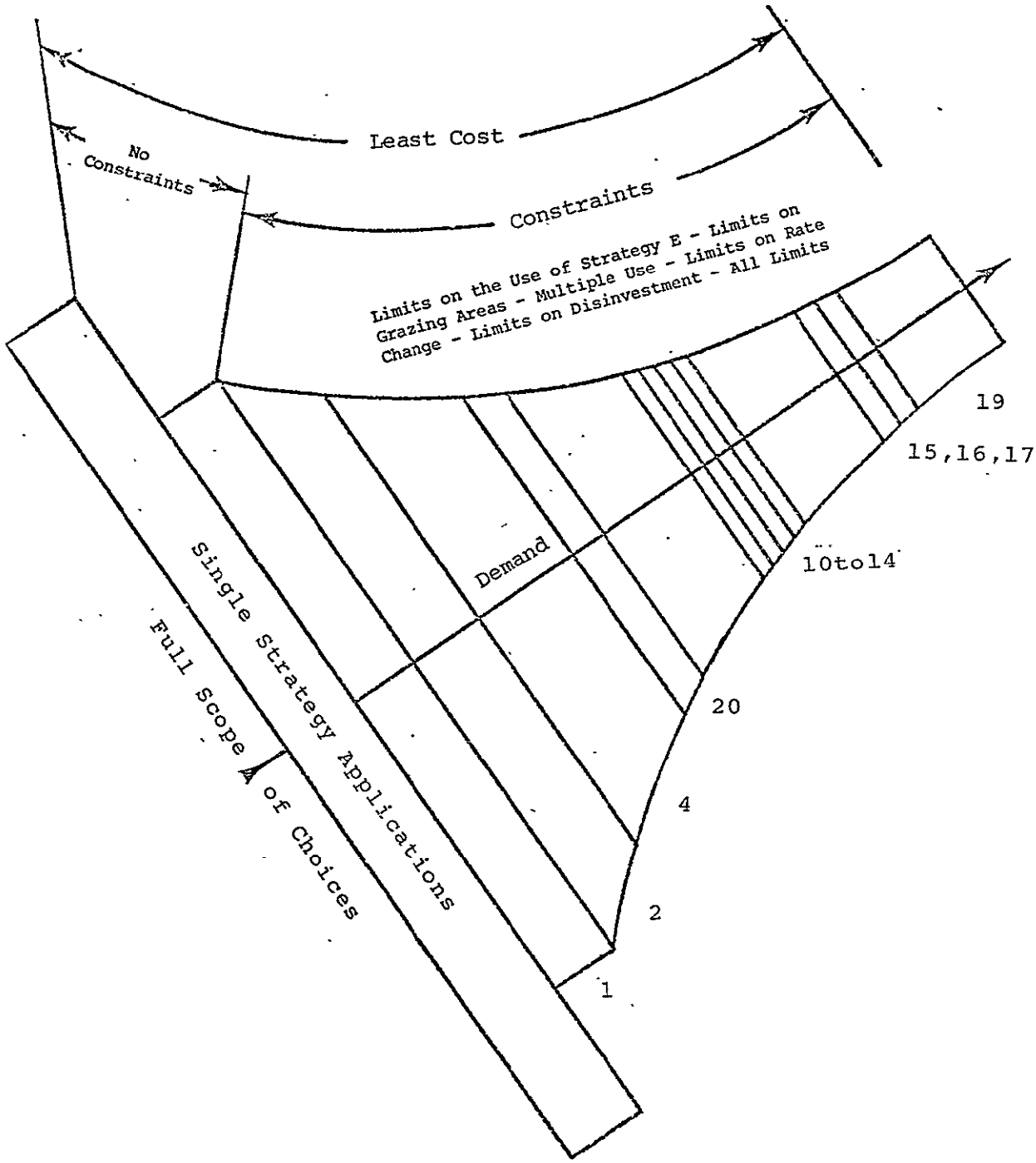

Figure 9 Development of the Alternative (FRES Study)

Source: USDA Forest Service, Forest Resource Report No. 19

and, if better inventories are possible with ERS data and these inventories in turn improve range resource reallocation decisions, it would be appropriate to attribute a share of the benefits of reallocation to the ERS system. Stating that it was not possible to determine the exact percentage of the share attributable to an ERS, the EarthSat team performed a parametric analysis of possible percentages; the results of this analysis are shown in Table 4. In the end, they concluded that $1.4 million could be attributed to an ERS system under the category of inventorying range resources for reallocation. However, it should be noted that no particular rationale was given for choosing this figure and that no mention was made of exactly how range managers might use information of the ERS variety or, more importantly, why these particular benefits could not be achieved without an ERS system.

In the area of monitoring range resources for improved range productivity, EarthSat cited two reports by National Resources Council of America [23] and the CNI Committee of the USDA [35], noting that 66% of private rangeland and 72% of public rangeland could be improved. ERTS-1 investigators have demonstrated that such an ERS system is capable of determining the effectiveness of these improvement investments [13, 22, 3]. EarthSat felt that "increases in range productivity can be achieved through improved investment decisions (stemming from better information available through an ERS system) resulting in cost reductions for producing an AUM [14b]." The study team again used a parametric analysis on percent cost reductions to estimate the benefits. Percentages chosen were 0.5 to 2.0% and were selected based on the results of expert interviews reported in the Frank-Heiss study [15]. The results of this parametric analysis are shown in Table 5. A final gross, annualized, discounted benefit of $5.6 million was estimated based on AUM cost reduction of one-half of one percent.

2.3.3 Halter-Dean Range-Feedlot Simulation

Halter and Dean simulated a large California cattle ranch in order to test alternative management policies for dealing with uncertainty. "Like most farm managers, the management of this ranch is faced with two sources of uncertainty: weather, which in this case affects the quantity, quality, and time distribution of range forage; and prices of factors and products [18a]." In order to perform this simulation, the authors observed a typical ranch and noted current decision policies. The particular ranch was a range-feedlot operation where the owners bought stockers to graze the range and later moved them into the feedlot. A calendar of cattle rotation on range and in the feedlot is shown in Figure 10. Typically, maximum and minimum stocking

Table 4 EarthSat-Estimated ERS Economic Benefit As A Share of Improved Range Resource Reallocation

Annualized Value a/ Associated With Improved Resource Allocation 1977-1986	Share of Value Attributed to ERS System	Annualized Benefits Using ERS Data in Improved Resource Reallocation 1977-1986	Total ERS Benefit Discounted b/ in 1970 Dollars 1977-1986	Total Discounted Benefits in 1973 Dollars 1977-1986	Discount Annualized Benefits, 1973 Dollars 1977-86
$ millions	percent of total value	$ millions	$ millions	$ millions	$ millions
114.3	0.5	0.57	3.50	4.42	0.7
114.3	1.0	1.14	7.00	8.85	1.4
114.3	1.5	1.71	10.51	13.28	2.2
114.3	2.0	2.29	14.07	17.78	2.9

a/ $4.11 (ave. annual cost/AUM if resource allocation continues under current (NOW) policy (1977-86) minus $3.66 (ave. annual cost/AUM with improved resource reallocation (1977-86) equals $0.45. 254 million AUM's is the average annual output 1977-86 under resource allocation (i.e., Alternative #19 of FRES) 1977-86. Multiplying 254 million AUM by $0.45/AUM equals $114.3 million

b/ factor 6.1446

c/ 100='67; 110.4='70; 139.5='73. Therefore if 100='70, 126.4='73
Based on all commodity wholesale price index, Council of Economic Advisers (1973)

Source: Earth Satellite Corporation, Earth Resources Survey Benefit - Cost Study, Rangeland Case Study, 1974.

Table 5 EarthSat-Estimated ERS Economic Benefits of Reducing the Cost Per AUM

Column/ Row	A Average Annual Total Costs a/ $ millions	B Unit Cost b/ $/AUM	C Average Annual AUM's c/ millions	D Average Annual Animal Output Value c/ $ millions	E Annual Net Animal Output Value d/ $ millions	F Net Value Added e/ $/AUM	G Average Annual Benefits $ millions	H Discounted Average Benefits 1977-85 f/ $ millions	I Discounted Benefits 1977-85 g/ (In 1973 dollars) $ millions	J Change In Cost h/ percent	K Gross Discounted Annualized Benefits (1973 dollars) $ millions
1	928.9	3.66	254.0	2088.5	1159.6	4.57	0				
2	924.3	3.64	254.0	2088.5	1164.2	4.58	4.6	28.3	35.8	0.5	5.6
3	919.6	3.62	254.0	2088.5	1163.9	4.60	9.3	57.1	72.2	1.0	11.2
4	915.0	3.60	254.0	2088.5	1173.5	4.62	13.9	85.4	107.9	1.5	16.7
5	910.3	3.53	254.0	2088.5	1178.2	4.63	18.6	114.3	144.3	2.0	22.4

a/ Total costs interpolated from FRES Report (USDA, FS, 1972) for alternative #19, 1977-86 range between 901.2 million (1977) and 956.5 (1986) or an average of 928.9 for the ten-year period (Line 1). For the purposes of the parametric analysis, the total costs are reduced by 0.5%, 1.0%, 1.5% and 2.0% in rows 2, 3, 4, and 5 respectively.

b/ Derived, not interpolated (A + C = B)

c/ An interpolation of FRES projections of AUM's for the year 1977-86 range between 238 (1977) and 270 (1986) or an average of 254 for the ten year period; average animal output value interpolated from FRES is 1931.4 (1977) and 2245.6 (1986) or 2088.5 for the ten year period.

d/ D - A = F

e/ E + C = F

f/ Factor 6.1446

g/ 100 = '67; 110.4 = '70; 109.5 = '73; 100 = '70; 126.4 = '73 (All commodity WPI, CEA & SCB)

h/ Reducing total costs (Column, Row 1) by 0.5% equals 924.3; by 1.0%, 919.6 etc.

Source: Earth Satellite Corporation, Earth Resources Survey Benefit-Cost Study, Rangeland Case Study, 1974.

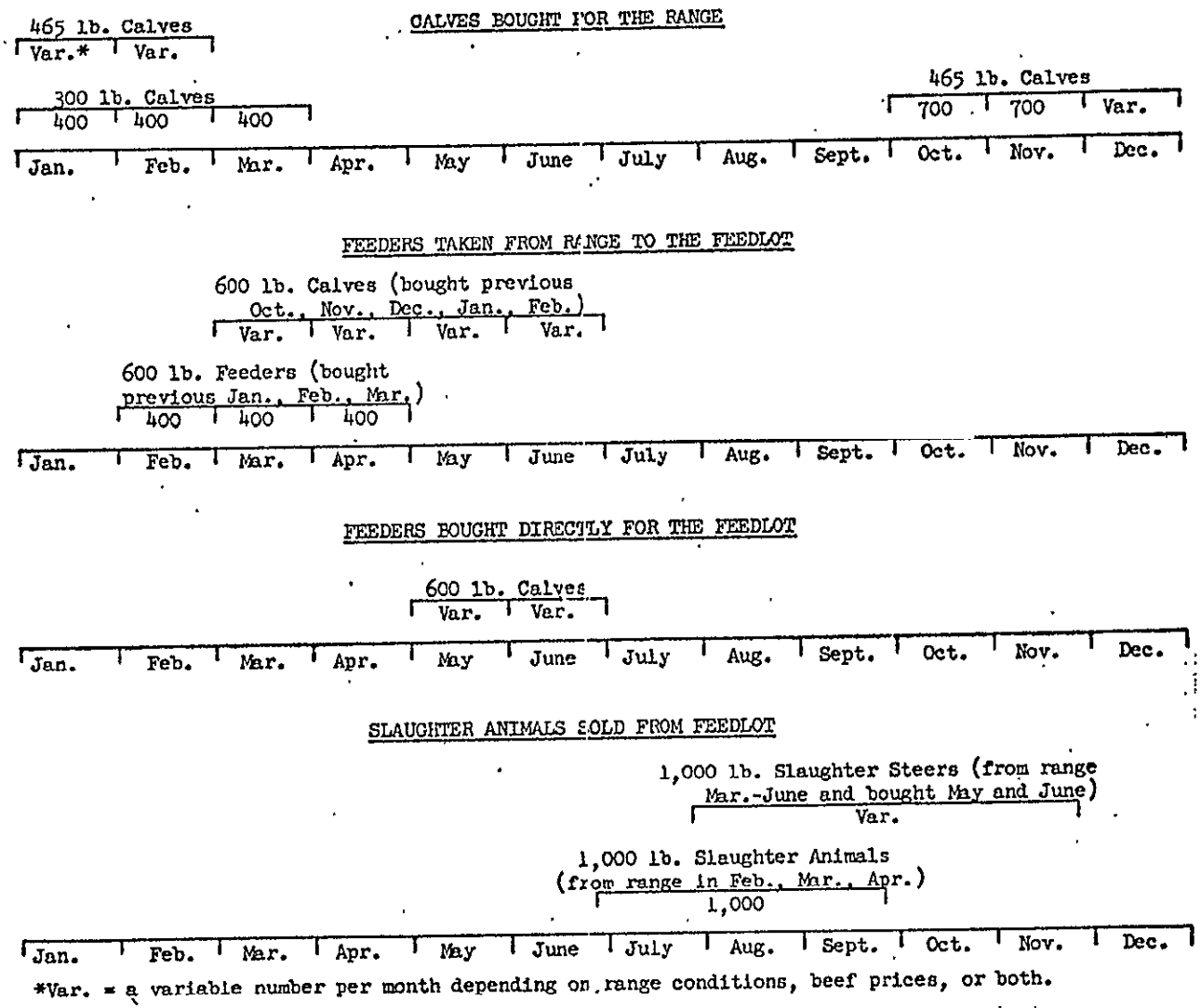

Figure 10 Calendar of Cattle Rotation on Range and in Feedlot (number per month) Halter-Dean Model

Source: Halter and Dean, Simulation of California Range Feedlot Operations, Giannini Foundation Research Report #282, 1965.

rates are predetermined from past experience. It can be seen that many stocking decisions are made independent of environment conditions; for example, 1400 465 lb. calves are purchased in October and November and 1200 300 lb calves in January, February, and March regardless of conditions because experience has demonstrated that the range will almost always support that number. The 465 lb. calves will go to the feedlot the following summer, while the 300 lb. calves will be grazed for almost one year before going to the feedlot. Additional calves are purchased in December, January, and February according to range conditions. Figure 11 illustrates points where decisions are to be made, indicated by valve (⋈) symbols, and the factors which influence these decisions. The three important decisions are:

1. Number of cattle to purchase for the range. This is a function of perceived range conditions; the exact rules which govern this decision are shown in Figure 12.

2. Rate at which cattle are transferred from range to feedlot. As shown in Figure 10, this decision is also a function of range conditions. For example, if good range conditions persist, it is profitable to delay the transfer.

3. Purchase of cattle directly for feedlot. Normal range carrying capacity is 4000 head, while feedlot capacity is 5000 head. Depending upon price conditions, feeder cattle may be purchased directly for the feedlot. In order to make this decision, management calculates a "break even" feeder price. If feeder cattle are at the price the ranchers estimate that they will just cover costs at sales time and so they will not buy. Below the "break even" price, management will purchase feeders. Management uses last year's prices as estimates for sales prices in calculating the "break even" feeder price. However, since there is uncertainty in exactly what the true "break even" price would be (since sale prices are not perfectly known) the management does not buy to capacity until feeder price falls below the calculated "break even" price by some uncertainty margin. Recently, the uncertainty margin used has been about $3.00 per hundred-weight. Figure 13 shows this decision process. The rate "1" represents purchases which fill the feedlot to capacity.

Halter and Dean used this simulation to determine if management policy could be improved by use of a less naive price expectation model. Alternative slaughter price expectation models were used and these are summarized in Table 6. Model A is an approximation of current practices; Model B assumes perfect knowledge, while incorporating a small uncertainty margin; Model C was developed by the authors as a simple alternative price expectation model which management might adopt.

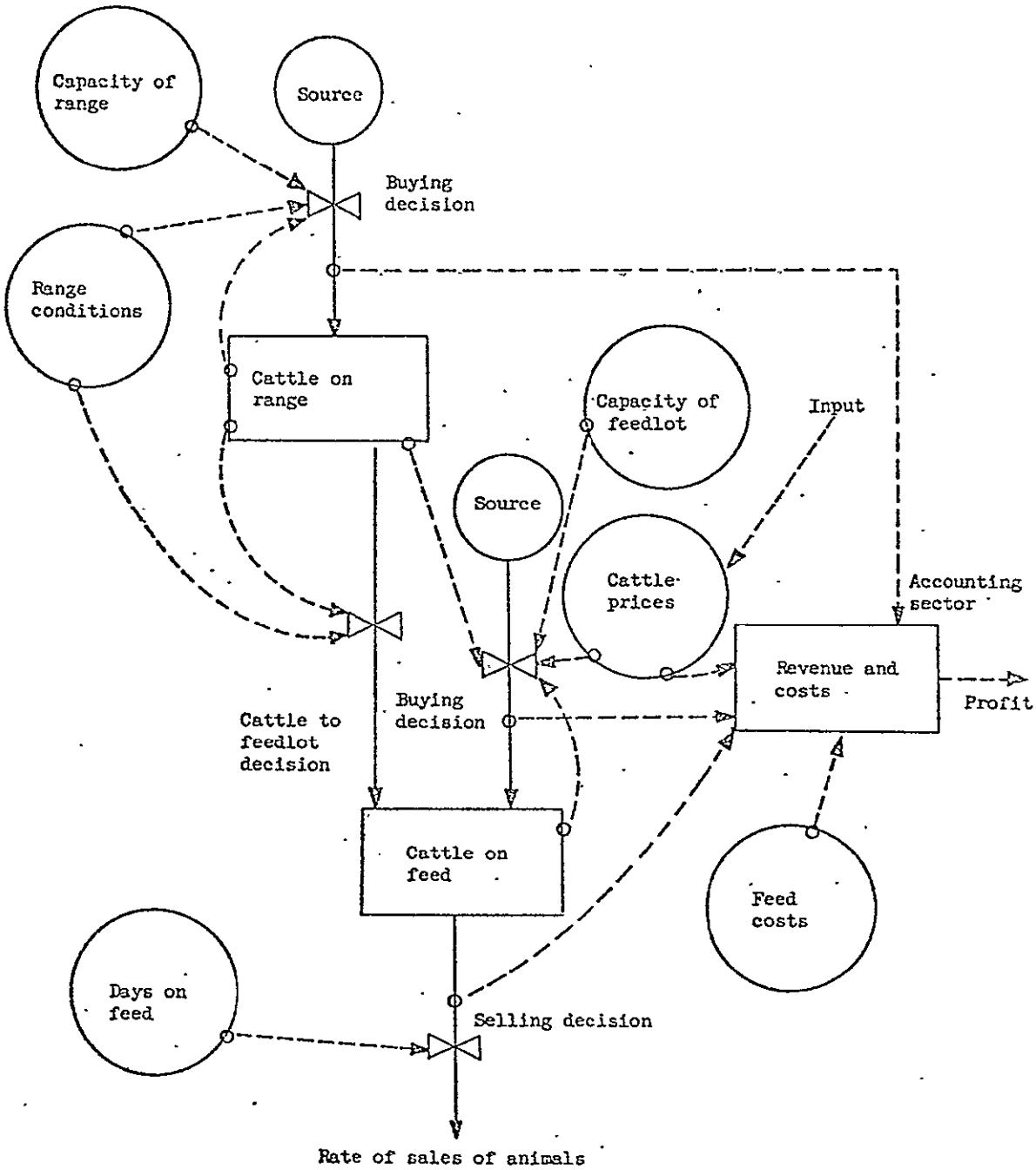

Figure 11 Diagram of Range-Feedlot Operation
Halter-Dean

Source: Halter, A.N. and Dean, G.W., Simulation of a California Range - Feedlot Operation, Giannini Foundation Research Report #282, 1965.

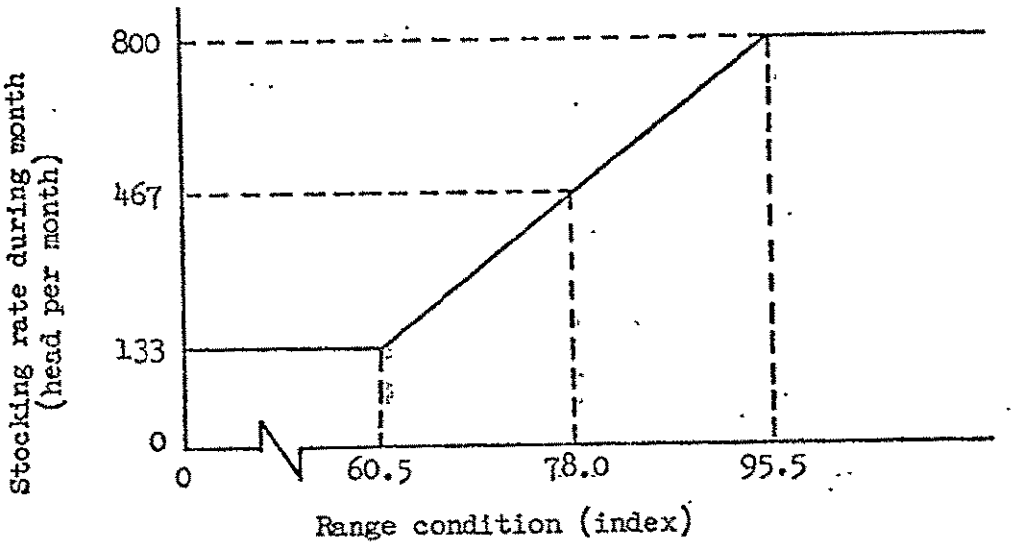

Figure 12 Stocking Rate in December, January, and February As a Function of Range Conditions — Halter-Dean

Source: Halter and Dean, Simulation of a California Range - Feedlot Operation, Giannini Foundation Research Report #282., 1965.

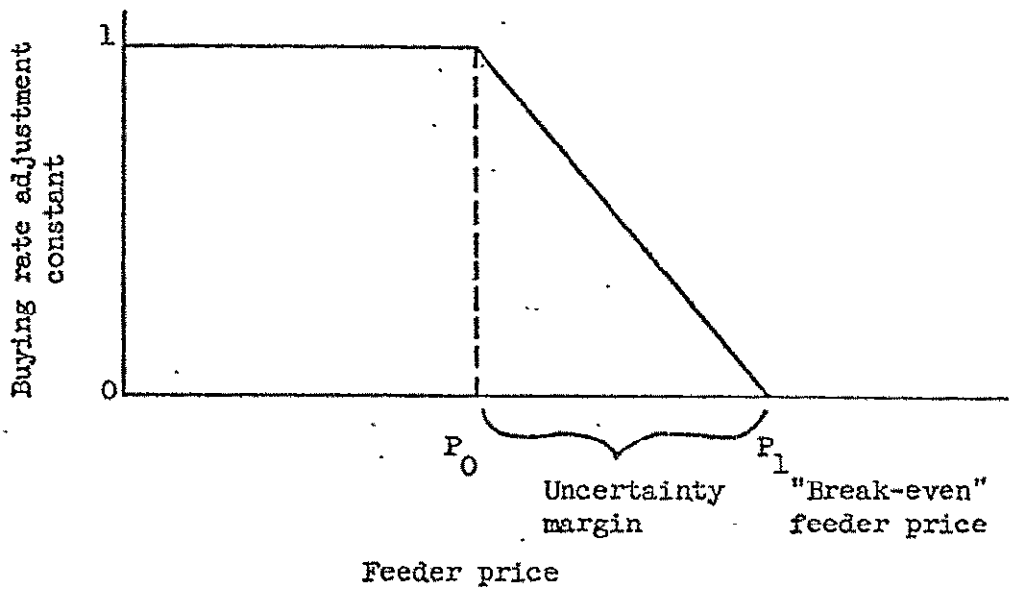

Figure 13 Determination of Buying Rate Adjustment Constant for Direct Feeder Purchases in May and June — Halter-Dean

Source: Halter and Dean, Simulation of a California Range-Feedlot Operation, Giannini Foundation Research Report #282, 1965.

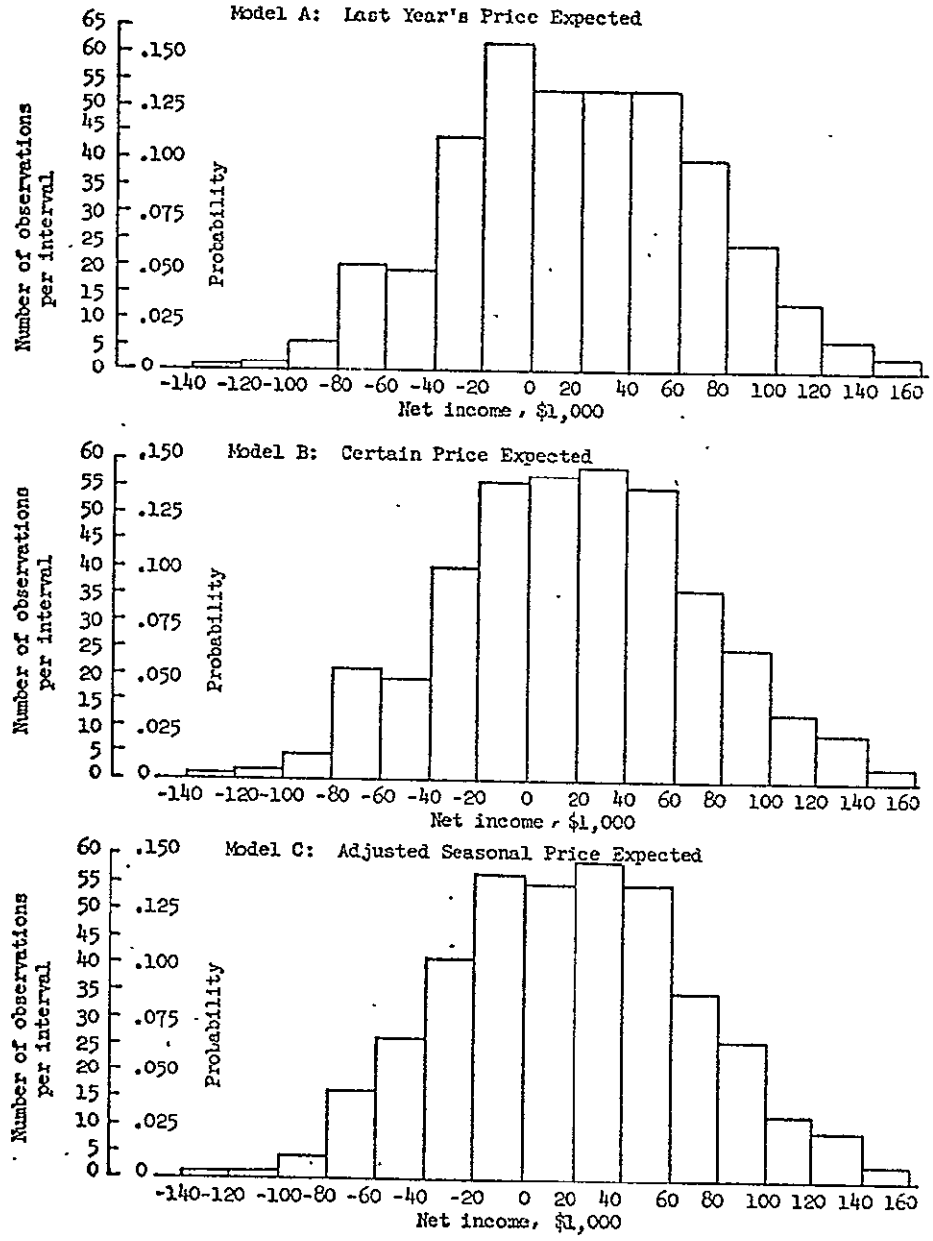

Figure 14 Distribution of Net Income Over All 400 Price-Range Condition Observations for Price Expectation Models A, B, and C — Halter-Dean

Source: Halter and Dean, Simulation of a California Range-Feedlot Operation, Giannini Foundation Research #282, 1965.

