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INCORPORATING WEATHER VARIATION INTO
CALIFORNIA RANGELAND STOCKING RATE DECISIONS

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Many factors affect domestic livestock stocking rate decisions on California's rangelands. This paper emphasizes the role weather has in determining stocking rates. As a case study, the objectives of this paper are to analyze the relationships between weather and forage production at the Sierra Foothill Range Field Station near Browns Valley, California; to show how this information, in general, could be incorporated into ranchers' decisions; and to explore what this information tells us about ranchers' risk attitudes in relation to the "conventional wisdom" of stocking at 80 percent of the average forage production.

WEATHER, FORAGE SUPPLY, AND THE STOCKING RATE DECISION

Weather variations create a large amount of uncertainty in the supply of forage. Often it is not feasible to adjust the stocking level quickly enough to react fully to seasonal (or even annual) changes in forage resources. If the actual stocking rate is too low, potential income is lost because forage resources are unused. If the actual rate is too high, income can be lost in a number of ways: livestock may show poor gains or a higher than normal death rate or the rancher may be forced to purchase hay, rent additional pasture, or make untimely cattle sales at low prices.

Uncertainty of forage supply is especially high on those ranges with a Mediterranean-type climate on the western slope of the Sierra Nevada mountains. Mountain ranges at higher elevations are usually leased under conservatively set stocking rate and season limitations causing forage availability to be more reliable. In most years, irrigated pasture production varies little due to reliable water supplies. Supplemental feeds are available in all seasons, if a rancher is willing and able to pay the going price.

In California's Mediterranean-type climate, forage growth starts in the fall after there has been a rainfall sufficient to germinate the annual plant seeds present in the soil. Rapid fall forage growth occurs until the temperatures become too cold in late fall at the beginning of winter when growth slows and available forage may even decline (George, et al., 1985). Rapid growth begins again in February or March when the temperatures begin to rise again. Plants mature in April or May depending on how long the rainy season continues into the spring. After maturing, the annual forage plants dry out, but remain standing through the summer and into the fall. Throughout this period, the forage decreases in both quantity and quality, but is available as dry feed for livestock. The dry forage remaining in the fall can offset poor fall forage growth in the next growing season. In the fall, the rains begin again, and the cycle repeats.

Even though there is variation in the forage supply in all seasons, the winter supply usually is the most critical level for ranchers. The winter forage supply is usually the lowest level compared to the other seasons and, thus, it is the bottleneck for increasing the cow herd or sheep flock. Extra forage supply in other seasons can be utilized by buying stocker animals for short periods of grazing. Therefore, we will pay special attention to the winter forage supply.

As with any agricultural production business, ranchers also face uncertain prices for products and inputs along with all the other uncertainties faced by any business operating today. While we do not intend to underestimate the impact of these sources of uncertainty, this report emphasizes the incorporation of the uncertain forage supply into ranch management.

LITERATURE REVIEW

Dean, Finch, and Petit (1966) evaluated the expected returns (but not variations) from different stocking rates of both cows and stocker cattle using linear programming. Their measurement of range productivity was in terms of a published range condition index which is no longer available. This paper uses methods similar to theirs except (1) forage growth probabilities are estimated from actual weather data and plant growth information, and (2) the decision criteria includes the dispersion of potential returns, not just maximum expected value. Linear programming was used by Weitkamp, et al., (1980) to analyze the effects of different forage production levels on ranch management, but they did not consider the stochastic elements causing variable forage production levels. Conner, et al., (1983) used a deterministic model to incorporate annual rainfall variation into the economic analysis of range improvement practices for an example in Texas.