In exercising the model, Halter and Dean used 40 years USDA range conditions reports and ten years of cattle prices. Results were that Model C gave improvements over Model A by yielding a greater mean income and a smaller income variation. Figure 14 shows the results of these simulations. However, the authors noted that the magnitude of the improvements from C compared to A are relatively small.

2.3.4 EarthSat's Use of the Halter-Dean Model

In the EarthSat study, the Halter-Dean Model was modified [14c]:

> to simulate the use of pertinent ERS data; and to test the supposition that the timeliness and accuracy of these data would serve to constructively influence managerial behavior. Mechanisms to parametrically account for the fluctuations in beef price levels, as well as the cost of the variable and fixed items, are also embodied in the program. Since this analysis is only concerned with environemental uncertainties, the mercurial effects of price were minimized by assuming perfect knowledge of slaughter prices. However, a small uncertainty margin of $0.25 per CWT was included in recognition of other sources of risk (in gains, feed conversion, and feed price).

EarthSat effected the entry of ERS data by assuming (1) that ranchers have a delay in recognizing changes in range condition; they estimated that this delay could be reduced from 25 to 5 days by use of an ERS ("with") System. This improvement is illustrated in Figure 15. EarthSat further assumed that ranchers hedge their stocking rates due to uncertainty and that superior information would promote confidence resulting in higher stocking rates; this is depicted in Figure 16. Using these modifications, EarthSat exercised the simulation for "with" and "without" systems. The results are summarized in Table 7. On the average, the ERS system yielded a $7,079 differential in net income. Using a figure of 16,200 AUM's of production from this range, EarthSat estimated that the net benefits accruing from the ERS system are $0.437/AUM. Using an estimate of 33.3 million AUM's grazed by stockers in 1973, EarthSat extrapolated that an upper limit on benefits of this type would be $14.6 million. However, this total benefit would not be realized for several reasons. It was felt that only 51%* of all stocker operations were large enough to utilize ERS data operationally; therefore, EarthSat reduced the $14.6 million by one-half. The effects of operational delays due to learning delays and discounting back to 1974 further reduce the benefits to $4.74 million.

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*Based on head size of 50 or more stockers [43].

Some of EarthSat's assumptions on modifying the Halter-Dean Model require comment. Although it is possible that ranchers have delays in perception of range condition changes as long as 25 days, it seems unlikely that the type of ERS system which EarthSat was studying would have reduced the delay to 5 days. The component of such a system which would produce the greatest measurement frequency would be an ERTS-type satellite, with overflight frequency of 18 days, yielding an average delay of 9 days in the absence of cloud cover. Data processing would contribute additional delays of at least one day and possibly 5 days or longer in an operational system. Data dissemination to the user would take further time. Additionally, and significantly, no rationale was given for the size of the difference in stocking rates as shown in Figure 16.

Table 6 Price Expectation Models for May-June Buying of Feeders Directly for the Feedlot--Halter-Dean

Model Designation	Price Expectation for Slaughter-Cattle Sept.-Oct.-Nov., Year t, Equal to:	Uncertainty Margin, dollars per cwt
A	Actual price, slaughter cattle, Sept.-Oct.-Nov., year t-1	3.00
B	Actual price, slaughter cattle, Sept.-Oct.-Nov., year t	0.25
C	Current slaughter price in May-June , year t, adjusted for average seasonal change from May-June to Sept.-Oct.-Nov.	

Source: Halter and Dean, Simulation of a California Range - Feedlot Operation, Giannini Foundation Research Report #282, 1965.

Table 7 Difference in Rancher's Net Income Effected by ERS System

Year	Net Profit ($K)		Differential ($K)	
	"With	"Without"	Unadjusted	Adjusted to 1973
1954	130.57	121.39	9.18	14.61
1955	38.16	31.66	6.50	10.35
1956	85.25	79.84	6.31	9.71
1957	-30.25	-29.05	-1.20	-1.80
1958	57.45	43.39	14.07	20.75
1959	68.36	76.82	-8.46	-12.45
1960	53.24	50.67	2.57	3.78
1961	131.08	122.39	8.69	12.87
1962	77.72	72.65	5.07	7.45
1963	14.60	10.87	3.73	5.32

Source: Earth Satellite Corporation, Earth Resources Survey Benefit-Cost Study, Rangeland Case Study, 1974.

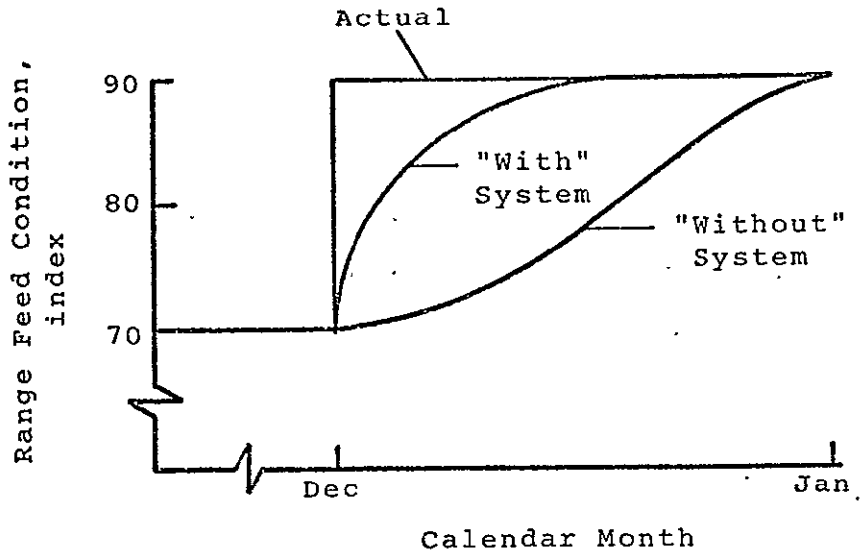

Figure 15 Perception of Range Feed Conditions -- EarthSat

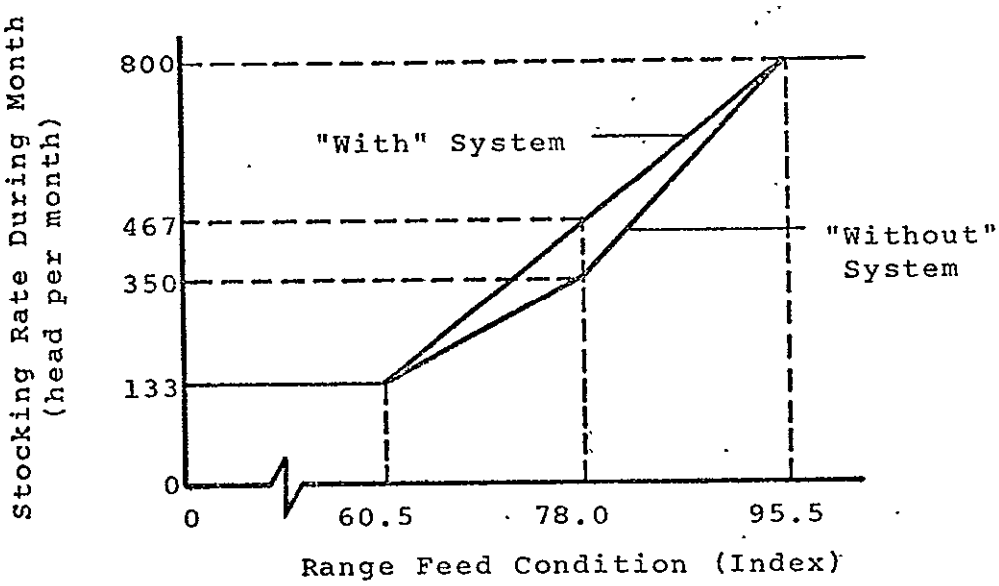

Figure 16 Stocking Rates in December, January, and February As a Function of Range Feed Conditions -- EarthSat

Source: Earth Satellite Corporation, Earth Resources Survey Benefit-Cost Study, Rangeland Case Study, 1974.

2.4 Hunter — Optimum Resource Allocation Through Chance - Constrained Programming

The purpose of Hunter's study was to apply chance-constrained programming techniques to ranch enterprises [19b]. The study used linear programming techniques to simulate a range operation where the primary criterion was assumed to be the maximization of net revenues. A secondary criterion was to maintain the ecosystem by preventing overgrazing of the available forage.

This model was developed from two prior models. A deterministic decision-making model was developed by D'Aquino [9]. This model was improved upon by the use of a serial matrix developed by Bartlett et. al. [1] which allows for the temporal nature of ecological conditions and where resources unused in one period can be held over for use in following peroids.

Both these models assumed perfect knowledge and, therefore, did not allow for an understanding of how management could or should deal with uncertainty. Since range managers have to deal with variables in a stochastic environment, Hunter's model was developed to assist their decision-making.

Whereas in general linear programming, the task is to:

$$\text{Maximize} \quad \sum_{j=1}^{n} c_j \; x_j$$

$$\text{Subject to} \quad \sum_{j=1}^{n} a_{ij} \; x_j \leq b_i \quad \text{for } i = 1,2, \ldots m,$$

in chance-contrained programming, the constraints are modified to probability statements, such that:

$$P \left(\sum_{j=1}^{n} a_{ij} \; x_j \leq b_i \right) \geq \alpha$$

$$x_j \geq 0 \qquad \text{for } i = 1,2, \ldots m$$

$$\text{for } j = 1,2, \ldots n.$$

This formulation allows either a_{ij} or b_i to be stochastic.

This capability is particularly important in range management. While overgrazing is to be avoided, the amount of grazing would have to be extremely small if the probability of overgrazing is to be held equal to zero. If the error in estimating available resources is normally distributed, this condition ($P_o = 0$) would effectively require no grazing whatsoever (see Figure 6, p. 1-10) and, while the assumption of normally distributed error breaks down at the tails of the distribution, it is apparent that severe limitation on the probability of overgrazing would allow only minimal grazing.

The goal of Hunter's study was to determine what probability of overgrazing should be tolerated by the rancher in order to maximize expected profits. This was achieved by performing a deterministic simulation using the mean available forage. Next, a Monte Carlo study was performed on the forage supply. The important result of the Monte Carlo simulation was that *"if the average forage production was normally distributed, the average net revenue was skewed downward* [italics added]" (see Figure 7, p. 1-13). From the results of this analysis, Hunter concluded that [19a]:

> Overestimating the carrying capacity of rangelands may result in such penalties as the necessity of having to buy supplemental feed or selling the livestock at a loss. On the other hand, underestimating the forage production could result in penalties due to underutilized resources that could have been profitably employed (Jameson, D'Aquino, and Bartlett, 1974). Although these conclusions cannot be directly obtained from this study, the results indicate that the penalties a rancher must assume for overestimating his carrying capacity are greater than the penalties for underestimating the carrying capacity.

From the Monte Carlo Simulation, Hunter determined that the "best" average stocking rate was 836 steers per season and that this solution could be achieved by constraining the probability of overgrazing to 42%. The significance of these results is that, given the *a priori* variation in available forage, the rancher's yearly stocking rate *"should be approximately 8% less than the number of cattle that can be supported by the average amount of forage produce on his rangelands* [italics added]." [*19a*].

3.0 STUDY APPROACH

Having now outlined the context in which this study was performed, this section will make explicit the purpose of the study and summarize the approach and scope of the effort.

3.1 Study Purpose

It is the intention of this study to provide a means for estimating the gross benefits from improved information as it affects rangeland management. In order to achieve this goal, a one-ranch grazing operation has been rigorously simulated to test the micro effect of different measurement systems. Benefits from better information on a one-ranch basis are then extrapolated to the national level in an *ad hoc* manner.

The question of benefits from information has become important recently in order to guide policy decisions in national investment in an Earth Resource Survey system. This study was designed to estimate gross benefits from measurement systems with different economic/operational capabilities; the specific system parameters important for this application are:

1. Measurement accuracy of forage on the ground at time of measurement (point measurement accuracy)
2. Frequency of measurement
3. Time lag in data availability.

The study was also designed to interface with engineering studies which determine the costs of systems producing capabilities discussed herein, and to use both studies to estimate economically optimal systems. No cost analysis was performed here; therefore, all benefits estimated are gross benefits.

3.2 Inadequacy of Available Models

Although several good range management models have been developed, none were felt to be quite suitable for this application. Some of these models have been discussed above. Two models stood out as possible candidates for use in this study: Halter-Dean [18] and Hunter [19]. The Halter-Dean model was found to deal well with the problem of price uncertainty, but it was felt that substantial revision would be necessary to properly simulate uncertainty in the physical environement. This model was also felt to be too situation-specific, i.e., the simulation was based on a particular rancher's management decision policies and not on policies fundamental to almost all enterprises, e.g., profit-maximization.

The Hunter model was found to be a good simulation of ways in which management could deal with uncertainty in forage availability. It was not clear, however, how it could be modified to permit the inclusion of measurement systems with different capabilities. Further, the resolution was not considered sufficient to assess the effects of only small changes in system capabilities; in particular, the fact that it dealt with only one decision period of one-season length was not felt to be sensitive enough to deal with further rancher decisions as a result of measurement updates. In light of these considerations, a new model was developed to handle all the requirements of this study.

3.3 Overview of Study Simulation

At the heart of the model developed for this study is a linear optimization which maximizes ranchers' *expected* profits. Maximization is of expected profits because input to the optimization routine includes *expected* prices and forage growth. Expected profit is maximized by manipulating range stocking rates, which is achieved by buying and selling cattle and supplemental feed according to expectations of growth and price and according to best estimates of how much forage is available at present; this last input comes through the measurement system. It will be to the rancher's benefit to select the one or two stocking rates which will be best for his entire decision horizon (six months), for costs are involved in going to and from the market. Having optimized on one decision horizon, the model steps forward one decision period (one month), receives new information and re-optimizes. The rationale for this procedure follows: whereas the rancher tries to select a stocking rate which will be best for a long period of time, new information may convince him that his previous decision should be modified; perhaps unusually good growth has been experienced since the last decision time and the profit possible from increasing the stocking rate exceeds the costs of doing so. Note that the rancher is not bound by the whole spectrum of decisions he made in the original six month's horizon optimization; he is only bound by the cattle or feed which he bought and sold the *previous* decision period, not by any actions which he *intended* to make in later periods.

The timeline shown in Figure 17 illustrates how the measurement system impacts the decision process. Actual growth (generated outside the optimization routine) proceeds independently of decision and measurements. Current stock of forage is observed at time of measurement, and estimates of growth can be inferred from subsequent measurements. Measurements are taken at equal intervals, although the measurement intervals may not be in harmony with the decision period intervals. At the time of

the decision, the rancher has available to him all measurements which were taken "n" days prior to the decision; this "n" day period represents the time lag in data availability and is illustrated by the shaded region in Figure 17. This data lag may be of length zero days (if the rancher surveys his range the same day that he decides on his stocking rates) to, possibly, several weeks or anywhere in between, depending on the efficiency of the data processing and dissemination. The measurement system provides the decision-maker with information on current forage availability and estimates of present forage growth rates and, perhaps, information by which he can improve prediction of future growth rates.

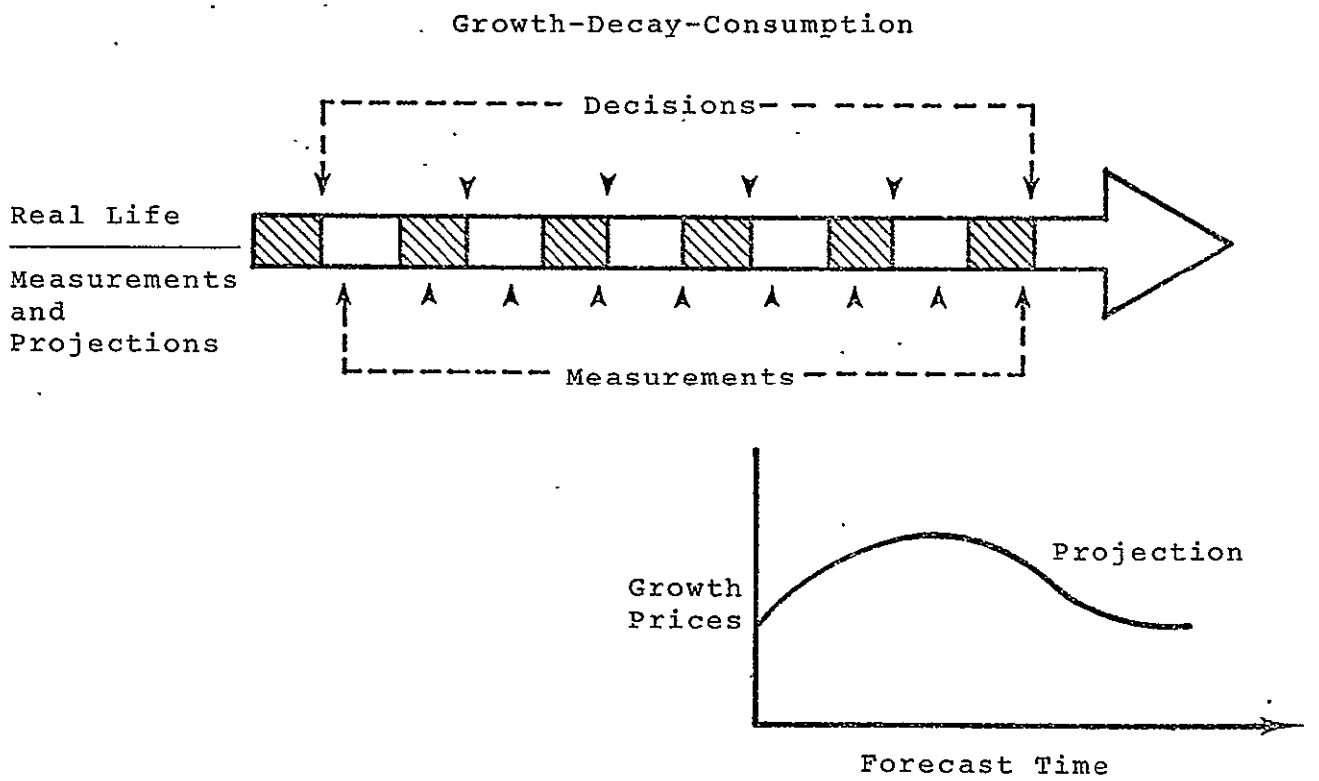

Figure 17 Range Management Timeline

Besides the measurement inputs and the rancher's decision policies, other inputs to the expected profit maximization routine are:

1. Naive forage growth predictions for the length of the decision horizon
2. Forecast of purchase and sale prices for cattle and supplemental feed and actual current prices
3. The amount of intentional undergrazing which will take place (the hedge factor), as a function of the probability of the overgrazing to be tolerated.

All these inputs come from separate routines, or will be generated and stored in the data base. The final input to the optimization routine is the current stocking rates, i.e., the cattle presently on the range at the time of the decision. This is determined by previous optimization and is set equal to zero at the beginning.

The size of the hedge factor is a function of two aspects: the accuracy in knowledge of forage availability and the probability of overgrazing to be tolerated. The existence of a hedge factor follows from the discussion in Section 1.2.2. Figure 6 (p. 1-10) shows how the hedge factor (X-X*) is changed by changing the probability of overgrazing; at X, $P_o = 0.5$; at X*, $P_o < 0.5$. Figure 8 (p. 1-14) shows how this distance changes as a size of the error in estimating forage availability. The error of the forage availability estimation is a function of (1) the accuracy forage point measurement and (2) the accuracy of predicting forage growth over the period. The first of these is a direct input to the system, while the second is a result of the growth prediction model (see Section 4.3.2.).

The outputs of the expected profit maximization routine are the current (decision) period stocking rates, forage consumption, cattle and feed purchase and sales, and the cash flow. The optimization is run every month for a period of several years. The final ouputs of the whole system are aggregated profits, stocking rates and cattle consumption for the several years. The setup of the entire system is depicted in Figure 18.

The model will be run for several year periods with different values of the measurement system parameters. Additionally, different probabilities of overgrazing will be input. An optimal P_o will be selected using the same criteria as Hunter [8]. Alternatively, the profit curve as a function of P_o will be compared to the cost curve of P_o (as P_o increases, so does the damage done to the range:. An estimate of optimal P_o (P_o*) will be selected which will represent the point where net profits are maximized. The process is shown in Figure 19 using hypothetical profit and cost curves.

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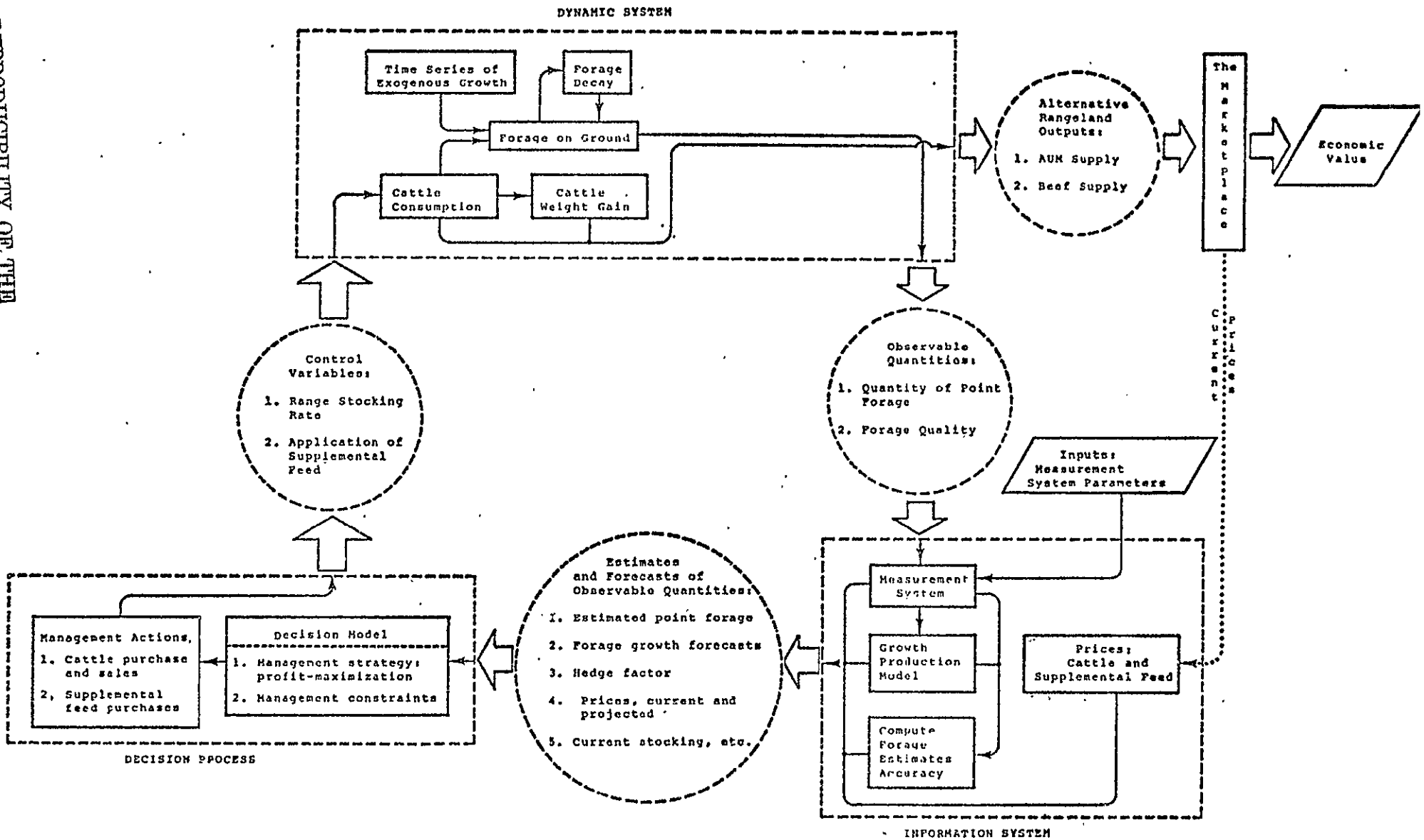

Figure 18 Flows in Range Management Simulation Model

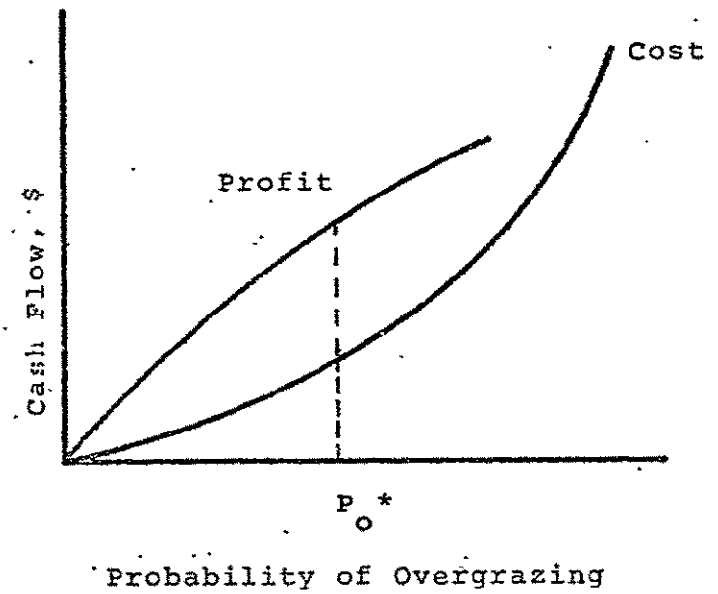

Figure 19 Maximizing Rancher's Net Profit

If the results show that improved measurement information leads to increased grazing on the same rangeland, it will then be considered that the improved information effectively increases the supply of AUM's available from any given land. Whereas it would be inappropriate to assume that all ranchers' profits would increase through the use of the improved system, because second order effects in prices would offset such profit potential, it would be reasonable to conclude that *such a system would increase the aggregate supply of forage*. Aggregate supply and demand analysis will be used to extrapolate the benefits from the one-ranch situation to the national level.

Most ranch operations can be classified as either stocker or cow-calf. Cow-calf operations are those which primarily are used for grass fattening. A stocker operation is simulated here because it affords more flexibility in selecting stocking rates. Benefits obtained will only directly be extrapolated to other stocker operations, with mention made of information effects on cow-calf systems.

3.4 Scope of Simulation

Whereas other studies have emphasized the use of ERS information for Federal administration of grazing lands, it was felt that the greatest potential for improved information in rangeland management would be in helping individual ranchers make more optimal stocking rate decisions because privately-owned ranges compose about 75% of all rangeland [2]. See Table 1, p. 1-1). Thus, the emphasis in this study was in simulating private one-ranch operation. Benefits found here could then be extrapolated to Federal lands, to ecologically different areas, and to the entire U.S. on an *ad hoc* basis.

Clearly, there are benefits provided by improved measurements which are not estimated in this study. The government agencies administering rangelands perform inventories every three to five years. A continuously-operating measurement system could make these inventories less expensive, make them more valuable, or make them unnecessary. Large benefits would be possible from monitoring the effects of range investment practices, such as those mentioned in section 1.1.3, aiding decisions about which rangelands should be opened or closed to grazing, and guiding rotational grazing policies. Although these benefits could be significant, as mentioned before, study emphasis was chosen on benefits from aiding stocking rate decisions.

Data reliability was not considered as a factor in benefit estimation. It was assumed that the measurement system would always provide information of consistent quality at the specified frequency without interruption.

4.0 MATHEMATICAL STRUCTURE OF THE BENEFIT MODEL: FORMULATION AND ESTIMATION

In estimating the economic benefits resulting from an information system in any application area, there are three elements which must be specified:

1. the dynamic system to be monitored
2. the decision process which manages the system, and
3. the economic output;

then one must study the response of the economic outputs to changes in attributes of the information system. Figure 20 illustrates this process. From Figure 20, we can also see the links between the elements which must be described. First, the observable quantities of the dynamic system must be specified; this requires study of the aspects of the dynamic system. Secondly, we must understand the control which the decision process, the resource manager, has over the dynamic

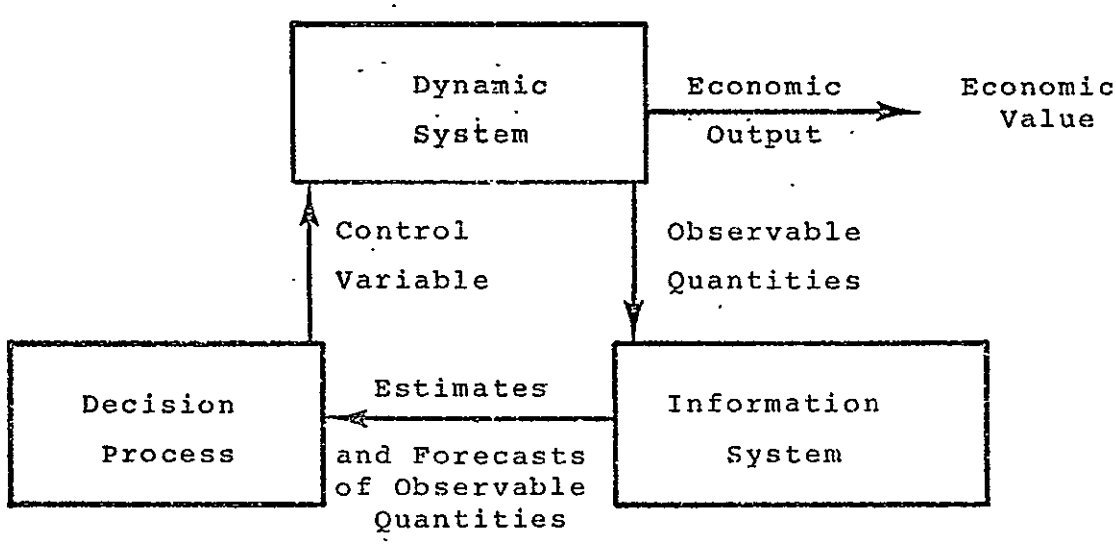

Figure 20 Flowchart of the Management of a Dynamic System

system. Thirdly, what is the information required by the decision-makers in orderto make optimal choices? Finally, we need a rational for determining the value of the economic outputs of the entire process.

In this rangeland case study, the dynamic system to be monitored is the range itself and the growth and decay of forage (natural vegetation). The quantity of standing biomass, at any moment in time measured in pounds per 1000 acres, is considered herein to be the observable quantity of the dynamic system. The decision-maker -- the individual rancher -- excercises partial control over the forage environment and produces the economic output by grazing cattle upon the range. The control is called partial because the decision-maker cannot know with certainty the effects of the application of control on the operation of the dynamic system. From the rancher's viewpoint, the economic output of this process is the increase in cattle weight (measured in pounds of beef) which can then be sold at a profit. For our purposes, however, we will consider the quantity of consumed forage produced by the range measured in AUM's (Animal Unit Months) as the economic output of the system. The use of AUM's as the economic output permits a more direct assessment of the range resources output and permits independence from the exigencies of cattle and feed markets. Standard demand and supply analysis as operating in the marketplace will be used to find the value of incremental AUM's.

Since it is the uncertainity of forage availability which we wish to model, estimates of point forage availability, forage growth, and decay are developed in a stochastic fashion. Other variables (consumption and feed) which affect the supply of biomass are considered deterministic. In this study, we will simulate the effects which improved information would have on the economic output. Holding all other factors constant, we will manipulate the values of certain forage measurement system parameters. The important measurement system attributes used as parameters in this study are:

1. accuracy of point measurement of standing biomass
2. frequency of measurement, and
3. time lag between point of measurement and point of information availability to the decision-maker.

We have briefly outlined the scheme used in this simulation and, as the details are described, we will make reference to this outline and to Figure 20.

4.1 The Range As a Dynamic System

Before embarking upon a discussion of the workings of the dynamic system of the range, it is useful to discuss the state variable and the time intervals to which it is referenced. We distinguish three types of forage, of which the latter two are subsets of the first. Total standing forage refers to the total amount of natural vegetation standing on the range at any moment in time. Utilizable forage refers to the amount of forage which is consumable by grazing animals. On the range that we are simulating, utilizable forage is considered to be about one-half of the total. The third class of forage we call grazable forage and it refers to the maximum amount of utilizable forage available for grazing during some time period, less some quantity which the rancher does not wish to graze in order to avoid damaging his renewable forage resource.

The variable x_i refers to the quantity of utilizable biomass on the ground at the beginning of the ith decision period. The term biomass is used to refer to the sum of utilizable forage and residual feed. This introduction of variables evokes a digression about the time parameters. The calendar year is divided into twelve decision periods of equal length, each of which is thirty "days" long. The maximum length of our simulation is defined as 204 decision periods, or 17 years. It was necessary to specify the frequency with which range managers make stocking decisions. Discussion with range economists at Colorado State University [21] indicated that ranchers with stocker operations make decisions once a month on average. The maximum frequency was felt to be about twice a month for some range operators, with some managers using much less frequent intervals. Thus, a decision period of one month was selected. A decision period is the smallest unit of time over which a rancher's decisions must hold; i.e., if management places 100 head of cattle on his range at the beginning of the 70th decision period, he cannot change his stocking rate until the beginning of the 71st decision period, 30 days later. The decision period is the time interval of greatest significance in the simulation. It is the period during which decisions are made and will be most frequently used in discussions and developments; it is also referenced with the subscript "i". Another time interval of consequence is the measurement period which is λ days in length, where λ is a simulation input parameter and refers to the number of days between consecutive measurements. The variable xk_k refers to the quantity of utilizable biomass on the range at the time of the kth measurement. The third time interval significant to this simulation is the forecast period. Each decision period has six forecast periods referenced to it.

It is in consideration of these six forecast periods that the optimal selections are made for the decision period. This is described in further detail in Section 4.2.2.

The relevant quantities describing the dynamic system are incorporated in the state variable, the state transformation, and the sequence of outputs. The state variable, utilizable biomass, is a function of time in discrete monthly intervals, and is denoted x_i, the subscript increasing with time. The state transformation produces x_{i+1} from x_i, the decisions y_i of time t_i and the process of forage growth and decay by the linear relation

$$x_{i+1} = (1-\mu)\ x_i - y_i + g_i \tag{4.1}$$

Here μ is the decay rate per month. The net addition (net consumption), y_i, is the difference of the month's consumption c_i and the supplemental feed increment f_i. Y_i is the output of the decision process, which is discussed in Section 4.2; g_i is the forage growth for the month. The sequence $\{g_i\}$ is itself a stochastic process, called the growth process. This process is discussed in Section 4.1.1. The connection between the state transformation, the economic output, and the growth process is diagrammed in Figure 21.

4.1.1 The Growth Process

The basis of our treatment of the growth process is a simulation model called RANGES IV designed at Colorado State University by Bradley Gilbert. RANGES IV was developed from three previous grassland simulation models and represents range and range management activity on a Colorado short grass prairie. The model is composed of driving or exogenous variables, a soil water submodel, a producer section within a feedback loop containing a consumer section and a market or economic section. It is the output of the producer section which is used in this study. This section produces forage growth data for input to the model developed here. A flow diagram of the RANGES IV model is shown in Figure 22.

The driving variables to RANGES IV are precipitation and mean daily temperature which are generated from actual weather data tapes. Soil water is determined from precipitation and evapotranspiration rates, the latter of which depends on soil type and temperature. Photosynthesis and respiration rates, which yield plant growth, are functions of soil water and temperature. The reader should refer to Gilbert's documentation, RANGES IV Grassland Simulation Model [17], for details. The real forage growth data upon which the development

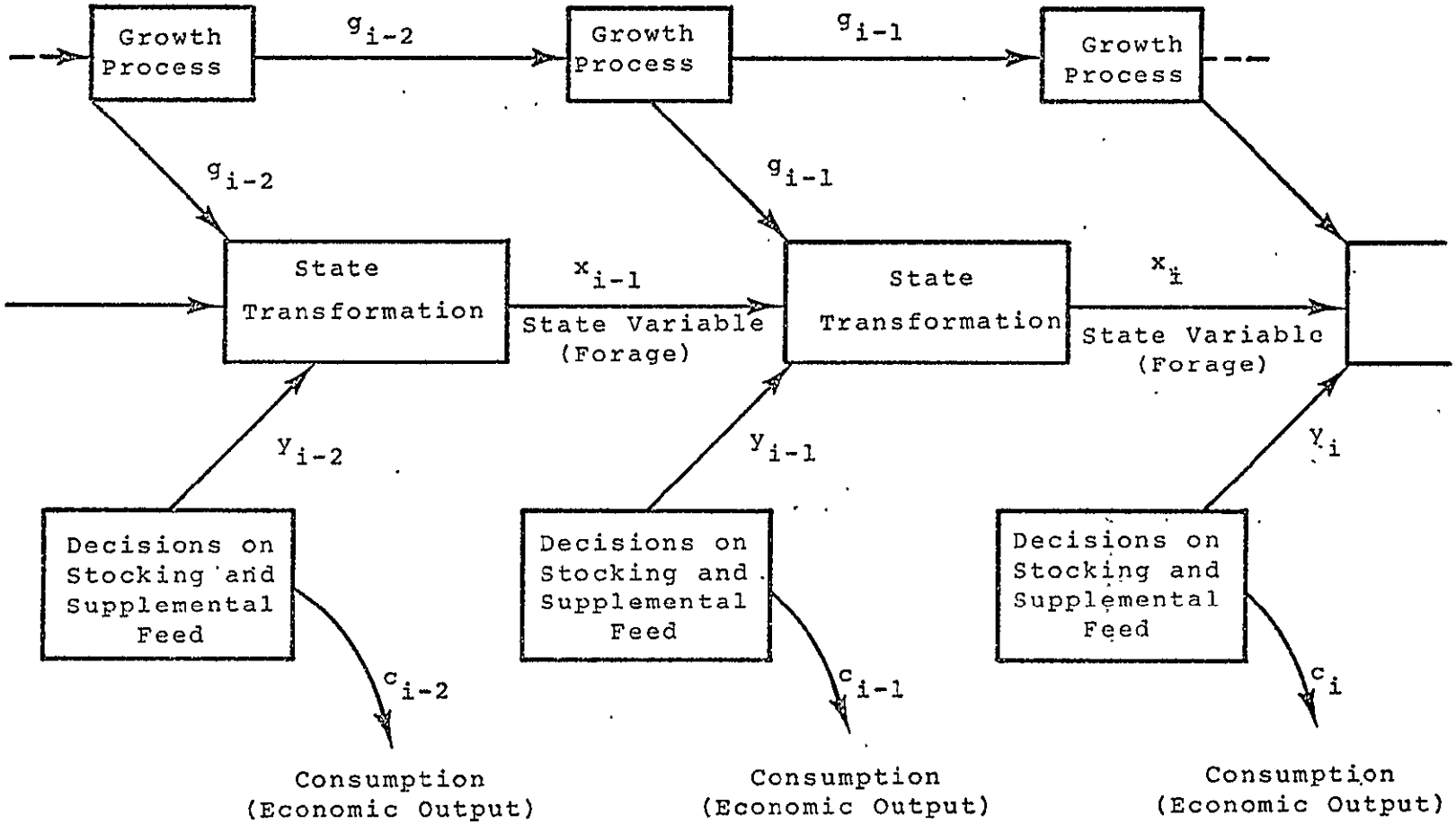

Figure 21 Growth Process and State Transformation of the Dynamic System

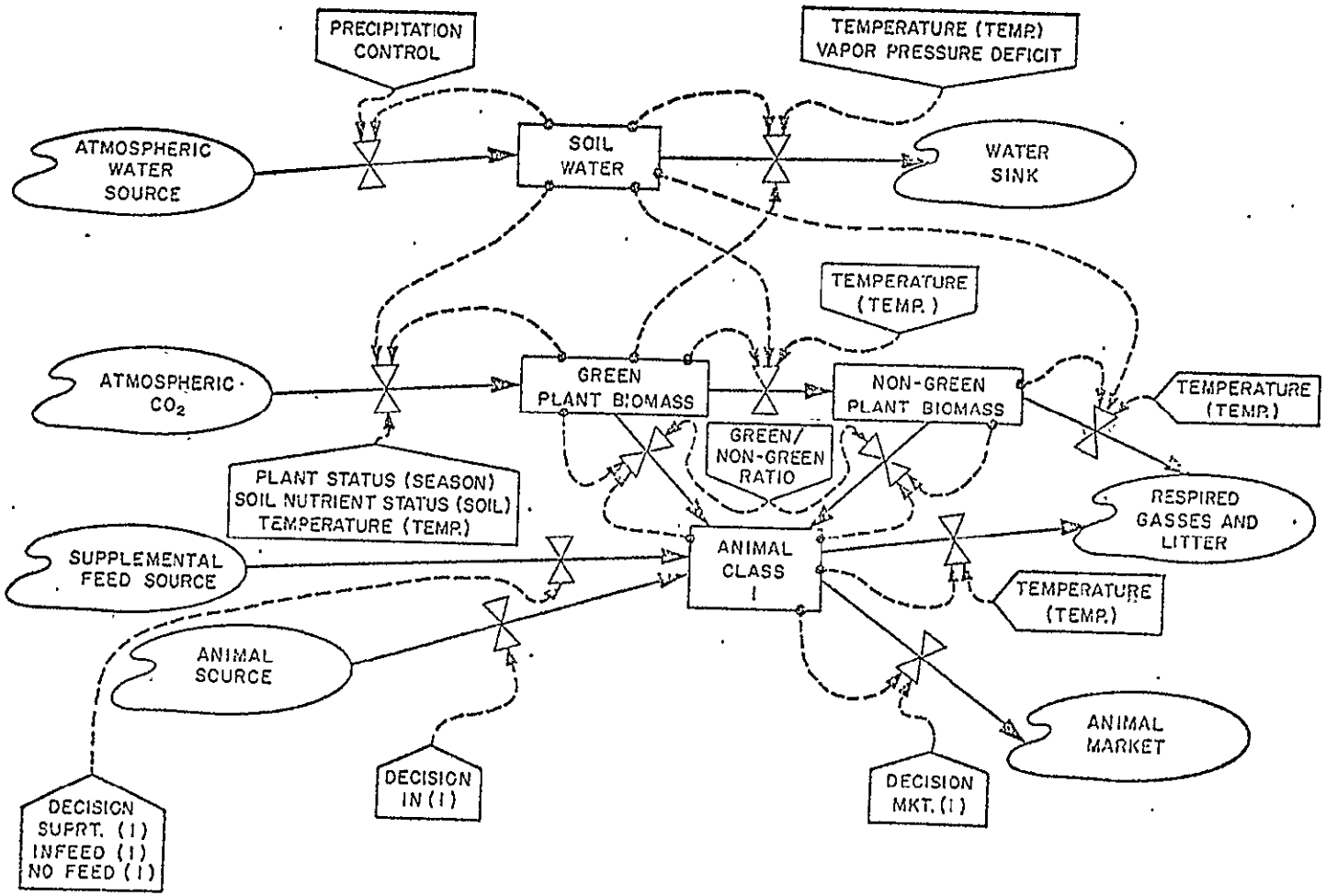

Figure 22 Box-and-Arrow Flow Diagram for the RANGES Grassland Simulation Model

Source: RANGES IV Grassland Simulation Model, Ranges Report No. 17, 1974, p. 5.

of RANGES IV is based is proprietary. The output of RANGES IV is used in our simulation as input in the form of "actual" forage growth data. Appendix A shows a listing of growth values used and a plot of some growth years.

4.1.2 The Decay Factor

In the linear relation describing the state transformation of the dynamic system, the term μ represents the percentage of biomass on the ground at the beginning of a decision period which decays during that period. This decay factor is also obtained from RANGES IV by regression analysis. The value of μ was found to be .3892. The regression was significant to the 99.5 percent confidence level. The equation which describes the decay rate (μk) for period of length λ (measurement periods) is:

$$\mu k = 1. - .9837^{\lambda} \tag{4.2}$$

4.2 The Rancher's Decision-Making Process

4.2.1 Selection of a Decision Simulation Technique

The first point we wish to make in specifying a technique for simulation is that the rancher represents a business firm in a very competitive market. This fact yields two very useful conclusions from the assumptions of simple economics:

1. profit maximization can be used as the decision rule of the firm, and

2. under competitive conditions, the firm is a price taker in all respects and thus its cost and revenue equations are linear.

We also wish to note here, and demonstrate later, that most of the factors which constrain the rancher's profit-maximization desires can also be accurately expressed in linear equations or inequalities.

There are some factors which affect the rancher's decision, however, which cannot be precisely expressed in linear form. An example of this is the amount of forage decay which takes place within a decision period. The forage variable which we will trace is total utilizable biomass; the quantity of decay is not linear in total utilizable biomass, but rather in dry biomass. Thus, we will only approximate the actual relationship between decay and total biomass by forcing linearity upon it and determining the "best" coefficients

(least-squares techniques). In this case, the costs of imposing this form seem small (see Section 4.1.2) relative to the benefits of retaining linearity throughout the decision constraints.

Maintaining linearity in the constraints and in the objective function and using the decision policy rule of profit-maximization allows for a linear programming solution of the simulation problem using a simplex algorithm. Linear programming has found frequent and broad application in economic problems [11] and has previously been used to simulate ranching operations [1, 9, 19].

In the following sections, we shall outline the policy variables with which the rancher operates, specify the objective function and constraints, and describe the techniques used to incorporate the effects of uncertainty in the linear programming simulation.

4.2.2 The Decision Variables

An optimal solution is obtained by manipulating certain decision variables. The rancher makes use of the resource available to him, forage, by harvesting it through consumption by cattle. He controls this consumption through the stocking rate which is determined, ultimately, by his cattle buying and selling decisions. Thus, although consumption is the means by which forage is utilized, cattle purchase and sales are the rancher's final management tools. Thus, the model in this study solves for optimal buying and selling rates which maximize rancher profits.

Another decision option is supplemental feed. This variable may come into play when the rancher is realizing that overstocking is occurring and yet finds it profitable to temporarily support the cattle on purchased feed instead of selling them immediately.

Being a serial optimization model, the rancher simultaneously optimizes over six forecast periods, using forecasted values as input to his decision process. Six one-month forecast periods were used for the optimization because it is the approximate length of a grazing season. Forecast periods are necessary because current decisions are a function of expected future conditions (e.g., expected prices when the rancher intends to sell). In specifying variables, double subscripting is used; for example, y_{ij},

refers fo the value of y during the jth forecast period of the ith decision period. Optimal values for cattle purchase and sales (and biomass consumption) and supplemental feed purchases are obtained for each of the six forecast periods with the values obtained for the first forecast period corresponding to the actual decisions made during the particular decision period; i.e., $y_{i,1} = y_i$ (in effect, this is only the simulation's way of saying that the decision-maker is not bound by what he expects to do three periods from the present). Once an optimum is found, outputs are recorded, time is incremented by one decision period, new decision model inputs are obtained, and re-optimization is performed.

4.2.3 The Profit Constraints

Several constraints upon rancher operation have been identified from previous range management simulations and the literature. The constraints discussed herein will hold for all forecast periods (subscripted j) in each decision period (subscripted i).

Utilizable forage at the beginning of the jth forecast period (the state variable) is constrained by the amount existing at the beginning of the last period plus or minus the effects of the growth and decay processes and the control variable (consumption less supplemental feed):

$$\hat{x}_{i,j} = (1-\mu)\ \hat{x}_{i,j-1} + \hat{g}_{i,j-1} + f_{i,j-1} - c_{i,j-1} \qquad (4.3)$$

Where

$\hat{x}_{i,j}$ = estimate of biomass on ground at the beginning of the jth forecast period in the ith decision period.

$\hat{g}_{i,j-1}$ = forecast of last forecast period's forage growth

$f_{i,j-1}$ = purchased supplemental feed during the previous forecast period

$c_{i,j-1}$ = biomass consumed by foraging cattle during the previous forecast period

Throughout, $y_{i,j-1}$ where $j = 1$ refers to y_{i-1}.

Within the decision process, only estimates and forecasts of point biomass and growth (indicated by "hats" over the variables) are used and represent the imperfect information available to the decision-maker.

Consumption is constrained by the amount of utilizable biomass available, less certain quantities which are used to avoid damaging overgrazing:

$$\hat{c}_{i,j} \leq (1-\mu)\ \hat{x}_{i,j} + \hat{g}_{i,j} + f_{i,j} - \delta_{i,j} - \omega_{i,j} \qquad (4.4)$$

Where

$\delta_{i,j}$ = the hedge factor (discussed in Section 3.3 and specified in 4.3.3).

$\omega_{i,j}$ = the threshold below which the range should not be grazed in order to aviod damage to the range; the minimum amount of forage which is is desirable to leave in the range (specified in Section 4.4.1).

The current stocking rate, h_{mij}, is found by the equation:

$$h_{m,i,j} = h_{m,i,j-1} + b_{m,i,j} - s_{m,i,j} \qquad (4.5)$$

Where

$b_{m,i,j}$ = the number of head of type m bought in the jth forecast period of i.

$s_{m,i,j}$ = the number of head of type m sold in period i,j.

m is a subscript which refers to the period in which the steer was purchased. This reference permits the model to assign different consumption rates and weights (and thus, prices) to head of different weight. (See Section 4.5.2). Biomass consumption is determined by:

$$c_{i,j} = \sum_{m=1}^{M} \beta_{m,i,j} \, h_{m,i,j} \qquad (4.6)$$

Where

$\beta_{m,i,j}$ = the average amount of biomass consumed by a steer of type m in period i,j (given an adequate supply of biomass).

Cattle sales must be constrained so that you cannot sell in the present period more head of steer than you possessed in the previous:

$$s_{m,i,j} \leq h_{m,i,j-1} \qquad (4.7)$$

In order to make the simulation model manageable we have stipulated that only one type of steer is able to be purchased in any particular forecast period:

$b_{m,i,j} = 0$ where m does not correspond to to the i,j period.

Finally, we add the constraint that all the variables must stay greater than or equal to zero.

4.2.4 The Rancher's Objective Function.

The source of rancher revenues and costs have been determined from USDA reports, previous range management simulations, and the literature. Only the factors which are variable in the short run are considered, and all such variables which contribute to costs and revenue are accounted for. This study is not concerned with factors which are only affected in the long run, such as range improvement investments or selling off capital, except as they influence short-run decisions. The only such factor identified is overgrazing, the effects of which are considered in Section 4.4.1.

The variables which affect profits in the short run are the prices and expected prices for cattle purchase and sales and for supplemental feed. The costs (and opportunity costs) of the rangeland are assumed to be fixed in the short run. This assumption is felt to be reasonable because most rangeland grazed is either owned by the rancher or available through multi-year leases. The objective function to be maximized for any particular decision period is specified by:

$$PROFIT_i = \sum_{j=0}^{J} \left(\sum_{m=0}^{M} PS_{m,i,j} \cdot s_{m,i,j} - PB_{m,i,j} \cdot b_{m,i,j} \right) - PF_{i,j} \cdot f_{i,j} \qquad (4.8)$$

where

$s_{m,i,j}$ = the number of cattle of type m to be sold in the jth forecast period in i.

$b_{m,i,j}$ = the number of cattle of type m to be bought in the jth forecast period in i.

$f_{i,j}$ = the amount of supplemental feed to be bought in the jth forecast period in i.

$PS_{m,i,j}$ = the sale price of a $s_{m,i,j}$ steer.

$PB_{m,i,j}$ = the purchase price of a $b_{m,i,j}$ steer.

$PF_{i,j}$ = the purchase price of supplemental feed.

and where the prices include the costs of going to market to make the transaction and are discounted from the initial time period. Further, these represent actual prices when $j = 1$ and predicted prices when $j > 1$.

4.2.5 The Use of Linear Programming Under Uncertainty

Generally, linear programming solutions are only used when the problem can be specified in a deterministic manner. For this study, we wish to study the effects of imperfect information and rancher decision policies in an uncertain environment. The general linear programming formulation is:

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$$\text{Maximize (Minimize)} \quad \sum_{j=1}^{n} c_j x_j$$

$$\text{Subject to} \quad \sum_{j=1}^{n} a_{ij} x_j \leq b_i \text{ for } i=1, 2, \ldots, m. \qquad (4.9)$$

where a_{ij}, b_i and c_i are known with certainty. Two techniques for permitting a stochastic b_i coefficient are recognized in literature: chance-constrained programming and Monte Carlo simulation. Both techniques are used in this rangeland model and are discussed below.

Chance-constrained programming was used by Hunter [19] in his range management simulation and is felt to provide a good method for investigating rancher policy reactions to uncertainty. Detailed explanations of the use of chance-constrained programming can be found in [7] and [8].

If some variables (e.g., the supply of forage available during a season) are not known with certainty, it may not be economically optimal to assure that constraints which contain those variables are satisfied 100 percent of the time. The key example of this situation with respect to range management is in the selection of optimal stocking rates. If a rancher expects his range to support two hundred head on the average (i.e., the mean amount of available forage supports two hundred head), depending upon the distribution of his error in knowing that available forage, he may be able to graze only one hundred head to guarantee that overgrazing does not take place. However, this would not maximize his profits over time, unless the expected costs of overgrazing were extreme. Thus, the rancher might choose a stocking rate which assures not overgrazing only a certain percentage of the time and less than 100 percent. This is achieved by "hedging" the expected available forage to be consumed. For example, if it could be determined that expected profit could be maximized by tolerating a probability of overgrazing of only 0.3, one would undergraze by an amount specified by the equation

$$\delta_{i,j} = z(P_o)\ \sigma_x \qquad (4.10)$$

where the value of $z(P_o)$ corresponds to the probability of overgrazing to be tolerated (the shaded area under the curve in Figure 6, p. 1-10). This assumes that the error in knowing forage availability is independent, normally distributed with a standard deviation of σ_x. The constraint of $P[ax \leq b] \geq P_o$ is thus achieved by the inequality:

$$ax \leq b - z(P_o)\ \sigma_x \qquad (4.11)$$

If $P_o = .3$, and the standard deviation of the error is 100 lbs per acre, one would graze below his expectation of available forage by

$$\delta = .84 \cdot 100 \text{ lbs/acre} = 84 \text{ lbs/acre}$$

The hedge value, δ, should be interpreted as <u>intentional undergrazing</u>. Thus, one technique of dealing with uncertainty is by limiting the probability that constraints are violated.

Another technique for dealing with uncertainty is Monte Carlo simulation. By this process, different values for the random variable are selected from its distribution and a solution determined for each value of the random variable. Using this method, the effects of a rancher's error in forecasting forage availability can be determined.

Both techniques outlined above are utilized in this range management simulation model. Chance-constrained programming is used to define and then simulate optimal rancher decision policy given uncertain knowledge of forage availability. Monte Carlo techniques are used to determine the way different measurement systems affect the rancher outputs under given decision policies.

4.3 The Information System

Crucial to any resource manager is the flow of information to him concerning the resource. This study is designed to measure the effects in economic outputs which come from changes in this information flow. In this section, we detail the types of information required by the rangeland manager and the ways in which they are derived.

There are three important inputs conerning the dynamic system to the decision model which result from the information system:

1. estimate of utilizable biomass on ground at the beginning of the decision period.
2. forage growth forecasts for the six forecast periods of each decision period, and
3. the uncertainty inherent in the estimate of biomass availability for each forecast period, expressed as the standard deviation of the error in that availability estimate.