Pope and McBryde (1984) used a multi-period, deterministic quadratic programming model to help choose the optimal stocking rate, allowing for range improvement activities and reduced forage supply over time, but they do not incorporate weather variation. Karp and Pope (1984) utilized Markov processes to analyze the range management under conditions of certainty, but they did not account for weather uncertainty. Rodriguez and Roath (1987) used dynamic programming to analyze short-term grazing decisions in Colorado, but they did not include either cow herd decisions or the stochastic elements of forage and price uncertainty. Vantassell, et al., (1987) modeled the relationship between calf growth and environmental uncertainty (including rainfall and temperature) and their approach and results are useful to guide the development of the coefficients in our planning model.

Three studies have taken place in the past at the San Joaquin Experimental Range (SJER) near Fresno, California, about 200 miles south of the Sierra Foothill Range Field Station. Rader and McCorkle (1966) calculated the probabilities of falling below the 25-year average forage level and the returns from range improvements under different assumptions about forage production. Duncan and Woodmansee (1975) found poor correlations between early fall precipitation and total forage yield. Pendleton, et al., (1983) developed physical models for the different components of the annual grassland ecosystem based on the SJER site.

Other studies have shown the strength or lack of strength in the relationship between weather and forage production. Murphy (1970) found that effective rainfall by November 20 has the highest correlation coefficient (.7) with total forage yield in the spring at the Hopland Field Station in the northern coastal ranges of California. In a synthesis study of all three field station sites, Sully (1977) found a similar result in that the Northern California stations had a high correlation between total forage production and early season precipitation, but at the San Joaquin station the relationship was weak. By including temperature and drought patterns in their regression analysis, Pitt and Heady (1978) found that correlations between forage yield and precipitation could provide reasonable estimates of forage yields throughout the growing season.

ESTIMATING WEATHER AND FORAGE RELATIONSHIPS

There are very few, if any, long-term series of monthly or seasonal forage production data. Most forage measurements are of total production, taken in late spring. Hence, we do not have an ideal data base with which to analyze the seasonality of forage production and its relation to weather conditions.

In this section, we estimate the relationships between weather and forage at the Sierra Foothill Range Field Station near Browns Valley, California, as a case study. We start by calculating historical probabilities of weather conditions and then estimate the impact of weather on forage.

Normal rainfall and cumulative heat sums as indicated by degree day conditions are defined as being what occurs 50 percent of the time (Connor, et al., 1983). The weather is classified as cold or dry if the measurement falls below the defined normal range and warm or wet if it falls above normal. Temperatures are transformed into degree-days by single-triangulation (Zalom, et al., 1983). Rainfall is measured in inches.

As an example, let's consider the historical frequencies and probabilities for years in each temperature category at the Sierra Station for the fall, winter, and spring seasons (Table 1). Fall is defined as September 1 through December 31; winter as January 1 through March 15; and spring as March 16 through May 31. We see that in 7 years out of 22 (or 32 percent) the fall was cold, in 10 years (or 45 percent) out of 22 it was normal, and in 5 years (or 23 percent) the fall season was warm.

Table 1. Historical frequencies and probabilities for years in each temperature category at the Sierra Foothill Range Field Station.

	Fall	Winter	Spring
COLD	7 (.32)	6 (.27)	6 (.27)
NORMAL	10 (.45)	11 (.50)	9 (.41)
WARM	5 (.23)	5 (.23)	7 (.32)

Assuming independence, the joint probabilities of rainfall and temperature conditions can be calculated from historical data (Table 2). At the Sierra Station, we see that out of 22 years, five percent of the winters have been both wet and warm. Only in 23 percent of the years has the fall had both normal rainfall and normal temperatures.

Forage production is the crucial variable in the rancher's decision process. Having the probabilities of weather alone is not sufficient for managers to make informed decisions. These probabilities do not provide the needed information relating weather to forage production. However, we do not have a sufficient database to estimate this relationship statistically. To fill this gap in our knowledge, we evaluated the types of weather conditions and their joint events and formulated a relationship between weather and forage production based on intensive experimental work and field knowledge. These relationships are summarized in Table 3.

Table 2. Joint probabilities for years in each combination of rain and temperature categories by season for the Sierra Foothill Range Field Station.