4.3.1 Estimation of Point Forage

For the rancher to decide upon a proper stocking rate for the decision period, it is necessary for him to have some estimate of how much biomass is on the ground and available to him at the beginning of that period. This estimate is obtained through actual measurements of biomass on the range taken some time before the present decision. The manner in which the measurements are made is the subject of Chapter 5. We have also chosen to use "alpha-beta" smoothing in order to make use of all the information at our disposal, including previous measurements.

The value of x at the time of measurement (denoted the variable xk_k) is found by the simple accounting equation:

$$xk_k = x_i + \Delta t \, (g_i + f_i - c_i - \mu x_i) \qquad (4.12)$$

where i is the number of the decision period during which the measurement occurs, where growth, feed, consumption and decay (the changes in x which occur during the decision period) are assumed linear during the decision time interval, and where

$$\Delta t = \frac{XBARD_k - IDAY_i}{30}, \qquad 0 \leq \Delta t < 1$$

$XBARD_k$ = the day of kth measurement (in number of days from simulation origin)

$IDAY_i$ = the day of the beginning of the ith decision period.

We obtain the measured value of xk_k ($\overline{xk}_k$) using the simple equation:

$$\overline{xk}_k = xk_k + \varepsilon_x \tag{4.13}$$

where ε_x is a random number taken from a normal distribution with a mean of zero and a standard deviation of σ_x. ε_x is referred to herein as the measurement error while σ_x is referred to as the size of the measurement error. σ_x is an input value and is the first parameter of the measurement system.

As noted before, we can do better than merely accepting $\overline{xk}_k$ as the best estimate of biomass in the ground at the time of the kth measurement. Were we standing at tk_k (the time of the kth measurement) without $\overline{xk}_k$, we would still be able to estimate xk_k using an adaptation of equation 4.1; we will call this "forecasted" estimate $\tilde{x}k_k$.

$$\tilde{x}k_k = (1-\mu k)\ \hat{x}k_{k-1} + \hat{g}k_{k-1} + fk_{k-1} - ck_{k-1} \tag{4.14}$$

where $\hat{x}k_{k-1}$ is the best estimate of biomass at tk_{k-1}.

The definitions of $\hat{g}k_{k-1}$, fk_{k-1} and ck_{k-1} are conditional upon the relationship between the measurement times and decision times. These are four possible cases, given the ranges of the input parameters with which we are working. Figure 23 illustrates these possibilities. For Case I:

$$\hat{g}k_{k-1} = \Delta t\ \hat{g}_{i-1}$$

$$fk_{k-1} = \Delta t\ f_{i-1}$$

$$ck_{k-1} = \Delta t\ c_{i-1}$$

where $\Delta t = \frac{\lambda}{30}$.

For Case II:

$$\hat{g}k_{k-1} = \Delta t_1\ \hat{g}_{i-1} + \Delta t_2\ \hat{g}_{i-2}$$

$$fk_{k-1} = \Delta t_1\ f_{i-1} + \Delta t_2\ f_{i-2}$$

$$ck_{k-1} = \Delta t_1\ c_{i-1} + \Delta t_2\ c_{i-2}$$

where

$$\Delta t_1 = \frac{XBARD_k - IDAY_{i-1}}{30}$$

$$\Delta t_2 = \frac{IDAY_{i-1} - XBARD_k}{30}$$

For Case III:

$$\widehat{gk}_{k-1} = \Delta t \ \hat{g}_{i-2}$$

$$fk_{k-1} = \Delta t \ f_{i-2}$$

$$ck_{k-1} = \Delta t \ c_{i-2}$$

where $t = \frac{\lambda}{30}$

For Case IV:

$$\widehat{gk}_{k-1} = \Delta t_1 \ \hat{g}_{i-2} + t_2 \hat{g}_{i-3}$$

$$fk_{k-1} = \Delta t_1 \ f_{i-2} + t_2 f_{i-3}$$

$$ck_{k-1} = \Delta t_1 \ c_{i-2} + t_2 c_{i-3}$$

where

$$\Delta t_1 = \frac{XBARD_k - IDAY_{i-2}}{30}$$

$$\Delta t_2 = \frac{IDAY_{i-2} - XBARD_{k-1}}{30}$$

These equations also hold for gk_{k-1}

Now we have obtained two expressions for xk_k ($\tilde{x}k_k$ and $\bar{x}k_k$) and we need to find some way to optimally combine them to find a "best" estimate of xk_k; our criterion for "best" will be the combination which minimizes $Var[\hat{x}k_k - xk_k]$. For now we will postulate the following growth model; in

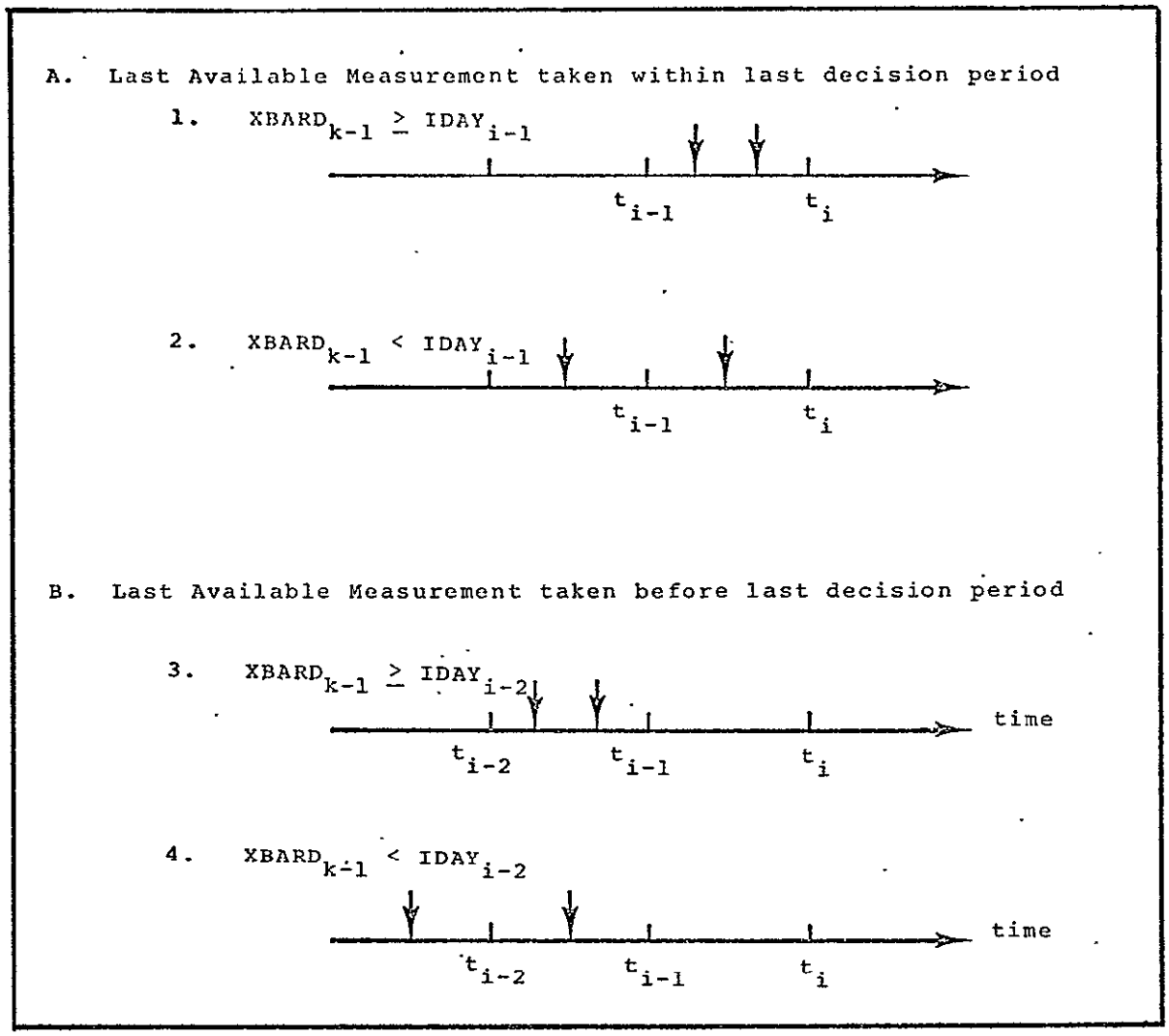

Figure 23 Possible Relationships Between Day of Measurement and Day of Decision

(Vertical arrows (↓) refer to measurement days)

Section 4.3.2 we discuss the selection of such a model and the estimation of its parameters:

$$gk_k = \tilde{g}k_k \quad 1 + {}^k\phi\gamma k_{k-1} + ak_k \qquad .(4.15)$$

where ${}^k\phi$ = constant = $.96714^{\lambda+1}$ (calculated from the value found in Section 4.3.2)

$$\gamma k_{k-1} = \frac{gk_{k-1} - \tilde{g}k_{k-1}}{\tilde{g}k_{k-1}} \qquad (4.16)$$

$\tilde{g}k_k$ = historical average growth during the period referenced by k-1

ak_k = random shock, normally distributed with a mean of zero and standard deviation of σ_a.

Equations 4.15 and 4.16 (with adjusted subscripts) yield

$$gk_{k-1} = \hat{g}k_{k-1} \left(1 + {}^k\phi \frac{gk_{k-2} - \tilde{g}k_{k-2}}{\tilde{g}k_{k-2}} + ak_{k-1}\right) \qquad (4.17a)$$

Changing subscripts of Equation 4.12 and solving for gk_{k-2} and then substituting into 4.17a, we obtain:

$$gk_{k-1} = \tilde{g}k_{k-1} \quad 1 + \frac{{}^k\phi}{\tilde{g}k_{k-2}} \left[xk_{k-1} - (1-\mu k)xk_{k-2} - fk_{k-2} + ck_{k-2}\right] - {}^k\phi + ak_{k-1}\Big\}$$

$$\tilde{g}k_{k-1} \left(1 - {}^k\phi + ak_{k-1}\right) + {}^k\phi \frac{\tilde{g}k_{k-1}}{\tilde{g}k_{k-2}} \left[xk_{k-1} - (1-\mu k)xk_{k-2} - fk_{k-2} + ck_{k-2}\right] \qquad (4.17b)$$

Substituting this expression into 4.12:

$$xk_k = (1-\mu k)xk_{k-1} + fk_{k-1} - ck_{k-1} + \tilde{gk}_{k-1}\left(1 - {}^k\phi + ak_{k-1}\right)$$

$$+ {}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} \left[xk_{k-1} - (1-\mu k)xk_{k-2} - fk_{k-2} + ck_{k-2}\right]$$

$$= \left[{}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} + 1 - \mu k\right] xk_{k-1} - {}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} (1-\mu k)xk_{k-2} + fk_{k-1}$$

$$- ck_{k-1} + {}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} \left(ck_{k-2} - fk_{k-2}\right) + \tilde{gk}_{k-1}(1-{}^k\phi) + \tilde{gk}_{k-1}\, ak_{k-1} \tag{4.18}$$

We have now arrived at an equation for xk_k which contains neither measurements at tk_k, nor growth terms other than $\tilde{g}k$, which are constants. We can now find the desired expression for $\tilde{x}k_k$ (4.19)

$$\tilde{xk}_k = \left[{}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} + 1 - \mu k\right] \hat{xk}_{k-1} - {}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} (1-\mu k)\, \hat{xk}_{k-2} +$$

$$fk_{k-1} - ck_{k-1} + {}^k\phi \frac{gk_{k-1}}{\tilde{gk}_{k-2}} \left(ck_{k-2} - fk_{k-2}\right) + \tilde{gk}_{k-1}\left(1-{}^k\phi\right) \tag{4.20}$$

Now suppose we use both $\tilde{xk}_k$ and the measurement $\overline{xk}_k$ to estimate xk_k in the form

$$\hat{xk}_k = \alpha_k\, \overline{xk}_k + (1-\alpha_k)\tilde{xk}_k \qquad 0 \le \alpha_k \le 1 \tag{4.21}$$

with the error in $\hat{xk}_k$ given by

$$\hat{xk}_k - xk_k = \alpha_k(\overline{xk}_k - xk_k) + \left(1-\alpha_k\right)\left(\tilde{xk}_k - xk_k\right)$$

Combining 4.13, 4.18, 4.20 and 4.21

$$\hat{xk}_k - xk_k = \alpha_k \varepsilon x_k + (1-\alpha_k)\left\{\left[{}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} + 1 - \mu k\right]\left(\hat{xk}_{k-1} - xk_{k-1}\right) - \right.$$

$$\left. {}^k\phi \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} (1-\mu k)\left(\hat{xk}_{k-2} - xk_{k-2}\right) - \tilde{gk}_{k-1}\, ak_{k-1}\right\}$$

which can be written as

$$\Delta xk_k = \alpha_k \varepsilon x_k + (1-\alpha_k)\ \psi_{k-1}\ \Delta xk_{k-1} - (1-\alpha_k)\ \theta_{k-2}\ \Delta xk_{k-2} -$$

$$(1-\alpha_k)\ \tilde{gk}_{k-1} ak_{k-1}$$

where

$$\psi_{k-1} = {}^k\phi\ \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}} + 1-\mu k$$

$$\theta_{k-2} = {}^k\phi\ \frac{\tilde{gk}_{k-1}}{\tilde{gk}_{k-2}}\ (1-\mu k)$$

Consider the quasi steady state solution in which

$$\tilde{gk}_{k-1} \approx \tilde{gk}_{k-2} \approx \tilde{gk}_{k-3} \quad . \ . \ .$$

We now write

$$\psi_{k-1} = {}^k\phi + 1 - \mu = \psi$$

$$\theta_{k-2} = {}^k\phi\ (1-\mu) = \theta$$

and since, during this period, $\alpha_k \approx \alpha_{k-1} \approx \alpha_{k-2} \ldots$, we have

$$\Delta xk = \alpha\varepsilon + (1-\alpha)\ \psi\ \Delta xk - (1-\alpha)\ \theta\ \Delta x - (1-\alpha)\ (\tilde{g}k)ak \qquad (4.22)$$

Then we set

$$\mathrm{Var}\ [\Delta xk] = \alpha^2\ \mathrm{Var}\ (\varepsilon) + (1-\alpha)^2\ \psi^2\ \mathrm{Var}\ [\Delta xk]$$

$$+ (1-\alpha)^2\ \theta^2\ \mathrm{Var}\ [\Delta xk] + (1-\alpha)^2\ \tilde{gk}^2\ \mathrm{Var}\ [\varepsilon] +$$

But in the quasi steady state,

$$\text{Var}\left[\Delta xk_k\right] = \text{Var}\left[\Delta xk_{k-1}\right] = \text{Var}\left[\Delta xk_{k-2}\right]$$

Thus

$$\left[1 - (1-\alpha)^2 (\psi^2 + \theta^2)\right] \text{Var}[\Delta xk] = \alpha^2 \text{Var}[\varepsilon] + (1-\alpha)^2 \tilde{gk}^2 \text{Var}[ak]$$

Since ε and ak have zero mean,

$$\text{Var}[\varepsilon] = \sigma^2_\varepsilon$$

$$\text{Var}[ak] = \sigma^2_a$$

and

$$\text{Var}[\Delta xk] = \frac{\alpha^2\sigma^2_\varepsilon + (1-\alpha)^2 \tilde{gk}^2\sigma^2}{1 - (1-\alpha)^2 (\psi^2 + \theta^2)},$$

where $(1-\alpha)^2 (\psi^2 + \theta^2) \neq 1$ (4.23)

We must now choose α to minimize Var $[\Delta xk]$.

For convenience, we write

$$\text{Var}[\Delta xk] = \frac{(1-\beta) A + \beta^2 B}{1 - \beta^2 C}$$

where

$$\beta = 1-\alpha$$

$$A = \sigma^2_{\varepsilon x}$$

$$B = \tilde{gk}^2\sigma_a^2$$

$$C = \psi^2 + \theta^2$$

Then

$$\frac{d\ \mathrm{Var}\ [\Delta xk]}{d\beta} = \frac{-2(1-\beta)\ A + 2\beta B}{1 - \beta^2\ C} + 2\beta C\ \frac{(1-\beta^2)\ A + \beta^2 B}{(1 - \beta^2\ C)^2} = 0$$

as long as $\beta^2 C \neq 1$. Solving for β in quadratic form:

$$\beta^2 - \beta\left(\frac{A + B}{AC} + 1\right) + \frac{1}{C} = 0$$

Thus

$$\beta = \frac{1}{2}\left[\frac{A+B}{AC} + 1 \pm \sqrt{\left(\frac{1}{C} + \frac{B}{AC} + \frac{C}{C}\right)^2 - \frac{4C}{C^2}}\right]$$

$$= \frac{1}{2}\left[\left(\frac{1}{C} + \frac{B}{AC} + \frac{C}{C}\right) \pm \frac{1}{C}\sqrt{\left(1 + \frac{B}{A} + C\right)^2 - 4C}\right]$$

$$= \frac{1}{2C}\left[\frac{A(1+C) + B}{A} \pm \sqrt{\left(\frac{A(1+C) + B}{A}\right)^2 - 4C}\right]$$

Let

$$Q = \frac{A\ (1 + C) + B}{A}$$

and note that A, B, and C are all positive.

Then

$$\beta = \frac{1}{2C}\left[Q \pm \sqrt{Q^2 - \frac{4CQ^2}{Q^2}}\right] = \frac{Q}{2C}\left[1 \pm \sqrt{1 - \frac{4C}{Q^2}}\right]$$

For the solution to exist $\frac{4C}{Q^2} \leq 1$ and $0 \leq \beta \leq 1$.

$$\frac{4C}{Q^2} = \frac{4CA^2}{[A(1+C) + B]^2} = \frac{4CA^2}{A^2(1+C)^2 + 2AB(1+C) + B^2} \leq 1$$

Note the range of C:

$$C = \psi^2 + \theta^2 = (1 + \phi - \mu)^2 + \phi(1-\mu)^2$$

The maximum value of C occurs for $\phi = 1$, $\mu = 0$

$$(0 \leq \phi \leq 1,\ 0 \leq \mu \leq 1)$$

$$C = (1+1)^2 + 1 = 5$$

The minimum value of C occurs for $\phi = 0$, $\mu = 0$, $C = 0$

Note also that

$$\frac{Q}{C} = \frac{A(1+C) + B}{AC} = 1 + \frac{1}{C} + \frac{B}{AC} > 1$$

Therefore

$$\beta = \frac{Q}{2C}\left[1 - \sqrt{1 - \frac{4C}{Q^2}}\right] \tag{4.24}$$

Proof that $\frac{4C}{Q^2} \leq 1$ from above

$$\frac{4C}{Q^2} \leq \frac{4C}{(1+C)^2} = \frac{4C}{1 + 2C + C^2} \qquad \text{for } 0 \leq C \leq 5$$

$$\frac{d}{d.}\left(\frac{4C}{(1+C)^2}\right) = \frac{4}{(1+C)^2} - \frac{8C}{(1+C)^3} = 0$$

and always $1 + C \neq 0$

$$4(1 + C) = 8C$$

$$4C = 4$$

$$C = 1 \qquad \therefore \frac{4C}{Q^2} \leq 1 \quad \text{always}$$

Given a best estimate of xk_k, it is quite simple to move on to a best estimate of x_i at the beginning of the current decision period. If $XBARD_k \geq IDAY_{i-1}$

$$\hat{x}_i = \hat{xk}_k + \Delta t \left(\hat{g}_{i-1} + f_{i-1} - c_{i-1} - \mu\hat{x}_{i-1}\right) \quad (4.25a)$$

$$\Delta t = \frac{XBARD_k - IDAY_{i-1}}{30}$$

If $XBARD_k < IDAY_{i-1}$

$$\hat{x}_i = \hat{xk}_k + \Delta t \left(\hat{g}_{i-2} + f_{i-2} - c_{i-2} - \mu\hat{x}_{i-2}\right) + \hat{g}_{i-1} +$$

$$f_{i-1} - c_{i-1} - \mu\hat{x}_{i-1} \quad (4.25b)$$

Again, in both equations 4.25a and 4.25b, k refers to the number of the last measurement available at the beginning of the ith decision period. Since we are dealing with the measurement system parameter of a data availability lag, it is not necessarily the case that k is "available" merely because $XBARD_k < IDAY_i$. The criteria for selecting the "last available measurement" is: k represents the number of the last available measurement at the beginning of the ith decision period if and only if:

$$XBARD_k \leq IDAY_i - dl$$

$$\text{and } XBARD_{k+1} > IDAY_i - dl.$$

Here we see the importance of this parameter. The data lag (dl) controls whether the last measurement taken can be used at decision time or whether older, inferior information must be depended upon. The data lag affects the average length of time between the last available measurement and the current decision [30 Δt or 30 (Δt + 1)] and, correspondingly, affects the uncertainty in the estimate of x_i as we shall see in Section 4.3.3. Quite obviously, the other factor which controls the time distance between last available measurement and current decision, and the uncertainty in $\hat{x}_i$, is the time interval between measurements, λ.

4.3.2 Forecasting Forage Growth

In order to decide how many cattle to place on his range, the rancher needs some estimate of how much forage will grow during the decision period. Since this is a quantity which takes place in the future (after the beginning of the decision period) it must be forecasted based on information about the past and present.

Since RANGES IV is used to provide the input of "actual" forage growth in our simulation, it is also used to find a model from which growth forecasts can be made. The simplest model which produces reasonable results simply predicts the long-run historical average growth for the period concerned. Table 8 shows the values of these averages for the twelve months of the year. We will call this model Growth Model 1.

Tests on the growth time series produced by RANGES IV showed a consistent, positive correlation between successive months' forage growth. A moving average model with a first order auto-regressive component on the differences (Growth Model 2) was fit to the RANGES data; this model took the form:

$$g_i = \tilde{g}_i + \varepsilon_{g_i}$$

where

$$\varepsilon_{g_i} = \phi\varepsilon_{g_{i-1}} + a_i$$

$$\phi = 0.36739$$

$\tilde{g}_i$ is historical average growth for the ith period (taken from Table 8) and a_i is random shock taken from a normal distribution with a zero mean and standard deviation of 1.7045866×10^5. Growth Model 2 was found to provide a better fit to the data than the simple moving average model first proposed. Predictions made using

$$\hat{g}_i = \tilde{g}_i + \varepsilon_{g_i}$$

$$\varepsilon_{g_i} = \phi\varepsilon_{g_{i-1}}$$

(random shock removed since its expected value is zero) offered superior properties to the model (Model 1)

$$\hat{g}_i = \tilde{g}_i$$

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Table 8 Historical Monthly Average Forage Growth for Short Grass, Colorado Range

Month		Growth, utilizable lbs. per 1000 acres
1	January	5.5166000×10^{1}
2	February	2.0757600×10^{1}
3	March	4.0202000×10^{2}
4	April	2.5277222×10^{3}
5	May	2.0200828×10^{4}
6	June	1.5768354×10^{5}
7	July	1.8756956×10^{5}
8	August	1.8220406×10^{5}
9	September	1.1875332×10^{5}
10	October	7.7794641×10^{4}
11	November	2.6275570×10^{3}
12	December	5.7802000×10^{1}

Source: RANGES IV Grassland Simulation, run using actual weather data, 1949 to 1965.

as judged by a smaller error in the quantity $\hat{g}_i - g_i$ $[Var(\hat{g}_i - g_i)]$. Examination of the residuals $(\hat{g}_i - g_i)$ of the auto-regressive model, however, showed non-stationarity suggesting that a better fit could yet be found.

The non-stationarity indicated that the residuals $(\hat{g}_i - g_i)$ changed in size according to the time of year and were larger in summer, smaller in winter, which corresponded with average growth. Thus, a model having a component which was autoregressive on the percentage differences $\left(\frac{g_i - \tilde{g}_i}{\tilde{g}_i}\right)$ was tried (Growth Model 3):

$$g_i = \tilde{g}_i + \varepsilon_{g_i}$$

$$\varepsilon_{g_i} = \gamma_i \tilde{g}_i$$

$$\gamma_i = \phi \gamma_{i-1} + a_i$$

where $\phi = 0.35630$

$$\gamma_{i-1} = \frac{g_{i-1} - \tilde{g}_{i-1}}{\tilde{g}_{i-1}}$$

and a_i is a normally distributed random shock with zero mean and standard deviation of .9270.

Growth Model 3 was found to work very well. The autoregression producing ϕ was significant to the 99.5 percent confidence level; additionally the non-stationarity of the residuals was removed and prediction errors conform more closely to those expected than did the errors from Model 2. The variance of the prediction errors $[Var(\hat{g}_i - g_i)]$ produced by each of the three models shown in Table 9 show the superiority of Model 3 over Model 2. In producing these error figures, last period's growth (g_{i-1}) was assumed known with certainty for Models 2 and 3.

While g_{i-1} was assumed known in compiling figures for Table 9, this is not the case in the simulation where biomass at any point in time is not known with certainty. Consequently, in winter months when the error in estimating g_{i-1} is large relative to the advantage of Model 3 over Model 1, it was found best to use Model 1. Model 3, then,

Table 9 Variance in Forage Growth Prediction Errors [Var $(\hat{g}_i - g_i)$] for Three Growth Models*

Month		Model 1	Model 2 (g_{i-1} assumed known)	Model 3 (g_{i-1} assumed known)
		Units, (utilizable pounds per 1000 acres)^2		
1	January	2.2950×10^4	2.9056×10^{10}	2.6152×10^3
2	February	2.5281×10^5	2.9056×10^{10}	3.7027×10^4
3	March	4.3817×10^5	2.9056×10^{10}	1.3888×10^5
4	April	7.0610×10^6	2.9056×10^{10}	5.4906×10^6
5	May	6.6483×10^8	2.9056×10^{10}	3.5067×10^8
6	June	5.6315×10^{10}	2.9056×10^{10}	2.1366×10^{10}
7	July	6.4269×10^{10}	2.9056×10^{10}	3.0233×10^{10}
8	August	5.0944×10^{10}	2.9056×10^{10}	2.8528×10^{10}
9	September	2.4989×10^{10}	2.9056×10^{10}	1.2118×10^{10}
10	October	1.3741×10^{10}	2.9056×10^{10}	5.2007×10^9
11	November	5.9126×10^7	2.9056×10^{10}	5.9329×10^6
12	December	3.2524×10^4	2.9056×10^{10}	2.8711×10^3

* Actual and historical average growth taken from RANGES IV output, 1949 to 1965

is used only for predicting forage growth during June, July, August, September and October. Additionally, since the autocorrelation coefficient (ϕ) drops off rapidly as the lag increases from one to two, Model 1 is also used when forecasting forage growth more than one period into the future. This means that the second through the sixth forecast periods for each decision model run use growth forecasts generated from Model 1.

4.3.3 Uncertainties in Forage Availability

The third output from the information system which the decision-maker requires is the uncertainty inherent in the estimates with which he is working. The rancher learns from experience how accurate his information is, but in this simulation we need to calculate the standard error in any estimate. The information is necessary due to the penalties involved in overgrazing the range and is used to find the amount of intentional (expected) undergrazing which is to take place: the hedge factor (see Section 1.2.2).

The rancher is interested in the uncertainty in his estimate of forage availability in any one decision or forecast period. In order to calculate this, we first must find the error in knowing the quantity of biomass at the time of the last available measurement. This error has already been calculated in deriving a best α and β in Section 4.3.1 (Equation 4.23). In going from the best estimate at time of measurement to the best estimate at the beginning of the decision period, we have two cases:

1. If $XBARD_k \geq IDAY_{i-1}$

$$\mathrm{Var}\,[\hat{x}_i - x_i] = (1-\mu k)^2\,\mathrm{Var}\,[\widehat{xk}_k - xk_k] + \Delta t^2\,\mathrm{Var}\,[\hat{g}_{i-1} - g_{i-1}] \qquad (4.26a)$$

where $$\Delta t = \frac{IDAY_i - XBARD_k}{30}$$

$$\mu k = 1 - (.9837)^{IDAY_i - XBARD_k}$$

and where $\mathrm{Var}\,[\widehat{xk}_k - xk_k]$ is obtained from Equation 4.23 and $\mathrm{Var}\,[\hat{g}_{i-1} - g_{i-1}]$ is obtained from previous calculations (yet to be shown) and is equal to $\mathrm{Var}\,[\tilde{g}_i - g_i]$ in the first instances.

2. If $XBARD_k < IDAY_{i-1}$

$$\mathrm{Var}\,[\hat{x}_i - x_i] = (1-\mu k)^2\,\mathrm{Var}\,[\widehat{xk}_k - xk_k] +$$

$$\Delta t^2\,\mathrm{Var}\,[\hat{g}_{i-2} - g_{i-2}] + \mathrm{Var}\,[\hat{g}_{i-1} - g_{i-1}] \qquad (4.26b)$$

where $\Delta t = \dfrac{IDAY_{i-1} - XBARD_k}{30}$

and $\mu k = 1 - (.9837)^{IDAY_{i-1} - XBARD_k}$

In the first measurement no "smoothing" is possible; $\widehat{xk}_k = \overline{xk}_k$ and $\mathrm{Var}\,[\widehat{xk}_k - xk_k] = \sigma^2_\varepsilon$

For decision periods in which Growth Model 3 is used, the variance of the forecast error must be calculated. Since we have an auto-regressive model for growth, we need to know the error in our best estimate of last period's growth. (When Growth Model 1 is used, the variance of the error is simply taken from Table 9, Model 1.) From Equation 4.1 and the equation for g_i in Growth Model 3, we can solve for ε_{i-1}

$$\varepsilon_{i-1} = x_i - (1-\mu)\,x_{i-1} - \tilde{g}_{i-1} + c_{i-1} - f_{i-1} \qquad (4.27)$$

Using recent information (a measurement taken between t_i and t_{i-1}) we can obtain an estimate of ε_{i-1} which is wuperior to a forecast from t_{i-1} by inserting expected values into Equation 4.27:

$$\hat{\varepsilon}_{i-1} = \hat{x}_i - (1-\mu)\,\hat{x}_{i-1} - \tilde{g}_{i-1} + c_{i-1} - f_{i-1}$$

$$\hat{\varepsilon}_{i-1} - \varepsilon_{i-1} = \hat{x}_i - x_i - (1-\mu)\,(\hat{x}_{i-1} - x_{i-1}) \quad \text{and}$$

$$\mathrm{Var}\,[\hat{\varepsilon}_{i-1} - \varepsilon_{i-1}] = [\mathrm{Var}\,[\hat{x}_i - x_i] + (1-\mu)^2\,\mathrm{Var}\,[\hat{x}_{i-1} - x_{i-1}] \qquad (4.28)$$

Since (from Model 3 equations)

$$g_i = \tilde{g}_i + \varepsilon_i = \tilde{g}_i + \tilde{g}_i \left(\phi \frac{\varepsilon_{i-1}}{g_{i-1}} + a_i\right)$$

and $$\hat{g}_i = \tilde{g}_i + \tilde{g}_i \left(\phi \frac{\hat{\varepsilon}_{i-1}}{g_{i-1}}\right) \qquad (\tilde{g}_i \approx \tilde{g}_{i-1})$$

$$\mathrm{Var}[\hat{g}_i - g_i] = \phi^2 \,\mathrm{Var}\,[\hat{\varepsilon}_{i-1} - \varepsilon_{i-1}] + \tilde{g}_i^{\,2}\sigma_a^{\,2} \qquad (4.29)$$

this finally gives us the forecast error variance for growth forecasts using Model 1, by combining with 4.28:

$$\sigma_{\hat{g}_i}^{\,2}(1) = \mathrm{Var}\,[\hat{g}_i - g_i] = \phi^2 \Big\{ \mathrm{Var}\,[x_i - x_i] + (1-\mu)^2\,\mathrm{Var}\,[x_{i-1} - x_{i-1}] + \tilde{g}_i^{\,2}\sigma_a^{\,2} \Big\}$$

The parenthetical 1 refers to the first forecast period. $\sigma_{\hat{g}_i}(j)$, $j = 2 \ldots 6$ is taken from Table 9. The calculation of the hedge factor $(\delta_{i,j})$ requires the uncertainty for the entire forecast period, $\sigma_{\hat{x}_i}(j)$, defined as

$$\sigma_{\hat{x}_i}(j) = \sqrt{\left[\sigma_{\hat{x}_i}(j-1)\right]^2 + \left[\sigma_{\hat{g}_i}(j)\right]^2}$$

where $\sigma_{\hat{x}_i}(0) = \mathrm{Var}[\hat{x}_i - x_i]$. Finally

$$\delta_{i,j} = z\,(P_o)\,\sigma_{\hat{x}_i}(j)$$

where $z(P_o)$ is discussed in Section 1.2.2 and is selected in the manner outlined in Section 4.4.1.

4.4 The Economic Output

In order to find the value of improvements in information, we need to specify a mechanism for measuring these benefits. The mechanism chosen herein for social benefit estimation is the change in consumer surplus plus producer surplus (rent) as measured from actions in the open market. Figure 24 shows the method for finding consumer and producer surplus. It is expected that improved information will yield an increased supply of annual AUM's (see Figure 8), represented

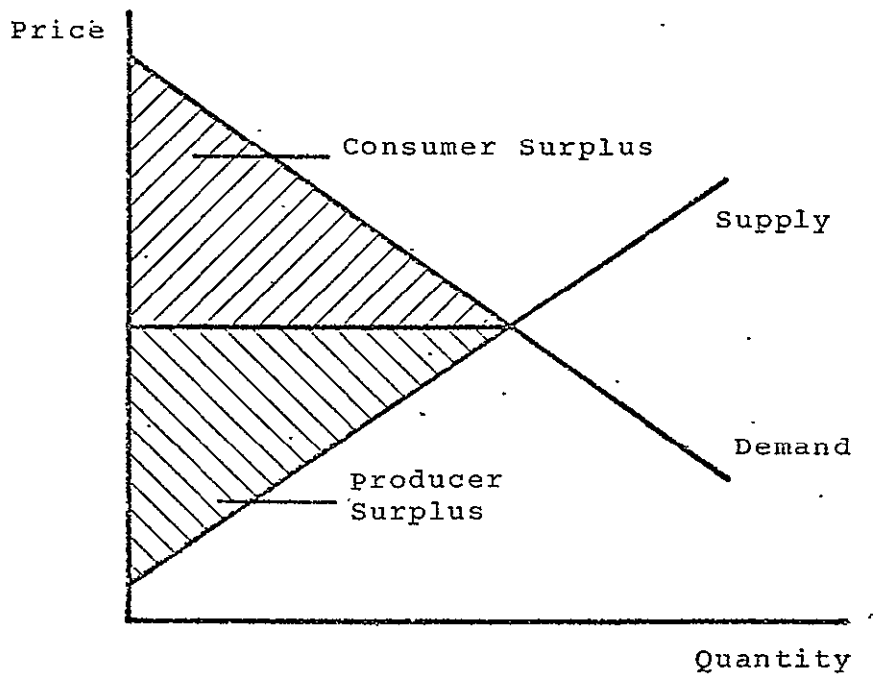

Figure 24 Consumer Surplus and Producer Surplus As Determined in a Free Market

by an outward shift in the supply curve. The shaded area in Figure 25 represents this increase in consumer surplus plus producer surplus resulting from the shift in the supply.

It can be seen that the size of this benefit is dependent upon the slopes of the demand and supply curves. Thus we need estimates of the equations of these curves.

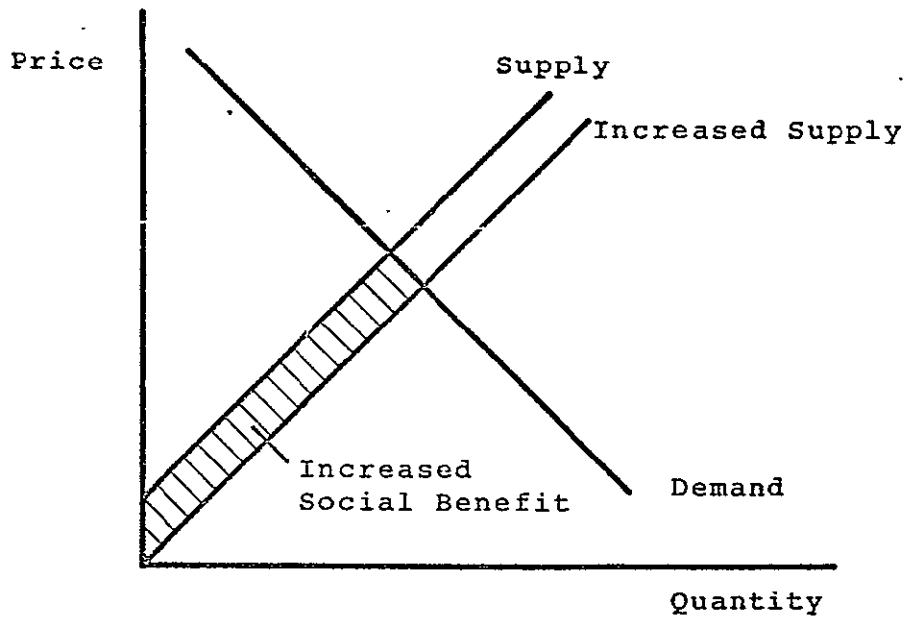

Figure 25 Increase in Consumer Surplus and Producer Surplus Resulting from an Outward Shift in the Supply Curve

Extensive contacts with the U.S.D.A. and with the academic community involved in rangeland management have shown that estimates of the supply and demand curves for forage have not been made. This was an unfortunate finding and requires that very rough approximations be developed in this study in order to estimate the value of improved rangeland information. A good estimate of the slope of the supply curve is developed in Section 4.4.3 using U.S.D.A. figures. A forage demand curve was derived using a very simplified model, but assumptions were required which made the estimate very crude. Thus, the slope of the demand curve could be considered a parametric input to the value of information equations, and should not be taken as a final estimate of the forage demand equation.

4.4.1 Probability of Overgrazing and the Cost of Overgrazing

Living in an environment of imperfect information, the rancher is subject to penalties over which he does not have full control. In placing *n* head of cattle on a range, the rancher does not know with 100 percent certainty that there will be adequate forage for the entire month; thus, he faces a certain probability that the forage supply will not be adequate and that the cattle will not have sufficient consumption to justify the type of weight gains upon which the rancher has

based his purchase decisions. Additionally, competition among cattle for forage may result in damage to the renewable resource. In this section we wish to find two estimates:

1. the quantity of forage which should be left on the ground after grazing in order to avoid unexpected costs: the overgrazing threshold (ω in Section 4.2.3)

2. the probability of overgrazing which the rancher will bear in placing cattle on the range.

In a study performed by R.E. Bement [2] in 1967, it was shown that average dollar return per acre could be maximized by leaving 300 pounds per acre ungrazed (see Table 10). This study was performed on the same range (Central Plains Experimental Range, Nunn, Colorado) from which our other data (forage growth and decay, cattle consumption, and weight gains) were obtained and thus is used in this simulation. Discussions with range scientists at Colorado State University indicate that the 300 pounds per acre figure has become widely used in the area.

Table 10 Cattle Returns Per Acre

Parameter	Unit	Quantity								
Yearling heifers per section	#/640 acres	67	58	49	41	34	31	29	28	
Ungrazed herbage left	lbs/acre	150	200	250	300	350	400	450	500	
Cattle return per acre	$/acre									Mean
1966		1.06	1.66	1.71	1.94	1.87	1.76	1.64	1.59	1.65
1965		1.96	2.40	2.63	2.70	2.49	2.32	2.17	2.10	2.35
1964		0.90	1.03	1.37	1.56	1.51	1.42	1.33	1.28	1.30
Mean		1.30	1.70	1.90	2.07	1.96	1.83	1.71	1.66	1.77

Source: Bement, R.E., "A Stocking Rate Guide for Beef Production on Blue Grama Range", Journal of Range Management, 27(1):85, 1969.

The probability of overgrazing which the ranchers do, or should, tolerate is not so easily discovered. Certainly, this probability is a function of the cost of overgrazing, but we find that this cost has not come under close scrutiny. Hunter [19] estimated the probability of overgrazing at .418 in comparing the results of an "average" forage year to the results of a Monte Carlo study; in doing so, he avoided explicitly defining the costs of overgrazing. His estimate is taken as one possibility of the optimal P_o. However, since Hunter's P_o was essentially a <u>seasonal</u> estimate, we expect the P_o for which we are looking (for each monthly decision period) to be considerably lower than .418. Thus, we take .418 an upperbound estimate of P_o.

It is possible to obtain a few data points for the cost of overgrazing from Bement's study. Several things can be noted from analysis of the figures in Table 10. In setting up a cost of overgrazing function, we will consider the cost equal to zero when 300 lbs/acre are left. Note, then, that we have nine data points which indicate measures of the costs of overgrazing: the returns per acre for the three years at 250, 200 and 150 lbs/acre ungrazed. The mean value of returns per acre for these three grazing intensities drops from the optimal $2.00 to $1.90 to $1.70 to $1.30. Clearly we can see the effects of grazing beyond some desirable limit. Additionally, we find (with the effects of different years' price levels removed) that the return per acre increases from 1964 values to the average 1965-66 value when 350 and 400 lbs/acre of forage are left. The size of this increase in return per acre (price level effects removed) is $.12 above the 300 lbs/acre rate for both grazing intensities (300 and 400 lbs/acre ungrazed). Thus, we have obtained six data points for the costs of overgrazing from -100 to 150 overgrazing lbs/acre at intervals of 50 lbs/acre.

One problem with Bement's study for our work is that it does not cover a long enough time period to assess the effect on the land of overgrazing. What would be the return per acre if for seven years the range was grazed to 150 lbs per acre? Nonetheless, this is the only information available concerning the effects of different stocking intensities and we shall use it. The next problem is finding a form for a regression to fit these data points. A second order polynomial was tried but it yielded a y-axis intercept (cost per acre with zero forage remaining) of around $7.00. It was felt that this figure was too low;

if no forage was actually left in the range, the range would be ruined and many cattle would have long since starved. The form

$$K(\dot{V}) = a_1 + \frac{a_2}{\gamma 1} + \frac{a_3}{\gamma 2}$$

was used to fit the points and yield the following coefficients

$$a_1 = -562.966$$

$$a_2 = 7.206634 \times 10^7$$

$$a_3 = 2.09179 \times 10^{13}$$

and was significant to the 99.5 percent confidence level. The form was chosen under the theory that it would take an infinite number of starving cattle to graze to where there was absolutely zero forage left. In the end, though, it was decided that a maximum penalty of $27 per acre would be levied against the rancher, the figure being roughly equivalent to one-fifth of the value of an acre of rangeland [36].

Finally, we were not wholly satisfied with any particular technique for estimating the optimal probability of overgrazing, suggesting that it perhaps be looked into in more detail for some further study. It was decided to use whichever P_o maximized net profits (gross profits less the cost of overgrazing) and then to determine the sensitivity of benefits to alternative P_o's .

4.4.2 The Demand Equation

The value of incremental AUM's could be determined using the current market price for AUM's. These prices for the recent year are shown in Table 11. This method of valuing assumes perfectly elastic demand and inelastic supply. It is felt that these assumptions can be improved upon; however, the lack of existing estimates of forage supply and demand equations require their development herein. In order to approximate the demand curve equation for AUM's, the following model is proposed: rancher profits are defined by

$$\pi = P_A A - k - P_X X - P_F F - P_C C$$

Table 11 Cash Rent: Average Monthly Rate per Head for Pasturing Cattle on Privately Owned Land, by Region and 11 Western States, March 1, 1970-74[1]

Regions and selected States	Monthly rate per head, dollars				
	1970	1971	1972	1973	1974
Northeast	3.04	3.17	3.40	4.06	4.65
Lake States	2.60	2.66	2.56	3.57	3.95
Corn Belt	2.97	3.01	3.08	3.70	4.63
Northern Plains	4.17	4.17	4.38	4.80	5.99
Appalachian	2.48	2.75	2.89	3.07	3.20
Southeast	2.08	2.14	2.12	3.19	2.90
Delta States	1.76	1.96	1.91	1.81	2.27
Southern Plains	2.94	3.09	3.30	4.14	4.31
Mountain States[2]					
Montana	3.87	4.03	4.32	4.82	6.87
Idaho	3.71	3.79	3.99	4.41	5.43
Wyoming	4.28	4.28	4.45	4.98	5.81
Colorado	4.03	4.23	4.45	5.11	5.51
New Mexico	3.62	3.40	3.92	4.10	4.41
Arizona	3.44	2.78	2.52	2.79	3.21
Utah	3.78	4.05	4.34	4.81	5.51
Nevada	4.76	4.32	3.94	4.36	5.41
Pacific States[2]					
Washington	3.66	3.63	3.53	3.91	5.36
Oregon	3.70	3.61	3.80	4.01	5.29
California	4.44	4.44	4.52	4.74	6.78
11 Western States[2]	4.05	4.06	4.17	4.57	5.82
48 States	3.49	3.55	3.70	4.27	4.95

[1] Based on rates for all classes of cattle obtained from crop reporters, Statistical Reporting Service

[2] State and regional rates are averages weighted by animal units months developed from SRS Western Grazing Survey, 1966.

Source: Farm Real Estate Market Developments, Economic Research Service, USDA, July 1974, p. 43.

where A = quantity (in pounds) of grazed, 700 lb. steer ready for feeding

X = quantity of AUM's grazed

F = quantity of feed (hay) consumed in tons

C = quantity of calves (in pounds) ready for grazing

k = fixed cost

The production function for A is:

$$A = a_1M + a_2M^2 + C$$

M = pounds of utilizable biomass

The supply of utilizable biomass is determined by the technical relationship between AUM's and feed:

$$M = b_1X + b_2F$$

b_1 = utilizable pounds of biomass/AUM = 425

b_2 = utilizable pounds of biomass/ton of hay = 2000

b_1 is obtained using the figure of 1 AUM = 850 pounds of forage (U.S. Forest Service figure [27]) and assuming a utilization rate of .5.

The prices have been obtained from USDA publications and represent averages from 1972 - 1974.

P_A = \$/lb. of feeder steer = .4415 [37]

P_C = \$/lb. of calf = .4908 [37]

P_F = \$/ton of hay = 48.6 [42]

All that is left to estimate are the coefficients a_1 and a_2. In order to do this, we assume that animals will gain 1.5 pounds per day on the range, consistent with the results in Bement [2]. We then use the digestible biomass requirements, (as found in [30], as a function of animal size, which will permit the weight gain assumed. Table 12 shows daily consumption and quantity of consumption required to sustain a 100 pound weight gain. Note that larger animals require more biomass for equivalent weight gain; this results from the fact that it requires more nutrients to simply maintain a larger animal at constant weight.

Table 12 Animal Consumption Requirements		
Steer Weight	Daily Consumption	Forage consumption required to produce total animal weight*
lbs. of steer	air dry lbs. of digestible forage	
300	5.6	0
400	6.7	373.33
500	7.8	820.00
600	8.7	1340.00
700	9.5	1920.00

* Average weight gain of 1.5 lbs. per day assumed

Source: Stoddard and Smith, Range Management, McGraw Hill, New York, 1955, p. 262.

In the equation

$$A = a_1M + a_2M^2 + C$$

M refers to the quantities in the third column of Table 11 while A refers to the quantities in the first column. A second order polynomial was fit to these data points to yield a_1, a_2 and C using least squares techniques. The resulting coefficients were found

$a_1 = .25448$

$a_2 = -.2397 \times 10^4$

$C = 304$ (C represents the initial weight of a a calf placed upon the range)

while the regression was significant to the 99.5 percent confidence level. This function exhibits the typical properties of standard production functions, i.e., positive, but diminishing returns to the input variable.

Substituting the equations for A and M into that for π, we find

$$\pi = P_A[a_1M + a_2M^2 + C] - k - P_XX - P_F\left[\frac{M-b_1X}{b_2}\right] - P_CC$$

$$= P_A[a_1(b_1X + b_2F) + a_2(b_1X + b_2F)^2 + C] - k - P_xx - P_F\left[\frac{M-b_1X}{b_2}\right] - P_CC$$

Solving for the first order condition (profit maximization)

$$\frac{d\pi}{dx} = P_Aa_1b_1 + 2P_Aa_1b_1X + 2P_Aa_2b_1b_2 - P_X + P_F\frac{b_1}{b_2} = 0$$

(We note that the second order condition is negative, since $a_1 < 0$). Solving for P_X

$$P_X = P_Aa_1b_1 + 2P_Aa_2b_1b_2 + P_F\frac{b_1}{b_2} + 2P_Aa_2b_1X$$

$$= \text{constant} - 8.997 \times 10^{-3}\ X$$

We will use this value as an estimate of the slope of the demand curve at equilibrium.

4.4.3 The Supply Equation

An estimate of the slope of the supply curve for AUM's per year is also required to obtain an estimate of the increase in social benefit resulting from an outward shift in the supply curve. This estimated slope will be derived from figures published in the FRES report by the U.S. Forest Service [39]. We will consider increases in supply as coming from range improvement investment. Several types of investments and management strategies have been outlined in the FRES report as explained in Section 2.3.1, so it is necessary to select the investments which would first be chosen to increase forage output. The additional output per acre in annual AUM's divided by the additional cost per acre is then used as the desired estimate of the slope of the supply curve. Although no particular management alternative was explicitly recommended in the FRES report, Alternative 19 was extensively discussed as a feasible choice. Alternative 19 shows the largest acreage

shift from Management Strategy B (some livestock) to management strategy D (intensive management) (comparison of Tables 47 and 56 in [39]). From Table 10 of the FRES report we find that shifts from Strategy B to Strategy D entail additional costs of $.29 per acre and from Table 49 we find that this same shift yields an additional .33 AUM's per acre annually :

1 additional dollar invested in range

$$= \frac{.33}{.29} \text{ additional annual AUM's}$$

$$= 1.1379 \text{ additional annual AUM's}$$

We will use this figure as our estimated slope of the supply curve.

4.5 Finding Values for Decision Model Coefficients

In looking back over the equations for the decision model (Section 4.2), we find that there are some as-yet-unspecified coefficients, namely the prices of cattle and supplemental feed and the forage consumption rate for each class of steer (β in Equation 4.6). In order to complete our model formulation effort, these coefficients must be estimated.

4.5.1 Prices

Time series expressed in dollars per hundredweight for steers as a function of time were derived from price data obtained from monthly cattle auctions in Greeley, Colorado. These figures were supplied by the U.S.D.A. Agricultural Marketing Service for eight years, 1955-1962, and were obtained for two weight classes: 300-500 lbs. and 500-800 lbs. for the "good" class of beef. Prices were then updated to current (1973-74) price levels and checked for correlation with quantity of forage produced as outputted by RANGES IV for those years and logged values. No significant correlation was found.

Using procedures outlined in Section 4.3.2., these time series were modeled and the effects of time (positive, but small, correlation) and a four-year cycle in evidence removed. It had been decided from the outset that trend and cyclic effects (greater than one year in period) would be removed because they would not affect rancher behavior and their removal would add to consistent results. The modeled time series for the two cattle weight prices follows:

$$P500_i = \overline{P500}_i + .96246\ (P500_{i-1} - \overline{P500}_{i-1}) + a_i$$

where $P500_i$ represents the historical average price for the ith (monthly) period and a_i is a random normal variable with mean of zero and standard deviation of 1.0557.

$$P300_i = \overline{P300}_i + .3301\ (P300_{i-1} - \overline{P300}_{i-1})$$

$$+ .5361(P500_i - \overline{P500}_i) + a_i$$

where a_i is normally distributed with mean of zero and standard deviation of 0.6761.

The six forecast periods in the decision model require that price be forecast for the latter five periods. (Actual prices are used in the first period which represents the present time.) Thus, price forecast equations are also required:

$$\hat{P500}_{i,j} = \overline{P500}_{i+j-1} + .9625(\hat{P500}_{i,j-1} - \overline{P500}_{i,j-1})$$

$$\hat{P300}_{i,j} = \overline{P300}_{i+h-1} + .9501(\hat{P300}_{i,j-1} - P300_{i,j-1})$$

here $j > 1$ and where the hats (^) represent predicted values; the j subscript represents the number of the forecast period, and where $j=1$, $\hat{P500}_{i,j} = P500_{i,j}$ and $\hat{P300}_{i,j} = P300_{i,j}$.

These prices only represent \$/CWT at the auction. In order to obtain the price for steers in the rancher's possession and steers which the rancher wishes to possess, the \$/CWT figure for the time period in question must be multiplied by the weight (in 100 lbs.) of the steers; these weights are discussed in the following section (4.5.2). Additionally, a surcharge of \$.22/CWT was added to the price when a steer was purchased and subtracted from the price when a steer was sold. This figure represents the transportation cost of making the transaction and is based on figures found in the Livestock and Meat Situation (Economic Research Service) [37].

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Prices for supplemental feed in the form of alfalfa hay were obtained from the Colorado Crop and Livestock Reporting Service for the same years, 1955-1962. The same techniques used in deriving a model for cattle prices were used here to obtain the following:

$$PSUP_i = \overline{PSUP}_i + .9212(PSUP_{i-1} - \overline{PSUP}_{i-1}) + a_i$$

where a_i is normally distributed, mean of zero and standard deviation of 2.3737 and

$$\hat{PSUP}_{i,j} = \overline{PSUP}_{i+j-1} + .9212(\hat{PSUP}_{i,j-1} - PSUP_{i,j-1})$$

as before. These prices are in units of dollars per ton. For supplemental feed, the constraint was also placed that $PSUP_i \leq 4.29 \; P500_{i+1}$ in order to avoid unboundedness in the linear program. To violate this constraint would mean that ranchers could purchase infinite feed for infinite cattle to graze on and make an infinite profit. The economic rationale for the constraint is that, any time in a real situation that the constraint is violated, ranchers will purchase all feed available and quickly drive up the price until the constraint is met.

4.5.2 Cattle Consumption and Weight Gain

Cattle consumption data are obtained by using subroutine RUMEN in the forage environment created by RANGES IV. RUMEN was developed by R. Rice, an animal biologist at University of Wyoming, and calculates consumption as a function of cattle weight, available green and dry biomass and nitrogen content. Using outputs of RUMEN appended to RANGES IV, a value for average deterministic consumption as a function of time was obtained for different head sizes in situations where there was sufficient biomass for all animals. The consumption rates used for each decision period are presented in Table 13. The assumption of deterministic consumption as a function of time and cattle weight is not a poor one so long as one is dealing with the same rangeland and so long as one also assumes minimal competition for the forage among the consumers,

i.e., that overgrazing is not taking place. When too many cattle are placed on the range, consumption is reduced and so is weight gain. Throughout the decision process, overgrazing is assumed not to occur. The effects which the actual occurrence of overgrazing have on outputs of the decision process are considered in Section 4.4.1.

Average cattle weight gain as a function of cattle weight and time of year was also compiled from RUMEN outputs. Weight gains are assumed deterministic, which is not a poor assumption so long as the type and quantity of forage consumed is known. In order to keep track of the steers in the rancher's possession without exorbitant computer costs due to cattle accounting, the rancher was permitted to buy steers of one weight only: 400 lbs. This weight is well within the range of steers usually purchased for grazing. The additional constraint that steers can only be grazed for 12 periods allows for the determination of cattle weight as a function of present time and time of steer purchase as shown in Table 14. The period in which the steer was purchased is referenced by the third (m) subscript in the variables representing head on range and in the purchase and sales prices (Sections 4.2.3 and 4.2.4).

Table 13 Cattle Consumption Matrix

Cattle Bought on Day	Will Consume in Period Starting Day, pounds of forage											
	0	30	60	90	120	150	180	210	240	270	300	330
0	270	270	270	270	290	290	350	400	450	500	400	300
30	300	270	270	270	290	290	340	380	430	480	380	300
60	300	300	270	270	290	290	340	380	430	480	380	300
90	300	300	300	300	290	290	340	380	420	470	370	300
120	300	300	300	300	320	340	380	430	480	530	430	300
150	300	300	300	300	320	340	380	430	480	530	430	300
180	300	300	300	300	320	340	380	430	480	520	420	300
210	300	300	300	300	320	340	380	430	480	520	420	300
240	270	270	270	270	290	290	250	400	450	500	400	300
270	260	260	260	260	280	280	340	390	440	490	390	300
300	260	260	260	260	280	280	340	390	440	490	390	300
330	260	260	260	260	280	280	340	390	440	490	390	300

Table 14 Cattle Weight Matrix

Steer Purchased on Day	Will Weigh on Day, pounds											
	0	30	60	90	120	150	180	210	240	270	300	330
0	400	390	380	380	390	410	460	520	570	615	620	610
30	600	400	390	390	400	420	470	530	580	625	630	620
60	610	600	400	400	410	430	480	540	590	635	640	630
90	610	600	590	400	410	430	480	540	590	635	640	630
120	600	590	580	580	400	420	470	530	580	625	630	620
150	580	570	560	560	570	400	450	510	560	605	610	600
180	530	520	510	510	520	540	400	460	510	555	560	550
210	470	460	450	450	460	480	540	400	450	495	500	490
240	420	410	400	400	410	430	490	550	400	445	450	440
270	375	365	355	355	365	385	445	505	555	400	405	395
300	370	360	350	350	360	380	440	500	550	595	400	390
330	380	370	360	360	370	390	450	510	560	605	610	400

5.0 THE MEASUREMENT SYSTEM

5.1 Input Parameters

ECON's rangeland simulation model was developed to estimate possible monetary benefits accruing from different rangeland monitoring systems. Accordingly, the model accepts inputs in three different parameters of measurement capabilities. It is not the purpose of this study to recommend systems which achieve certain estimated benefits; rather to quantify the economic value of certain attributes of any measurement system with which this study is concerned can be inclusively defined by the following characteristics:

1. Forage Measurement Accuracy. The ability of the system to measure quantity of biomass with an ecologically homogeneous area with minimum size of about twenty acres.* The input parameter is the standard deviation of the measurement error. This parameter takes on the range of 2,000 to 60,000 utilizable pounds per 1000 acres.

2. Measurement Frequency. In this simulation, measurements are assumed to occur every "n" days with 100 percent confidence. The reader should note that there is a strong interdependence between measurement frequency and measurement accuracy due to the possibilities of broad base sampling. This parameter is varied over the range of three to 36 days.

3. Data Availability Lag. This refers to the time it takes from time of measurement until the information is available to the decision-makers: the data *turn-around time*. It is expected that information gathered by a centralized agency would be distributed on a subscription basis or would be made available through local extension offices. The entire data availability lag consists of the time it takes to process the data plus the time it takes to disseminate it. This parameter is varied from one to seven days.

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*It would be more correct to say that the important parameter here is the accuracy in comparing this year's biomass with biomass from previous years; this type of measurement has been called "change detection." See discussion on p. 5-6.

5.2 Defining the Baseline System

For our purposes the "base" measurement system presently used consists of current rancher practices. We attempt to determine values for the measurement system parameters on the basis of examining rancher behavior.

5.2.1 Current Rancher Practices

The first problem encountered when attempting to compare the measurement system used by a range manager with a centralized, mechanized system is in estimating the accuracy with which a rancher calculates his current forage available. The rancher does not view his range with an attempt to estimate the total quantity of biomass; he merely wishes to know how present conditions compare with past conditions. For example, if there is no apparent difference between this year's conditions and those of last year, the range manager will adjust this year's stocking rates in accordance with last year's results.

A priori, we can say that there are two errors involved in the rancher's measurement process:

(1) measurement error in estimating the difference between present forage supply and supply last year (or other previous years) at this time and given sample plot, and

(2) sampling error in extrapolating from any plot or several plots to a larger area.

Attempts to estimate the actual size of these errors have met with little success. However, we can substitute a good proxy for rancher measurements which should represent an upper bound of rancher's capabilities. Interviews with scientists at the Central Plains Experimental Range indicate that their measurement techniques, including clipping studies, enable them to estimate total forage "within twenty percent of the actual value eighty percent of the time [29]."

The range which we are simulating is a 1000 acre ranch where the most critical measurements are taken as the forage supply gets low. We wish to select a stocking range which results in a season-end residual of 150 pounds of utilizable forage per acre (= 300 pounds of total forage per acre). In order to obtain a single standard deviation in the error for the active season, we will calculate it for when there are 200 pounds of utilizable forage on the ground.

For this range at this quantity of forage, we obtain a standard deviation of error of 31,250 pounds of utilizable forage. This is the value which we will use for the "baseline" system for the first system parameter: forage measurement accuracy.

In estimating a lower bound for this paramter, it was felt that ranchers could possibly possess only one half the capabilities of scientists in experimental ranges; thus our lower bound estimate is an error of 60,000.

Interviews have also indicated that ranchers survey their entire range about four to six times during the six month grazing season. Thus, we will consider the measurement frequency of the "baseline" system as thirty days.

We will assume that the rancher takes three days on the average to assess his resource before going to market; we will attribute to him a data lag of three days.

5.2.2 Current Publicly Obtained Information

Most publicly obtained information is used to administer public grazing lands. Due to manpower and budget constraints it seems evident that public lands administrators are unable to match the accuracy or frequency of measurement on privately-owned ranges. The Forest Service of the USDA has responsibility for 105 million acres of rangeland [33c] for which they have allocated $16.5 million, only a small part of which goes toward determination of resource capabilities; other activities included in the budget allotment include [33d]:

> ". . . prescription and application of intensive range management techniques such as rest-rotation grazing, administration of permits, construction and maintenance of range improvements, range vegetation, control of livestock trespass, and control of resource-damaging insects and diseases."

Similarly, the Bureau of Land Management administers 133 million acres of rangeland, with a $9.1 million budget for activities comparable to those of the Forest Service [30e]

Interviews with range scientists from the Forest Service [27] and the BLM [29] have indicated that public ranges are not as intensively monitored as are private ranges. Permissible stocking rates are set at the beginning of the season according to what the range is expected to yield based on previous years. One update of

this stocking rate is made about two-thirds through the grazing season based on very rapid surveys of the grazing areas. Additionally, the Forest Service adjusts the end of the grazing season according to forage availability based on this mid-season survey.

The initial "measurement" of the forage at the beginning of the season can only be as accurate as historical forage availability at that time of year is variable. Since there is little forage ever on the range at the beginning of the season, the accuracy is probably not too bad; however, the accuracy of the mid-season survey can be expected to be very poor, given the vast areas of land and the great variability in forage growth. It is certainly evident that measurements made by Federal range surveys are not as accurate as those made by range scientists on experimental ranges; however, it appears that no estimates of Federal range managers' accuracy are available. The U.S. Forest Service has in its employ less than 1000 range conservationists and forest rangers to administer over 100 million acres of rangeland out of a total of 187 million acres total National Forest system area [27]. This yields an acreage per man ratio of greater than 100,000 to one, more than 100 times the estimated ratio of privately administered lands. Accordingly, we assume that an accuracy of one-half of that available on private lands is available on public lands. This estimate would yield a standard deviation on measurement error for a 1000 acre range of 60,000 pounds of forage. It will also be considered that one measurement is taken at the beginning of the grazing season, about May 1 in this simulation, and another two-thirds through the season, about August 1. A data availability lag of seven days is estimated as the mean time to complete a quick survey.

Besides ranger surveys on public lands, the USDA publishes feed conditions reports. These reports are compiled based on mailed inquiries sent to ranches and farmers. These are published monthly by the Statistical Reporting Service with weekly updates based on weather reports. In general, these reports are not used by range managers due to lack of timeliness (about a one-month delay) and lack of resolution.

5.3 ERS System Capabilities

5.3.1 Current.

NASA's Earth Resource Survey (ERS) Program consists of spaceborne and high-altitude aircraft imaging devices which gather information about the earth's resources. Primary emphasis in the development of an operational data-gathering system has been on the LANDSAT (formerly ERTS) satellite system. Since the launch of the first LANDSAT satellite, on-going Principal Investigator studies have documented the capabilities of the system.

The ability to monitor forage growth stages is an important capability found by several LANDSAT-1 experimenters. Carneggie and DeGloria [6] have demonstrated that LANDSAT data can be used to easily follow seasonal range condition changes in annual grassland in California, while Tueller, et.al., [32] have shown phenological mapping also possible on Nevada perennial ranges. Bentley [3] has emphasized the application of using LANDSAT imagery in monitoring ephemeral forage and guiding stocking decisions in those areas.

In a recent report [5], Carneggie, DeGloria, and Colwell outline benefits possible from currently demonstrated LANDSAT techniques:

(1) more accurate determination of germination and drying periods for planning movement of grazing animals to or from annual grassland ranges;

(2) predictions of the remaining length of the green feed period made early enough to plan more efficiently for alternative sources of livestock feed;

(3) comparison of conditions and relative forage production between grazing areas within a season, and comparison of conditions and productivity for a given area between seasons;

(4) determination of time when dry forage creates a fire hazard in order to better allocate men and equipment for fire suppression; and

(5) assess extent and location of grazing areas influenced by abnormal climatic conditions, be it drought or abundance of forage.

Other studies have indicated that LANDSAT imagery can be used directly in measurement of forage biomass. Wiegand et. al. [45] state that there is a "... one-to-one correspondence between yield and vegetation density of crops grown for hay or forage," and that LANDSAT data "... should clearly indicate differences in vegetation density." Rouse et.al. [25] have shown at one Texas test site that one vegetative measure from LANDSAT imagery (TVI, Transformed Vegetative Index) is a very good indicator of forage conditions:

> At Throchmorton, the vegetation moisture content and percent green estimate, along with their interaction accounts for 99 percent of the variation of TVI for eight sampling dates.

This relationship is shown in Figure 26.

Investigators at the Space Sciences Lab at University of California at Berkeley have indicated in an as yet unpublished study for the BLM that a LANDSAT-1 multi-tier data collection system can perform very accurate forage biomass measurements. This system consists of ground measurements which are then used to extrapolate to larger areas by means of light aircraft and LANDSAT imagery. Although their study is not yet complete, expected results indicate measurement accuracy to "within ten percent of the true value ninety-five percent of the time [31]." Using the same procedures as before (p. 5-2), we will use a value of 10,204 pounds per 1000 acres as the value for the first measurement system parameter, the standard deviation of the measurement error distribution in simulating rangeland resource capabilities of a LANDSAT-like monitoring system.

Discussions with members of the BLM-ERTS study team indicated that potential LANDSAT system forage measurement accuracies could far exceed currently documented capabilities [16]. Once an imagery data base has been accumulated, distinctions betwen present and past imagery are possible at much greater detail than is presently possible. This fine discrimination technique called change detection is likely to far advance the current state of remote sensing information; however, due to the current lack of a data base, no studies have been made to determine the extent of these capabilities.

Although there are indications that a LANDSAT system can produce data which could be used in forage growth prediction models [5], this has not been tested and possible prediction accuracies are unknown. We will assume that such an ERS system can produce no better predictions than an otherwise naive system.

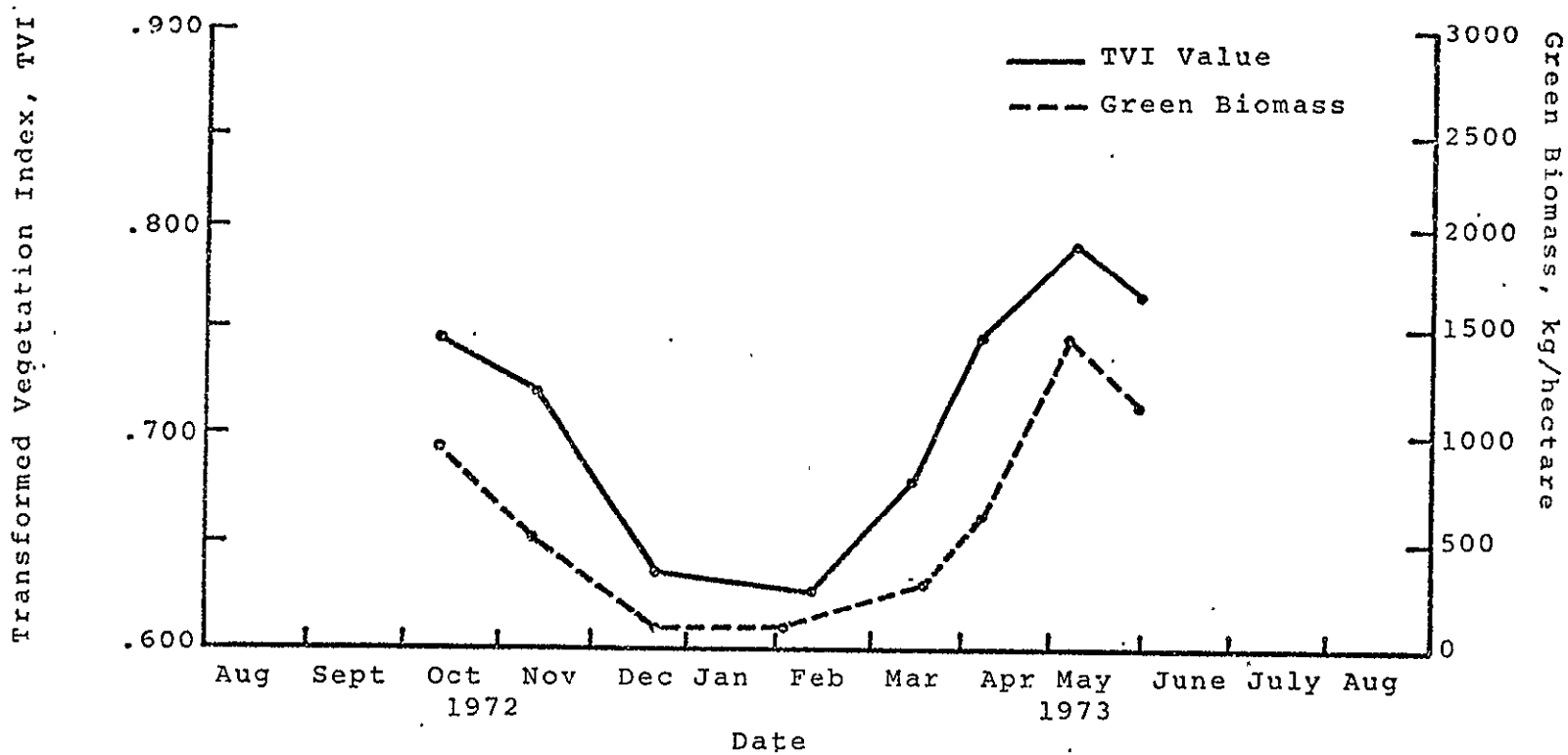

Figure 26 ERTS-1 Transformed Vegetation Index Values vs. Green Biomass Data, Throchmorton Test Site

Source: Rouse et. al., "Monitoring Vegetation Systems in the Great Plains with ERTS," 1973.

We have attributed to the LANDSAT system a measurement frequency of eighteen (18) days, consistent with its characteristic overflight frequency. Since a multi-tier system is assumed in the estimated accuracy, in case of cloud cover, "mop-up" could be achieved by non-satellite measurement systems.

Current turn-around time reported by researchers is very long: several months. However, this does not reflect the true capabilities of an operational data processing system, given a need for timely data. We will estimate that an overflight-to-user lag of seven days is currently possible, were the ERS system made operational. It is conceivable that this lag could be as short as one day.

5.3.2 Potential

Advanced ERS systems with highter spatial and spectral resolution would be expected to produce accuracies in excess of those estimated for the experimental LANDSAT system. One study by Pearson and Miller [24] obtained ground measurement accuracies greater than ninety-five percent. As previously indicated, potential capabilities for change detection over a large data base that have been amassed are great but unknown.

Additionally, future systems could provide vast improvement upon present capabilities. Measurement frequency could be increased to almost no limit with multi-imager or multi-satellite systems. Continuous monitoring would be possible from satellites in synchronous earth orbit, with possibly some loss to spatial and spectral capabilities due to the higher orbit altitude. The minimum data lag is conceivably only the computer processing time involved.

6.0 SIMULATION RUNS AND RESULTS

6.1 Simulation Methodology

With the simulation programming complete, the first task is to find an operational probability of overgrazing, under which the rancher would operate, using the techniques outlined in Section 4.4.1. Eight runs were made using estimated upper bound rancher's measurement parameters (σ_ε = 30,000, λ = 30, dl = 3), varying P_o from .1 to .5. The results of these runs are shown in Figure 27. Net profit is found to maximize at P_o = .22. This P_o produces a system output (net consumption) of 226 pounds per acre per year. Another run representing rancher capabilities was performed, using the lower bound capability estimate (σ_ε = 60,000). Here it is found that the optimal P_o is close to .10. The system output is 179 pounds per acre. The P_o value of .22 is then used for most other simulation runs since it would have been too costly to re-optimize P_o for each parameter change.

Having established a P_o with which to work, we were able to make simulation runs comparing different measurement systems. The input parameters took on values within the following ranges:

1. $2{,}000 \leq \sigma_\varepsilon \leq 60{,}000$ util. lbs/1000 acres
2. $3 \leq \lambda \leq 36$ days
3. $1 \leq dl \leq 7$ days

The output (net consumption) of these runs is then compared to the outputs of the rancher capability simulations to determine if, and where, potential benefits exist.

Additionally, since we recognize inaccuracies in estimating the optimal P_o, certain runs where benefits appeared to exist were re-run with P_o = .42 (Hunter-estimated) to determine the sensitivity of benefits with respect to P_o. The estimates of optimal P_o, taken here, assume risk neutrality on the part of the decision-maker. Where risk averseness exists, a lower value of P_o would be chosen. This would result in larger benefits where they exist.

It was found that three years (6, 12, 16) produced insufficient growth for grazing. In order for the overgrazing threshold to be satisfied in these years, the rancher would have to purchase feed while not consuming. Thus, it was decided that decisions would not be made in these years in order to conserve run time.

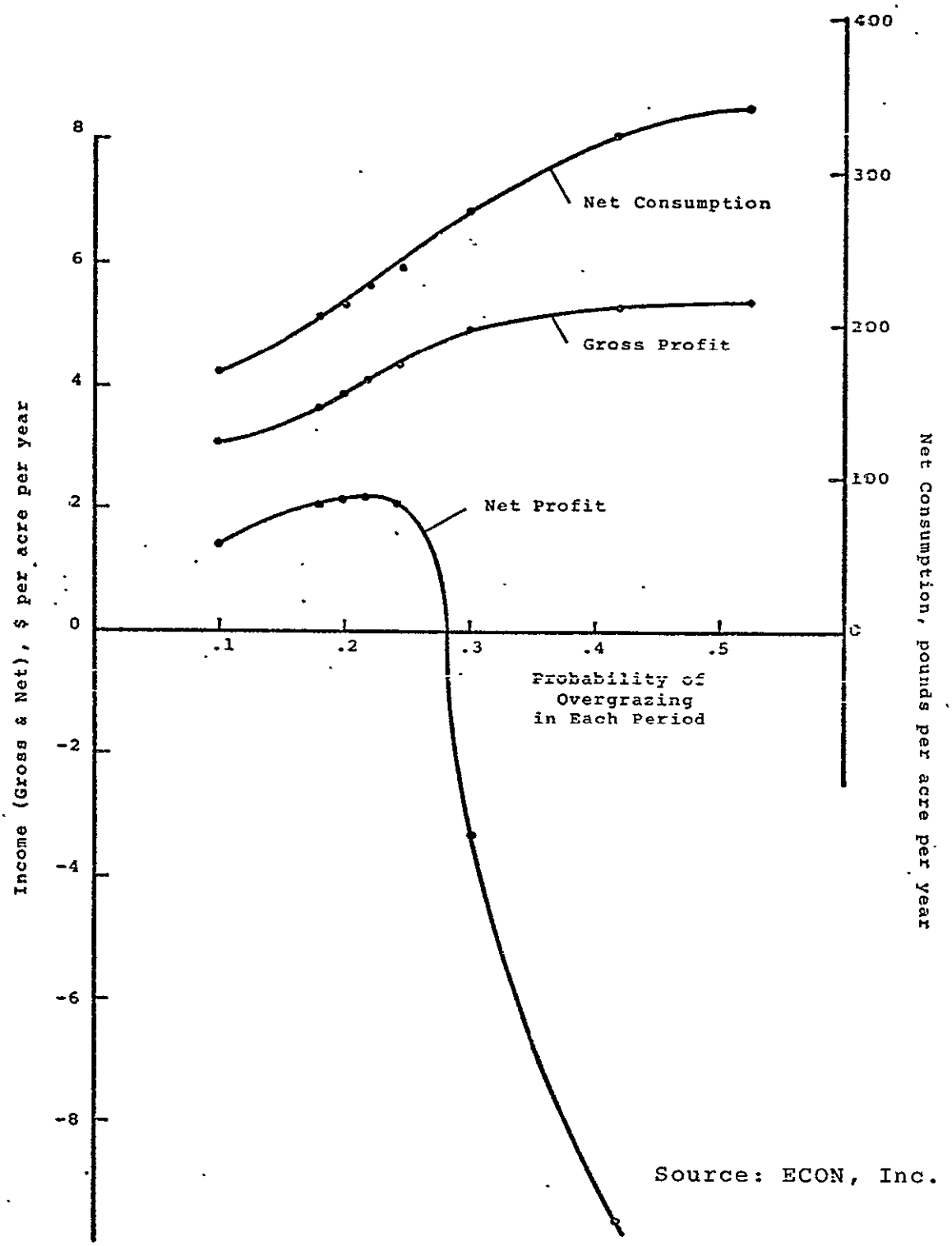

Figure 27 Net Profits, Gross Profits and Net Consumption As a Function of Probability of Overgrazing in Rancher Simulation

Finally, we simulated management behavior on government ranges. This was done by limiting access to the range and limiting the number of stocking decisions, i.e., suppressing changes in stocking rates in June and August. This procedure corresponds with government management behavior of permitting a set number of AUM's to be consumed on a site at the turn-out date in May; a mid-season update, if necessary, in July; and finally closing the range in September or October (as discussed in Section 5.2.2). The present measurement system was simulated by taking measurements before the turn-out date, in mid-season and again at season's end. A measurement error of 60,000 util. lbs./1000 acres was used, representing the lower bound in rancher capabilities. The lower bound was chosen due to the lack of manpower available for government monitoring. A data lag of seven days was attributed to the current system.

6.2 Simulation Validation

In general, we were quite pleased with the model results. An "average" year (historical average growth values used) with a probability of overgrazing of .42, produced a gross rancher income of approximately $24,000. "Average" runs in Hunter's model produced an income of $54,000. The two ranges were 1000 and 900 acres in size, respectively. These results compare favorably when one considers:

1. Hunter assumed 100 percent utilization rate; we used fifty percent, which is closer to the actual rate; this difference accounts for a factor of 2 in the results.

2. Hunter assumed no decay, while we used a decay rate of .3892 per month; this difference would explain the remaining inconsistency very well.

Another favorable point in viewing our results is that the rancher simulation (upper bound capability) produces a dollar return per acre (net profit) of $2.119 (Figure 27). Bement[2] found a dollar return per acre of $2.06 in an actual grazing study (Table 10). This comparison may not be too accurate, though, because it appears that Bement's study subtracts out the cost of maintenance (rancher activity), while our study represents rancher income, and thus rancher activity is assumed provided at no cost.

In comparing our study to values computed in the FRES report [39], we find that our annual AUM's per acre of .226 is small relative to the .33 reported for similar ranges (see Table B-2, Appendix B, Mountain Grasslands, Intensive Management). In looking for an explanation for this discrepancy, it seems likely that the decay rate used in this study may be considerably too high during grazing seasons. Analysis of forage decay was performed on ungrazed ranges; on ranges where cattle were placed, much of the forage which would have decayed would be consumed by grazing animals. It seems likely that this would produce substantially more consumption per acre, perhaps enough to match the figure reported in the FRES report. This would also yield a higher dollar return per acre so that rancher profits might compare more favorably with those reported by Bement. If this is the case, (that our estimated decay rate is too high), the effect on the results of this study (relative differences between measurement systems) would be negligible; it would be possible to simply say that the range (dynamic system) modeled more closely represents a 700 acre ranch than a 1000 acre one.

6.3 Simulation Results

The results of the simulation runs, simulating alternative measurement systems applied to private stocker management, are presented in average net consumption per acre per year, and illustrated in Figure 28. There is little to discuss at this point, except to point out that net consumption can be expressed as a function of measurement frequency, measurement accuracy, and data lag as shown. One should note the clear significance of timeliness (frequency and data lag) relative to the measurement error.

Figure 29 shows the results of runs made which assume the measurement information system is adapted to the rancher's needs; i.e., the system obtained measurements every 30 days, as necessary before ranchers' decision times. Estimated rancher capabilities are represented by the shaded region between A and B. Note that point B results from a run using a P_o of .10, while the other points assume an optimal P_o of .22. A represents the estimated upper bound rancher capability (σ_ε = 30,000 util. lbs/1000 acres, dl = 3 days); B represents the lower bound estimate (σ_ε = 60,000 util. lbs./1000 acres, dl = 3 days). Figure 29 is not comparable with values shown in Figure 28 for a frequency of 30 days because the simulation runs which produced Figure 29

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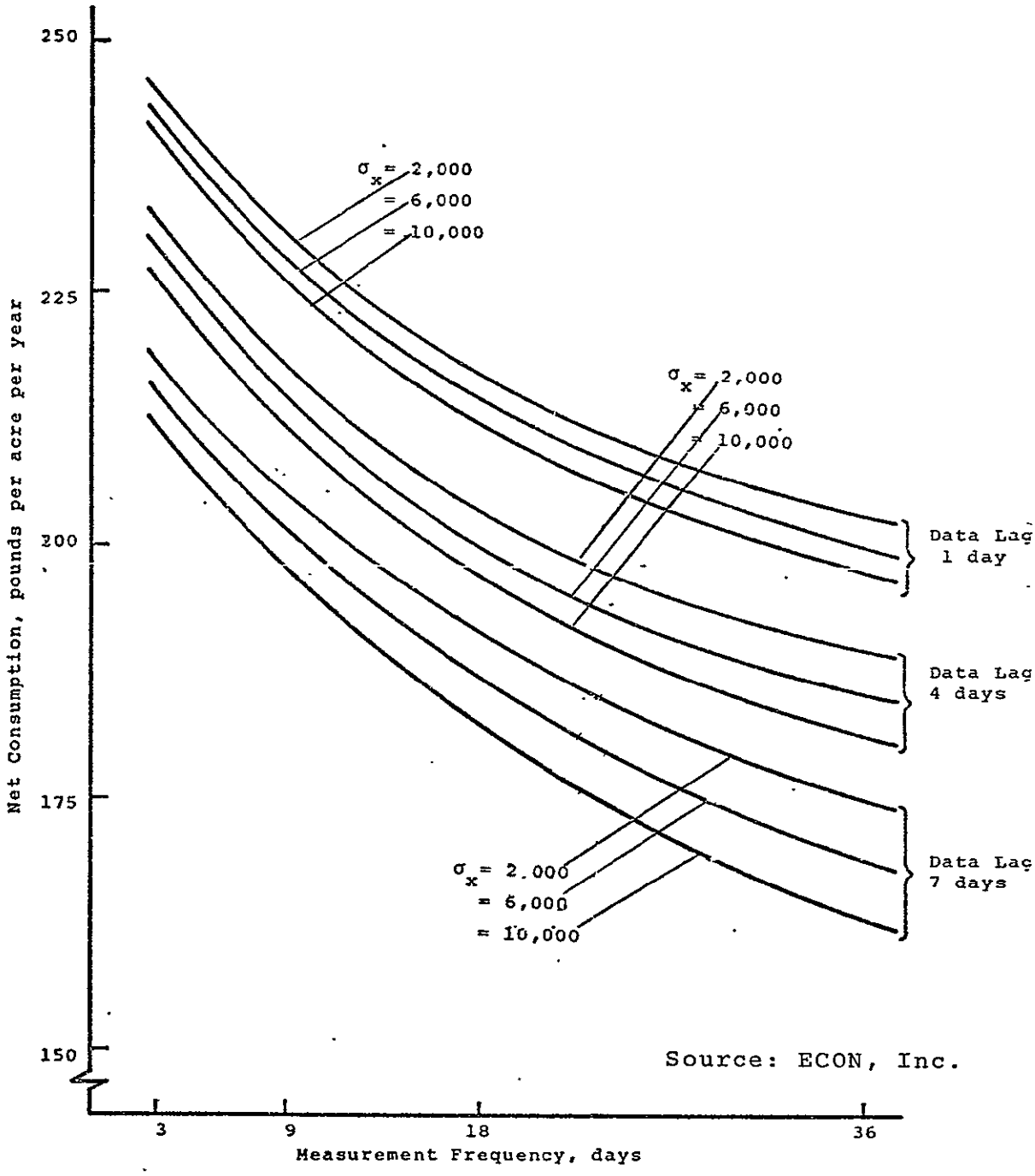

Figure 28 Variation of Net Consumption As a Function of Information Parameters on Private Stocker Ranges

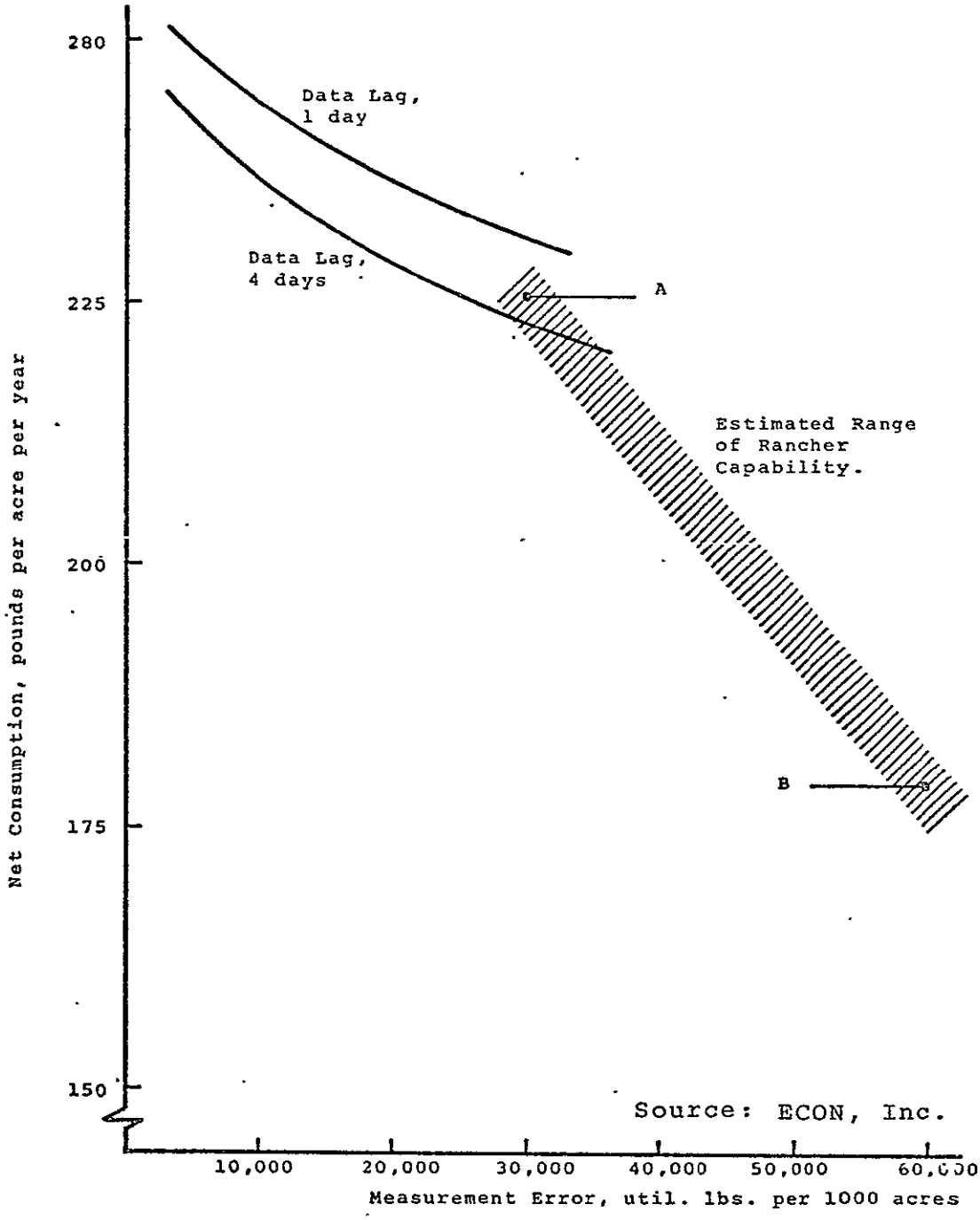

Figure 29 Net Consumption Resulting from User-Oriented* Measurement Systems and Estimated Rancher Capability

*Assumes satellite overflight occurs at the optimal time before rancher's decision time, (30-day frequency).

assumed that measurements are taken in phase with the rancher's decision-making frequency.

Figure 30 illustrates the simulations of government-managed ranges. The shaded area represents estimated conventional capabilities.

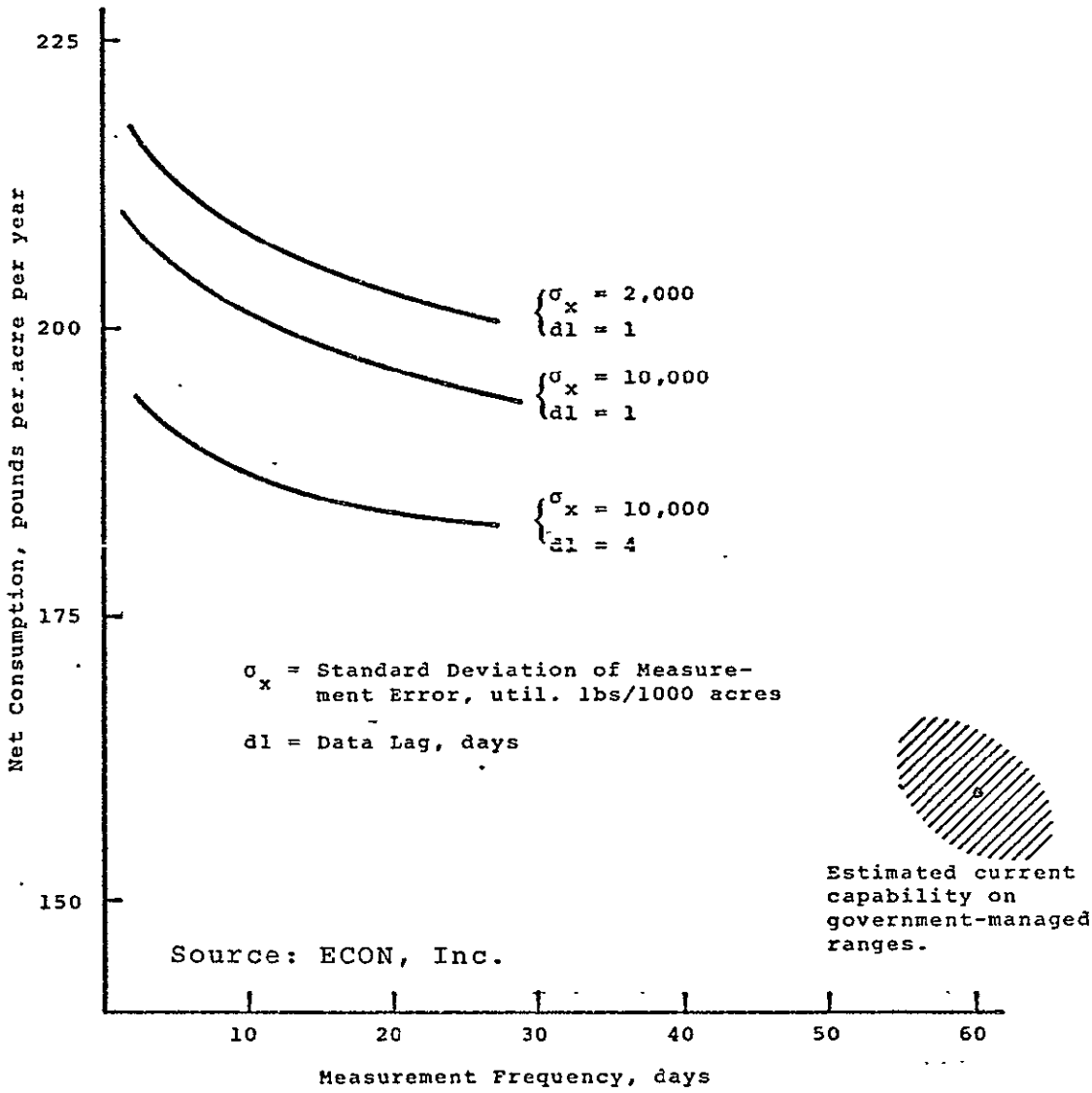

Figure 30 Simulation of Government-Managed Ranges

7.0 ECONOMIC BENEFITS FROM IMPROVED INFORMATION

We have illustrated the simulation results in Section 6. Here we combine these results with the techniques developed in Section 4 for valuing rangeland output.

We have hypothesized a demand curve slope of -9.0×10^{-3} and a supply curve slope of 1.1379. We wish to know the area of region ABCD in Figure 31. From Table 11, we can place the y-ordinate of point A at \$4.95, and from the FRES report, we know point A to have an x-axis value of \$213 million. Elementary trigonometry then tells us the area of ABCD as a function of AB (i.e., the social benefit value of an outward shift in the supply curve as a function of the size of the outward shift).

$$Z\ (AB) = \text{area of ABCD as a function of AB}$$

$$= EC \times AD$$

$$\theta = \angle ADC = \tan^{-1}\left(\frac{BD}{DF}\right) = \tan^{-1}\ (\text{slope of AD})$$

$$= \tan^{-1}\ (1.1379)$$

$$= 48.7°$$

$$EC = DC \cos\theta = .660\ DC$$

$$AD = \frac{AG}{\sin\theta} = \frac{4.95}{.75116} = 6.5898$$

thus,

$$Z\ (AB) = 4.34929\ AB\ .$$

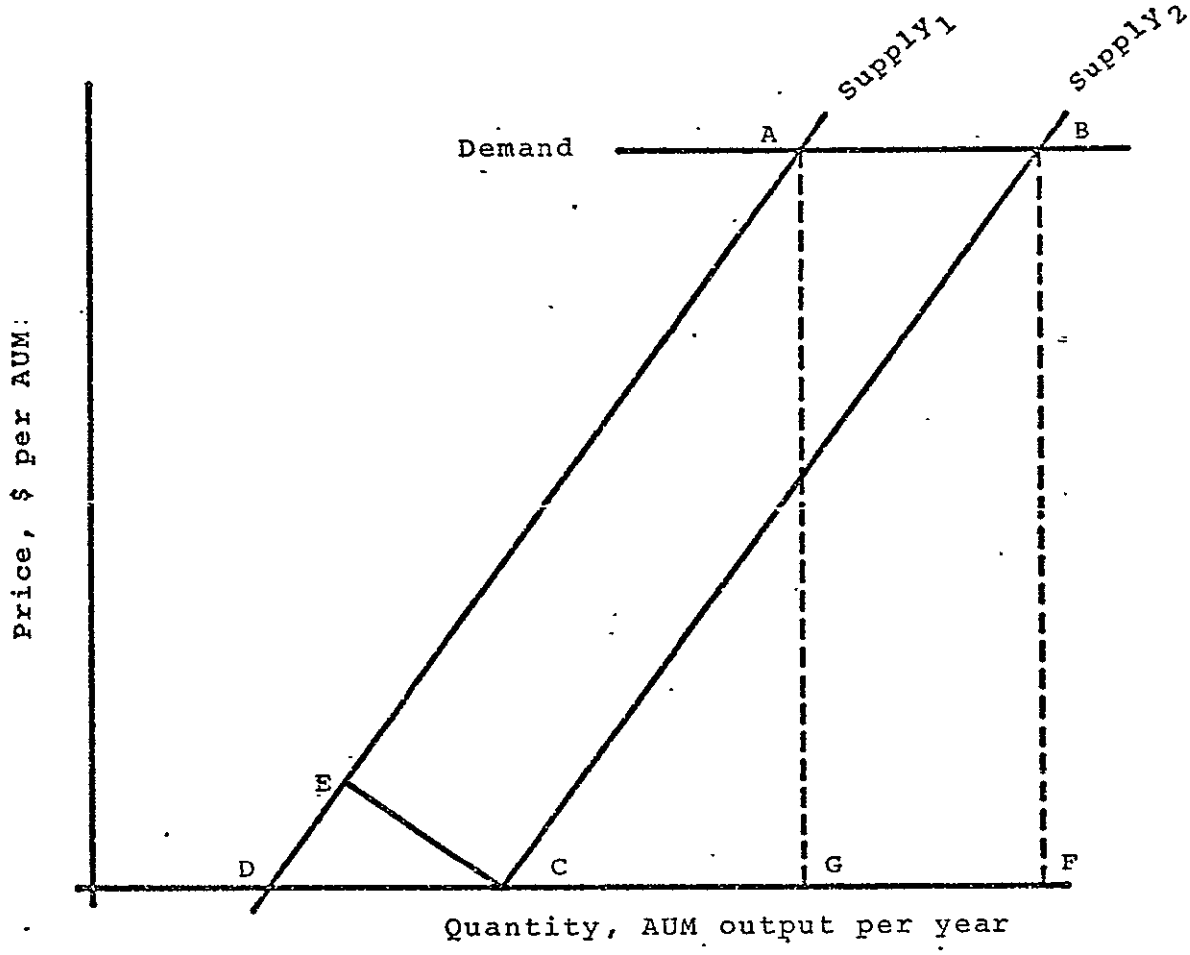

Figure 31 Value of an Increase in Supply

7.1 The Value of Information on Private Stocker Ranches

In looking at Figures 28 and 29, one can see that high capability remote sensing systems can offer rangeland output in excess of that available strictly through conventional rancher practices. One can also see that the main problem in assessing the size of these incremental improvements is in specifying exactly where rancher capabilities lie. A measurement error of 30,000 util. lbs/1000 acres is certainly a very upper bound of rancher capability, for it represents capabilities of systems using clipping studies and photographic techniques, methods that are rarely practiced by ranchers themselves. Our choice of a lower bound measurement error of 60,000 util. lbs/1000 acres has only as its support that it was "felt" that ranchers could have errors at least twice the size of those from experimental ranges. Our best guess of true, average rancher capabilities lies, of course, somewhere in between these two extremes. One tends to say that their capability lies closer to the lower end, but this overlooks the years of experience and professional "intuition" which ranchers have at their access.

Table 15 shows the percentage increases in range output (net consumption) available from measurement systems of differing capabilities. Social benefits resulting from the use of improved measurement systems are derived by taking the percentage increase found in this simulation and multiplying it by 30 million, which is the estimate of U.S. stocker AUM's consumed annually made by Earth Satellite Corporation [14] (see Appendix C) and multiplying this value by $4.349 (social value of an additional AUM). There was no aspect of our simulation which would restrict the results to application in particular areas in the U.S. Even though geography and climate may change, it is felt that the results can be crudely extrapolated to all areas so long as the manager is a profit-maximizer.

The proposed measurement system which produces on-demand information for ranchers yields substantial benefits, although we cannot say what type of system is capable of producing the assumed capabilities. In this system, measurement data are provided every 30 days, at "dl" days before the decision is to be made. Table 16 shows benefits possible from this type of system.

Table 15 Estimated Potential U.S. Social Benefits Resulting from High Capability Remote Sensing Systems Applied to Private Stocker Ranches

Measurement System Parameters			Percentage Increase in Output*,	Estimated Annual Value of Production Increase to All U.S. Stocker Operations*, $ millions
Measurement Frequency, days	System Data Lag, days	Measurement Error util. lbs.per 1000 acres		
3	4	10,000	0.885-27.374	1.15-35.72
	4	2,000	2.212-29.050	2.77-37.90
	1	10,000	5.531-33.240	7.22-43.37
	1	2,000	8.142-36.313	10.62-47.38
9	1	2,000	1.770-28.492	2.31-37.18

*Lower bound estimate refers to comparison with point A in Figure 29; upper bound estimate refers to comparison with point B in Figure 29.

Source: ECON, Inc.

Table 16 Estimated Potential Benefits from a User-Oriented** Measurement Information System Applied to Private Stocker Ranching

Measurement System Parameters		Percentage Increase in Output*,	Estimated Annual Value of Production Increase to All U.S. Stocker Operations*, $ millions
Data Lag, days	Measurement Error, util.lbs. per 1000 acres		
4	20,000	2.168-28.492	2.83-37.18
	10,000	4.867-32.402	5.35-42.28
	5,000	7.080-35.196	9.24-45.92
1	20,000	4.425-31.846	5.77-41.55
	10,000	7.522-35.754	9.81-46.65
	5,000	9.292-37.989	12.12-49.49

*Lower bound estimate refers to comparison with point A in Figure 29; upper bound estimate refers to comparison with point B in Figure 29.

Source: ECON, Inc.

**Assumes satellite overflight occurs at the optimal time before rancher's decision time (30-day frequency).

7.2 The Value of Information on Government-Managed Ranges

Substantial benefit seems possible from using remotely sensed information to assist in the management of government-operated ranges. In these areas, manpower is at a premium and aids which improve areal or temporal coverage should find large application. Table 17 shows possible benefits from measurement systems of differing capabilities. Estimates in Table 17 assume a total federally-managed AUM output of 30 million, consistent with Table 1.

Table 17 Estimated Potential Social Benefit from Use of Improved Measurement Systems on Government-Managed Ranges

Measurement System Parameters			Percentage Increase in Output	Estimated Annual Value of Production Increase to Government-Managed Ranges*, $ millions
Measurement Frequency, days	System Data Lag, days	Measurement Error, util.lbs.per 1000 acres		
18	4	10,000	15.72	20.51
	1	10,000	23.90	31.18
	1	2,000	28.30	36.93
9	4	10,000	18.23	23.79
	1	10,000	27.04	35.28
	1	2,000	31.45	41.04
3	4	10,000	27.01	28.72
	1	10,000	30.82	40.21
	1	2,000	35.22	45.95

*Lower bound estimate refers to comparison with point A in Figure 29; upper bound estimate refers to comparison with point B in Figure 29.

Source: ECON, Inc.

7.3 Generalization and Discussion

The results obtained are as expected, once it is recognized how much the variability in forage growth contributes to rancher uncertainty relative to measurement error. From Table 9 (p. 4-30), it is obvious that the rancher would pay a large price in uncertainty if his measurement information comes too early. In Figure 32, we identify three sources of rancher uncertainty about how much forage will be available for consumption in the present decision period. σ_ε represents standard deviation of measurement error; σ_{AG} represents standard deviation of error in estimating forage growth between the time of measurement and the decision time; σ_{BG} represents the standard deviation of error in predicting forage growth over the first forecast period. The results of this study clearly show that the rancher derives relatively large uncertainty in the form of σ_{AG} and that it is to his advantage to sacrifice measurement accuracy for timeliness. Thus, alternative measurement systems only become clearly competitive with very high measurement frequencies and very short data lags.

On the other hand, measurement systems of the types hypothesized could provide considerable improvement both in accuracy and timeliness over conventional techniques on governmental ranges because of extreme shortages in allotted manpower to cover large areas.

Varying the probability of overgrazing from .22 to .42 resulted in no significant change in the comparative outputs of rancher and alternative, high capability systems.

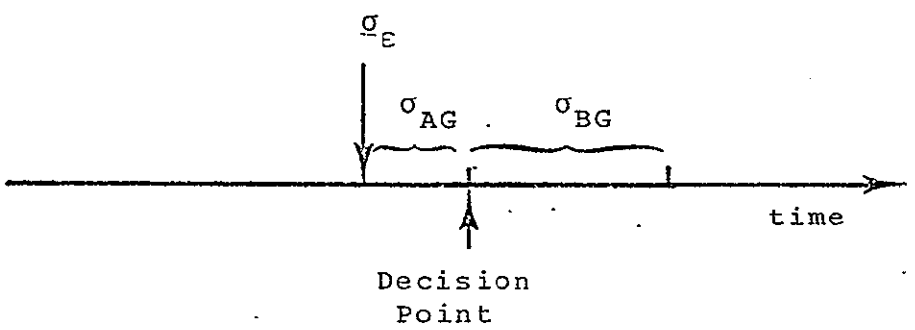

Figure 32 Sources of Rancher's Forage Uncertainty

To us, these estimates seem to be good approximations of the true benefits available from the alternative measurement systems with the proposed capabilities. One should keep in mind that these results are probably only accurate to about 10 percent due to (1) only seventeen years of data were available for the Monte Carlo study and (2) small errors were introduced when estimations, approximations, and simplifications were made. One should also recall that re-optimization of the probability of overgrazing was not performed for each case. As mentioned before, this would have the effect of pivoting all the curves in Section 6.3 to a more vertical position; the curves would pivot around some point between 179 and 226 pounds of consumption per 1000 acres, representing true rancher capability. This would have the effect of increasing the magnitude of benefits where they exist. It seems that optimal P would increase under superior systems because, although the incidence of overgrazing might increase, the average severity (and thus cost) would not.

Additional benefits seem possible in privately owned cow-calf operations, but these are small and were not estimated herein. Further, there are other benefits which this study did not attempt to quantify, such as monitoring improvements resulting from range investments, selecting range sections for use in rest-rotation grazing, and early recognition of unique events, such as severe overgrazing in isolated drought areas.

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APPENDIX A: RANGES GROWTH

In this section we present a listing of the seventeen years of growth values used in this simulation. Values are in units of utilizable pounds of forage per 1000 acres. These figures are obtained directly from RANGES IV using actual weather tapes for the years 1949 to 1965. Figure A-1 shows a partial plot of these values; the x-axis shows monthly (decision period) units. Table A-1 lists the growth values actually used.

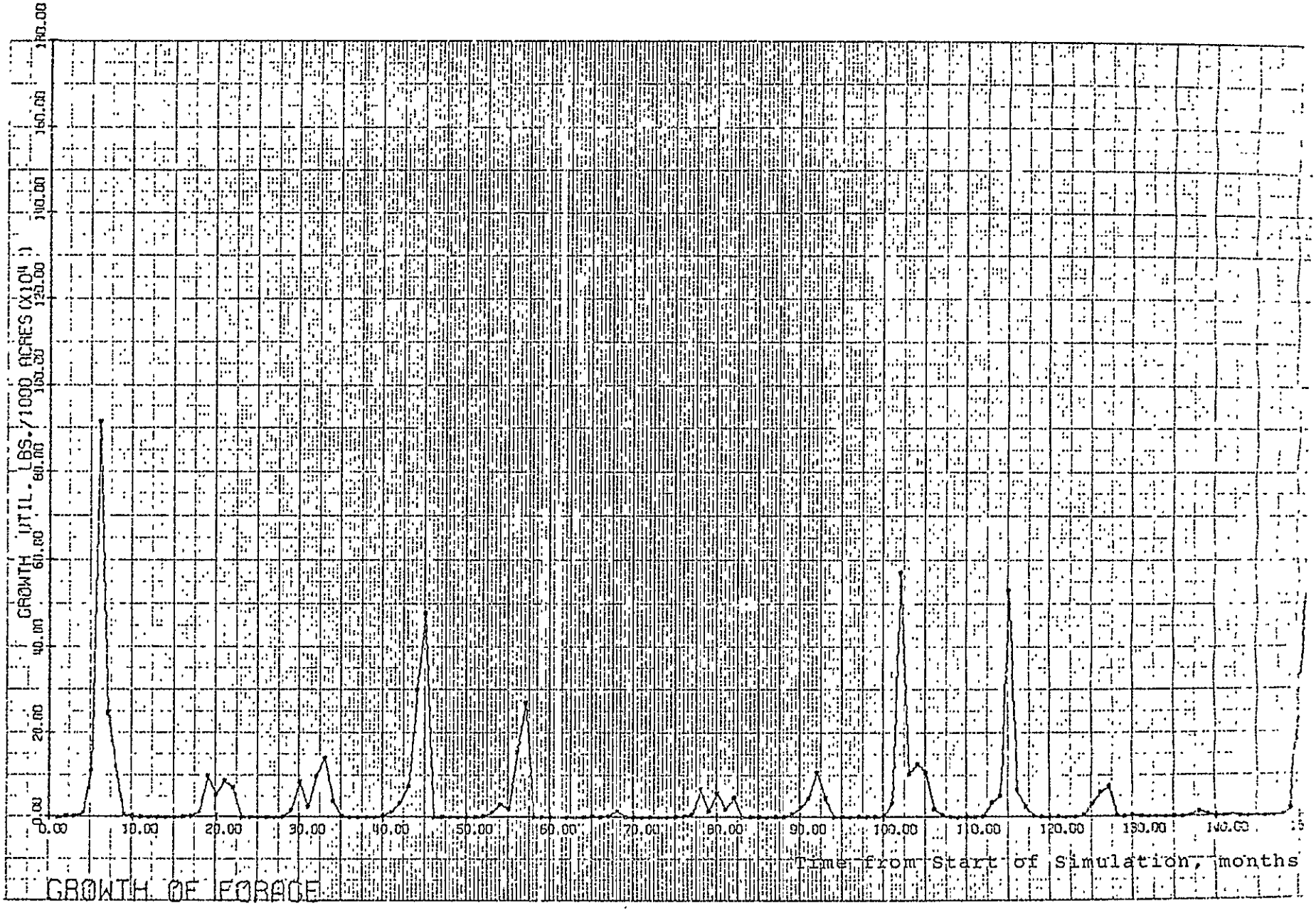

Figure A-1 Partial Plot of Forage Growth Used in the Simulation

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Table A-1 Forage Growth Used in the Simulation

Month	Growth, util, lbs/1000 acres
1	0.00000
2	2054.76800
3	2456.78800
4	10184.44000
5	113369.30000
6	915130.30000
7	249475.00000
8	122973.10000
9	8174.40200
10	2233.44400
11	357.35100
12	0.00000
13	0.00000
14	0.00000
15	0.00000
16	446.68890
17	3305.43700
18	14025.98000
19	100013.30000
20	55970.05000
21	88444.18000
22	72095.43000
23	0.00000
24	0.00000
25	0.00000
26	0.00000
27	0.00000
28	446.68890
29	18224.89000
30	86612.68000
31	26577.92000
32	99700.75000
33	143207.80000
34	41184.64000
35	2948.14500
36	0.00000
37	0.00000
38	0.00000
39	0.00000
40	2814.13800
41	15946.73000
42	36673.03000
43	74507.50000
44	301558.80000
45	478090.30000
46	0.00000
47	670.03290
48	0.00000
49	0.00000
50	0.00000
51	44.66901
52	2412.11800
53	12149.92000
54	33546.26000
55	20547.67000
56	157636.00000
57	271407.50000
58	178.67500
59	402.02000
60	0.00000
61	0.00000

Table A-1 Forage Growth Used in the Simulation (continued)

Month	Growth, util, lbs/1000 acres
62	0.00000
63	0.00000
64	670.03290
65	2010.09900
66	1652.74800
67	3305.49700
68	17197.46000
69	938.04580
70	759.37100
71	0.00000
72	44.66901
73	0.00000
74	0.00000
75	938.04580
76	3439.50200
77	9961.15600
78	68566.62000
79	15410.75000
80	59186.21000
81	21887.69000
82	48555.01000
83	0.00000
84	759.37100
85	625.36400
86	0.00000
87	446.68890
88	89.33800
89	8665.75700
90	24523.16000
91	46902.26000
92	109527.80000
93	46991.64000
94	0.00000
95	89.33800
96	0.00000
97	134.00700
98	446.68890
99	44.66901
100	2456.70000
101	35824.39000
102	571984.10000
103	104971.50000
104	129450.00000
105	108544.80000
106	21441.05000
107	4913.57400
108	178.67500
109	0.00000
110	312.68180
111	402.02000
112	3350.16600
113	36226.41000
114	52664.55000
115	531782.10000
116	66467.18000
117	26711.98000
118	2680.13200
119	223.34390
120	0.00000
121	178.67500

Table A-1 Forage Growth Used in the Simulation (continued)

Month	Growth, util. lbs/1000 acres
122	0.00000
123	0.00000
124	4779.56600
125	33814.28000
126	60704.94000
127	74328.81000
128	2769.46900
129	848.70800
130	5226.25700
131	44.66901
132	0.00000
133	0.00000
134	0.00000
135	491.35790
136	0.00000
137	5583.60500
138	15812.73000
139	6834.33500
140	670.03290
141	3796.85400
142	5092.25000
143	893.37690
144	0.00000
145	0.00000
146	0.00000
147	1608.07900
148	2278.11200
149	18582.19000
150	297360.00000
151	547505.30000
152	193371.00000
153	128645.80000
154	278643.80000
155	0.00000
156	0.00000
157	0.00000
158	714.70190
159	134.00700
160	134.00700
161	16706.10000
162	286684.30000
163	896146.00000
164	864252.60000
165	64189.16000
166	199446.10000
167	32965.62000
168	0.00000
169	0.00000
170	0.00000
171	268.01290
172	89.33800
173	4511.55400
174	85406.68000
175	36807.14000
176	300308.10000
177	539420.50000
178	297181.50000
179	1161.39100
180	0.00000
181	0.00000

Table A-1 Forage Growth Used in the Simulation (continued)

Month	Growth, util. lbs/1000 acres
182	0.00000
183	0.00000
184	2546.12500
185	1831.42400
186	5628.27700
187	0.00000
188	4109.53500
189	3394.83300
190	0.00000
191	0.00000
192	0.00000
193	0.00000
194	0.00000
195	0.00000
196	6834.29200
197	6700.32800
198	123643.10000
199	453566.80000
200	612320.00000
201	84111.31000
202	347791.10000
203	0.00000
204	0.00000

APPENDIX B : RANGELANDS OF THE U.S.

Figure B-1 illustrates the major AUM (Animal Unit Month) producing states in the U.S. Cattle grazing is an economic reality largely because rangelands occupy areas which are non-arable and, therefore, would not produce high yield crops. Most grazing areas are in regions which have little rainfall (compare Figures B-1 and B-2) and shallow, rocky soil. More importantly, the rainfall here is of a highly variable nature, such that one year's rainfall might support crops well, but crops planted in the next year might easily be wiped out by drought. Cattle grazing is not an exclusive activity and can take place side-by-side with other activities such as recreation, wild animal habitat, and forestry, in multi-use environments. This frequently happens on Federal lands. Cattle grazing offers a very low cost means for harvesting vegetation on otherwise unavailable (economically, legally, or geographically) land.

Table B-1 lists grazing land area by ecosystem and ownership. Table B-2 shows rangeland output as a function of management strategy used.

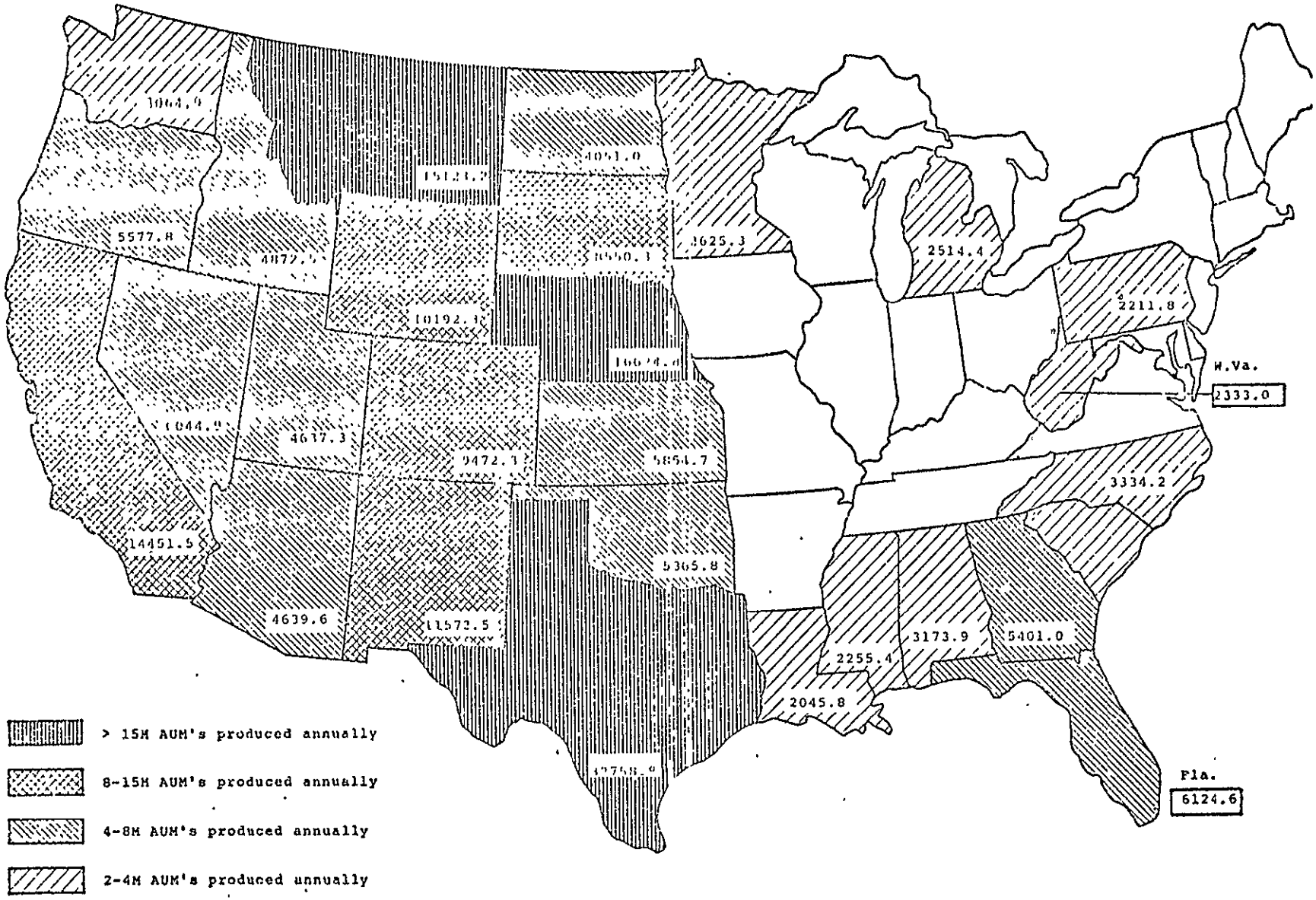

Figure B-1 Major U.S. Rangeland Areas

Source: Compiled from date in Forest Service Report No. 19

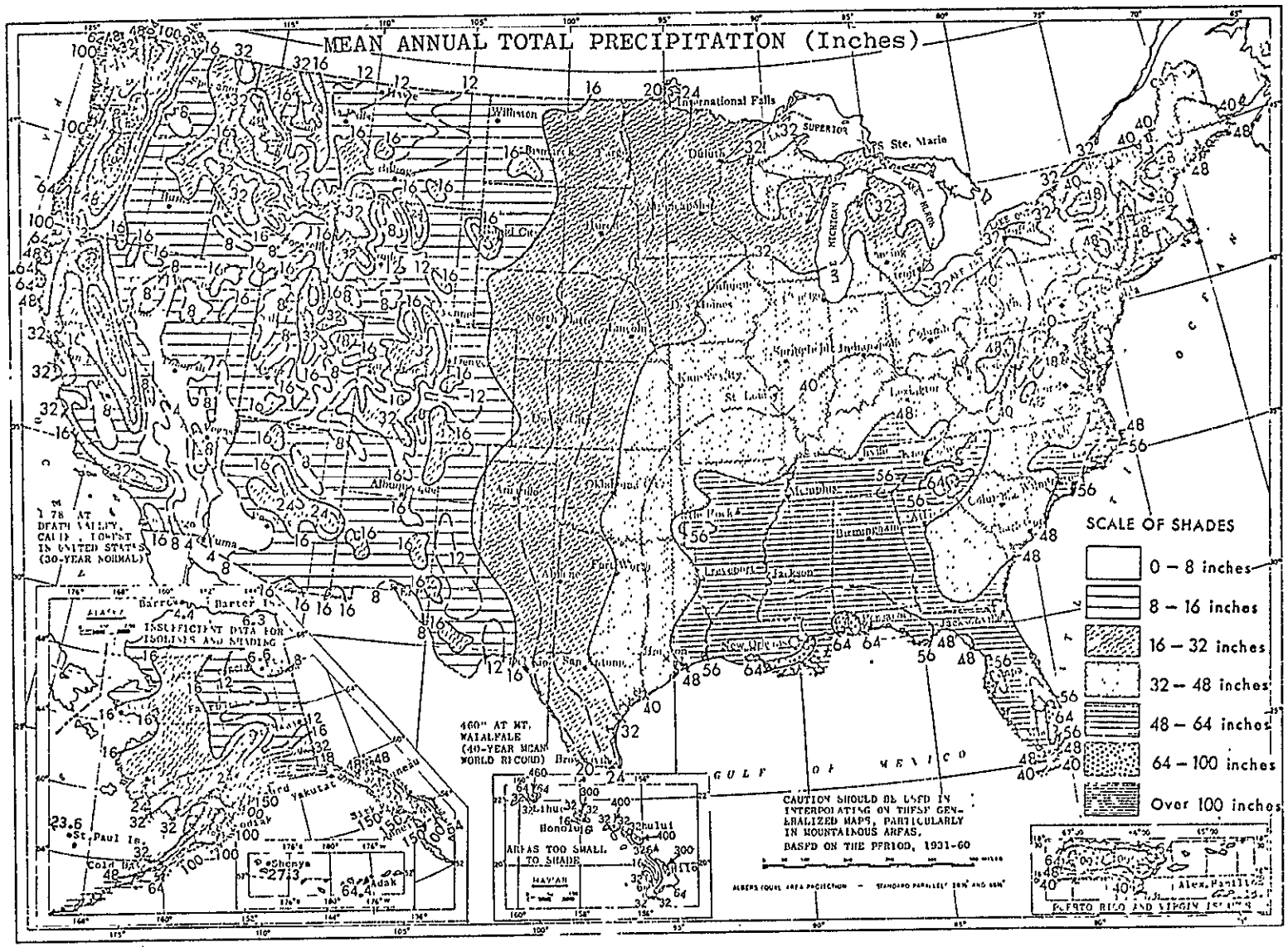

Figure B-2 Mean Annual U.S. Precipitation

Source: U.S. Department of Commerce, Climates of the United States, 1973, p. 70.

Table B-1 Areas Grazed and Ungrazed by Ecogroup, Ecosystem, and Ownership, 1970
(Million acres)
[Totals may not add due to rounding]

Ecogroup by ecosystem	National Forest System			Other Federal land			Non-Federal land			All ownerships		Forest-Range environment
	Grazed	Ungrazed	Total	Grazed	Ungrazed	Total	Grazed	Ungrazed	Total	Grazed	Ungrazed	
Western Range:												
Sagebrush	9.9	.1	10.0	63.6	3.5	67.2	16.9	0.2	17.1	90.5	3.8	94.2
Desert shrub	1.1	3.9	5.0	43.5	11.7	55.3	14.1	11.6	25.8	58.8	27.3	86.0
Southwestern shrubsteppe	.9	.1	1.1	8.3	1.9	10.3	26.1	1.1	27.2	35.4	3.2	38.6
Chaparral-mountain shrub	6.6	.1	6.7	11.1	1.7	12.8	12.4	.2	12.6	30.1	2.0	32.1
Pinyon-juniper	8.4	1.8	10.2	12.6	4.8	17.4	13.2	1.9	15.1	34.2	8.5	42.7
Mountain grasslands	6.4	.7	7.2	5.1	.6	5.6	63.7	3.4	67.0	75.2	4.6	79.8
Mountain meadows	1.8	.1	1.9	.1	.1	.1	1.9	.1	2.0	3.8	.3	4.0
Desert grasslands	1.2	----	1.2	9.6	----	9.6	15.3	----	15.3	26.1	----	26.1
Annual grasslands	----	----	----	.4	(1)	.4	6.3	----	6.3	6.7	----	6.7
Alpine[2]	.2	8.1	8.3	(1)	(1)	(1)	----	----	----	.2	8.2	8.3
Total	36.6	15.0	51.6	154.5	24.3	178.8	169.8	18.4	188.2	360.8	57.8	418.5
Western Forest:												
Douglas-fir	9.6	10.6	20.2	.7	2.6	3.3	3.7	11.8	15.4	14.0	24.9	38.9
Ponderosa pine	19.1	.2	19.2	1.5	.2	1.6	14.9	1.8	16.7	35.5	2.1	37.6
Western white pine	1.4	2.1	3.5	----	.1	.1	----	.5	.5	1.4	2.7	4.1
Fir-spruce	7.4	11.0	18.4	----	1.8	1.8	----	4.2	4.2	7.4	17.0	24.4
Hemlock-Sitka spruce	----	2.2	2.2	----	.5	.5	----	4.4	4.4	----	7.1	7.1
Larch	3.3	----	3.3	.1	.1	.2	1.3	.3	1.7	4.7	.4	5.1
Lodgepole pine	9.5	4.0	13.5	.3	2.3	2.6	1.4	1.6	3.0	11.2	7.9	19.1
Redwood	----	(1)	(1)	----	.1	.1	----	.9	.9	----	.9	.9
Hardwoods	6.7	.1	6.8	1.5	.2	1.7	14.8	.1	15.0	23.0	.4	23.4
Total	56.9	30.1	87.1	4.1	7.7	11.9	36.2	25.5	61.7	97.2	63.4	160.6
Great Plains:												
Shinnery	.1	----	.1	(1)	(1)	(1)	1.9	(1)	1.9	2.0	(1)	2.0
Texas savanna	----	(1)	(1)	----	.1	.1	14.9	.2	15.1	14.9	.4	15.2
Plains grasslands	3.1	.5	3.6	5.7	1.1	6.8	155.0	8.0	162.9	163.7	10.0	173.3
Prairie	.3	(1)	.3	.1	.1	.2	36.2	1.7	37.9	36.5	1.8	38.4
Total	3.4	.5	3.9	5.8	1.4	7.1	208.0	9.9	217.9	217.1	11.8	228.9
Eastern Forest:												
White-red-jack pine	----	1.5	1.5	----	.1	.1	.2	10.8	10.9	.2	12.4	12.6
Spruce-fir	----	2.2	2.2	(1)	.2	.2	.2	21.0	21.2	.2	23.4	23.6
Longleaf-slash pine	.6	.5	1.1	(1)	.8	.8	14.0	5.0	19.0	14.6	6.3	20.9
Loblolly-shortleaf pine	1.9	1.7	3.6	.1	.7	.7	28.3	22.4	50.7	30.3	24.8	55.1
Oak-pine	.6	1.6	2.2	(1)	.7	.7	23.1	8.4	31.6	23.7	10.7	34.5
Oak-hickory	.3	6.5	6.8	.1	1.9	2.0	51.1	65.2	116.2	51.5	73.5	125.1
Oak-gum-cypress	(1)	.5	.5	(1)	1.2	1.2	9.8	22.6	32.4	9.8	24.2	34.1
Elm-ash-cottonwood	(1)	.3	.3	(1)	.2	.2	15.0	9.5	24.5	15.0	10.0	25.0
Maple-beech-birch	.1	2.6	2.7	(1)	.2	.2	7.7	25.0	32.8	7.8	27.9	35.6
Aspen-birch	.1	2.3	2.4	(1)	.1	.2	5.6	14.4	20.0	5.8	16.8	22.6
Wet grasslands	----	(1)	(1)	(1)	2.7	2.7	.9	.8	1.7	.9	3.6	4.5
Total	3.6	19.7	23.3	.2	8.7	9.0	155.9	205.2	361.1	159.8	233.6	393.5
Total 48 States	100.5	65.4	165.9	164.7	42.1	206.8	569.8	259.1	828.9	835.0	366.6	1,201.6

[1] Less than 50,000 acres.
[2] Includes barren areas above treeline.

Source: USDA, Forest Service Report No. 19.

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Table B-2 Average Animal Unit Month Production by Strategy and Ecosystem, 1970

Ecogroup by ecosystem	Production by Strategy, AUM's per acre per year					1970 average
	Some livestock (B)	Extensive management (C)	Intensive management (D)	Maximum livestock (E)	Exploitative (X)	
Western Range:						
Sagebrush	0.03	0.13	0.28	0.23	0.05	0.12
Desert shrub	.01	.05	.11	—	.01	.03
Southwestern shrubsteppe	.03	.09	.17	.08	.05	.05
Chaparral-mountain shrub	.02	.12	.21	.16	.01	.07
Pinyon-juniper	.02	.05	.14	.16	.01	.05
Mountain grasslands	.10	.28	.33	.49	.11	.29
Mountain meadows	.60	.93	2.50	2.70	.45	1.14
Desert grasslands	.03	.22	.25	.25	.01	.19
Annual grasslands	.32	.92	1.52	2.49	.46	1.05
Alpine[1]	.21	.21	.20	—	—	.21
Western Forest:						
Douglas-fir	.04	.05	.23	—	.23	.04
Ponderosa pine	.04	.09	.27	—	.03	.07
Western white pine	—	—	—	—	—	—
Fir-spruce	—	—	—	—	—	—
Hemlock-Sitka spruce	—	—	—	—	—	—
Larch	.01	.02	—	—	—	.01
Lodgepole pine	.01	.02	—	—	—	.01
Redwood	—	—	—	—	—	—
Hardwoods	.06	.34	.64	1.00	.10	.33
Great Plains:						
Shinnery	.07	.19	.26	.22	.08	.23
Texas savanna	.13	.22	.44	.61	.09	.34
Plains grasslands	.22	.31	.35	.50	.61	.31
Prairie	.40	.75	.84	1.28	—	1.01
Eastern Forest:						
White-red-jack pine	—	—	—	—	—	—
Spruce-fir	—	—	—	—	—	—
Longleaf-slash pine	.64	.64	1.56	—	.78	.77
Loblolly-shortleaf pine	.17	.21	—	7.69	.04	.22
Oak-pine	.16	.24	—	1.21	.07	.21
Oak-hickory	.26	.24	.46	—	.05	.23
Oak-gum-cypress	.14	—	—	—	.03	.03
Elm-ash-cottonwood	.20	.35	1.13	—	.23	.36
Maple-beech-birch	.84	.98	—	—	.43	.62
Aspen-birch	1.43	2.01	2.60	—	.71	.99
Wet grasslands	.92	1.54	3.93	—	1.12	2.61
Weighted average	0.11	0.25	0.44	0.90	0.22	0.26

[1] Includes barren areas above treeline.

APPENDIX C: U.S. STOCKER AUM's

This section presents estimates of stocker AUM's consumed annually in the U.S. The source of this information is the Earth Satellite Corporation [14].

Table C-1 Estimates of Annual Consumption by Stockers in U.S., As reported by Earth Satellite Corporation

State	Source of Estimate	Animal Units, 1000	Months Grazed Per Year	Stocker Consumption, 1000 AUM's
SOUTHEAST				
North Carolina	A.B. Allen Dept. of Animal Science, N.C. State	13.2	5	66.0
Arkansas	J.A. Clower Extension Dept, Little Rock	24.0	5	120.0
Louisiana	H. McFatter Extension Dept. Louisiana State	0	-	-
Kentucky	Bolen, Meat Dept. U. Kentucky, Lexington	85.2	5	426.0
Tennessee	E. Rawls Extension Dept. U. Tennessee Knoxville	1.2	5	6.0
Mississippi	L. Monroe Extension Dept. Jackson	0	-	-
Alabama	A. Brown Extension Dept. Auburn	29.4	8	235.2
Georgia	F.S. Baker's recommendation W.J.Green, Leico Land Co. Guitman	6.0	6	36.0
South Carolina	J. Smith Extension	1.0	6	6.0
Florida	K. Mathis Extension Dept. Gainesville F.S. Baker Ag Research Qunicy	60.0	6	360.0
Virginia	K.C.Williamson Extension, VPI Blacksburg	150.0	7	1050.0

Table C-1 Estimates of Annual Consumption by Stockers in U.S., As reported by Earth Satellite Corporation (continued)

State	Source of Estimate	Animal Units, 1000	Months Grazed Per Year	Stocker Consumption, 1000 AUM's
West Virginia	J. Emsch Extension U.West Virginia Morgantown	45.0	5	225.0
		TOTAL SOUTHEAST		2530.2
NORTHERN PLAINS				
North Dakota	K. Gee Colo. St.	144.6	5	723.0
South Dakota	K. Gee Colo. St.	235.8	5	1179.0
Nebraska	B. Belort USDA, SRS Lincoln	23.2	5	116.0
Kansas	K. Gee Colo. St.	247.2	5	1236.0
		TOTAL NORTH PLAINS		3254.0
SOUTHERN PLAINS				
Oklahoma	L. Harwell Okla. State	262.4	6	1574.4
Texas	C. Boykin Texas A&M and Texas Liverstock Statistics	1896.0	8	15,168.0
		TOTAL SOUTH PLAINS		16,742.4
MOUNTAIN				
Idaho	J. Early & K. Gee Colo.	912	5	456.0
Montana	Kropf Montana & K. Gee	196.8	5	984.0

Table C-1 Estimates of Annual Consumption by Stockers in U.S., As reported by Earth Satellite Corporation (continued)

State	Source of Estimate	Animal Units, 1000	Months Grazed Per Year	Stocker Consumption, 1000 AUM's
Wyoming	K. Gee Colo.	87.5	6	525.0
Colorado	K. Gee & H.J. Winn	571.2	6	2826.0
Utah	S. Finch Utah State Logan	228	6	136.8
Nevada	K. Gee Colo.	37.2	6	223.2
		TOTAL MOUNTAIN		5151.0
PACIFIC				
California	J. Cothern Extension Dept. U. of Calif. Davis	778.2	6	4669.2
Oregon	D. Frischknect & S.C. Marks Extension Oregon State Corvallis	60.0	5	300.0
Washington	O. Wirak Washington State Extension	84.0	5	420.0
		TOTAL PACIFIC		5389.2
SOUTHWEST				
Arizona	Curtis Cable Extension U. Arizona Tucson	23.4	5	117.0
New Mexico	R.L.Coppersmith & Katner, Extension N. Mex. State	50.4 25.2	5 5	252.0 126.0
		TOTAL SOUTHWEST		495.0

Table C-1 Estimates of Annual Consumption by Stockers in U.S., As reported by Earth Satellite Corporation (continued)

State	Source of Estimate	Animal Units, 1000	Months Grazed Per Year	Stocker Consumption, 1000 AUM's
NORTHEAST a/				
Pennsylvania	H.C. Moore Extension Penn State	0	0	0
Iowa	Zlomack Iowa State	27.0	4	108.0
Michigan	J. Ferris Michigan State	15.0	4	60.0
Minnesota	K. Egerston U. Minnesota	9.0	4	36.0
Missouri	G. Grimes Extension Econ. Univ. Missouri Columbia	450.0	5	2250.0
Indiana	W. Farris Purdue Univ. Lafayette, Ind.	0	-	-
Illinois	B. Kirtley Extension U.Ill, Urbana	60.0	5	300.0
Wisconsin	No one available until April	63.0	5	315.0
		TOTAL a/ NORTHEAST		3069.0
		GRAND TOTAL		36,630.8

a/ states not listed do not have stockers
SOURCE: USDA Livestock & Meat Statistics Stat. Bulletin 522 July 1973; Texas Dept. of Ag & USDA, Texas Livestock Statistics 1972, people listed as source above were contacted by phone during March 1974.

APPENDIX D: SUMMARY OF MATHEMATICAL VARIABLES USED

This section shows a summary of the major mathematical variables frequently used for easy reference.

Table D-1: Summary of Mathematical Variables Used			
Variables	Definition	Unit	Defined in Context in Section
i	subscript representing ith decision period		4.1
j	subscript representing jth forecast period		4.1
k	subscript representing kth measurement and measurement period		4.1
m	subscript representing type of steer, corresponds to month in which steer are purchased		4.5.2
t_i	time at the beginning of ith decision period	days from origin	
$t_{i,j}$	time at the beginning of the jth forecast period of the ith decision period	days from origin	
tk_k	time at the kth measurement	days from origin	
x_i, $x_{i,j}$, xk_k	actual utilizable biomass at times t_i, $t_{i,j}$, tk_k	lbs/1000 acres	4.1
g_i, $g_{i,j}$, gk_k	actual forage growth during periods beginning at t_i, $t_{i,j}$, tk_k	lbs/1000 acres	4.1
f_i, $f_{i,j}$, fk_k	actual supplemental feed purchased	lbs/1000 acres	4.2.2
c_i, $c_{i,j}$, ck_k	actual biomass consumption	lbs/1000 acres	4.2.2
λ	time interval betwen successive measurements [INPUT]	days	5.1
dl	data lag [INPUT]	days	5.1
μ	biomass decay rate for a 30 day period		4.1.2
M	biomass decay rate for a period λ days in length		4.1.2
$\hat{x}_i$, $\hat{x}k_i$	"best" guess of utilizable biomass on the ground at t_i, tk_k	lbs/1000 acres	4.3.1
$\overline{xk}_k$	measured value of xk_k	lbs/1000 acres	4.3.1

Table D-1: Summary of Mathematical Variables Used (continued)			
Variable	Definition	Unit	Defined in Context in Section
$\tilde{x}k_k$	"predicted" value of xk_k from tk_{k-1}	lbs/1000 acres	4.3.1
ε_{x_k}	error in the kth measurement	lbs/1000 acres	4.3.1
σ_ε	standard deviation of measurement errors [INPUT]	lbs/1000 acres	5.1
α, β	"smooth parameters," values which minimize Var $[\hat{x}k_k - xk_k]$		4.3.1
$\tilde{g}_i$, $\tilde{g}_{i,j}$, $\tilde{g}k_k$	historical average growth for the i, i,j and k periods	lbs/1000 acres	4.3.2
ϕ	growth autoregressive coefficient for 30 day period		4.3.2
Φ	growth autoregressive coefficient for λ day period		4.3.2
a_i, ak_k	random shock to growth	lbs/1000 acres	4.3.2
σ_a^2, σ_{ak}^2	variance of a_i, ak_k		4.3.2
$\hat{g}_i$, $\hat{g}_{i,j}$, $\hat{g}k_k$	best estimate (forecasts) of growth during i, i,j, and k periods		4.3.2
$\bar{g}k_{k-1}$	best guess of growth during period k-1, given $\hat{x}k_k$	lbs/1000 acres	4.3.2
$\sigma_x(j)$	standard deviation of error in knowing utilizable biomass available during the i,j period	lbs/1000 acres	4.3.4
$\delta_{i,j}$	the hedge factor, intentional under-grazing during i,j period		4.3.4