Rainfall Category	Temperature Category: Cold	Normal	Warm
FALL SEASON			
Dry	.09	.12	.06
Normal	.16	.23	.12
Wet	.07	.10	.05
WINTER SEASON			
Dry	.09	.16	.07
Normal	.12	.23	.10
Wet	.06	.12	.05
SPRING SEASON			
Dry	.06	.10	.07
Normal	.16	.24	.19
Wet	.05	.07	.06

For the fall, both dry and cold conditions can be detrimental to forage growth. Either of these two conditions could cause poor fall growth; they do not have to occur jointly. However, for a high level of growth to occur, both warm temperatures and wet conditions need to be present. Other joint conditions of rainfall and temperatures will result in average forage production.

Poor growth in the winter will occur if either dry or cold conditions occur. As in the fall, these do not have to occur jointly to cause poor production. A high level of production may occur if the weather is warm and rainfall is either normal or wet. Other conditions will result in average growth.

The critical factor in the spring is rainfall since temperatures normally are not limiting. If the spring is dry, forage production will be poor. If rainfall is normal, forage production will be average. If the spring is wet, forage production will be high.

Table 3. Relationship between rain and temperature categories by season for the Sierra Foothill Range Field Station.

Rainfall Category	Temperature Category: Cold	Normal	Warm
FALL SEASON			
Dry	Poor	Poor	Poor
Normal	Poor	Average	Average
Wet	Poor	Average	High
WINTER SEASON			
Dry	Poor	Poor	Poor
Normal	Poor	Average	Average
Wet	Poor	High	High
SPRING SEASON			
Dry	Poor	Poor	Poor
Normal	Average	Average	Average
Wet	High	High	High

Using the subjective evaluations (Table 3) and the joint probabilities for temperature and rainfall (Table 2), the joint probabilities for forage production are estimated for each season (Table 4). The levels of forage production under different weather conditions are estimated by George, et al., (1985) and adapted for this analysis (Table 4). The forage production is measured in animal-unit-months (AUMs). An AUM is the amount of forage required to maintain a 1000 lb. cow for one month.

Table 4. Forage production levels and probabilities by season for the Sierra Foothill Range Field Station and used in the linear programming analysis.

Forage Production	- Fall -		- Winter -		- Spring -	
	AUMs	prob.	AUMs	prob.	AUMs	prob.
Poor	100	(.50)	100	(.50)	1000	(.23)
Average	500	(.45)	300	(.35)	2000	(.59)
High	1000	(.05)	500	(.15)	2500	(.18)

These are subjective evaluations, but they are the best information that is currently available. Much of this is intuitively known by experienced ranchers, but is less apparent to new managers. This is the information that can be used to incorporate weather into stocking rate decisions.

INCORPORATING WEATHER INTO THE STOCKING RATE DECISION

Let us consider how to set the base stocking rate for a rancher who raises calves and/or feeds stockers. By utilizing a linear programming (LP) model, the impacts of weather variation on expected income and its variance can be estimated.[1]

The optimal base cow herd size is chosen on the basis of maximum expected income over different types of weather years. First, the cow herd size for each type of weather year is chosen by using an LP model of the ranch. Then the LP model is used to estimate expected income under

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[1] An example to the LP matrix for an average weather year is listed in the appendix.

different weather conditions with fixed cow herd sizes. For each cow herd size, the expected income is estimated from the estimated incomes under different weather conditions and the probabilities of those conditions. The expected income for each potential herd size is compared to find the size with the maximum expected income.

The objective of the LP model is to maximize long-term net cash income excluding fixed costs and subject to several constraints. Long-term net cash income defined as calf sales and stocker income less lease payments, hay purchases, and other costs of maintaining cows and calves not accounted for elsewhere. Stated in other terms, the objective is to maximize the gross margin (i.e., the returns to fixed costs, operator labor, management, and capital). The net cash income is defined mathematically as:

$$Z = -\Sigma_{t=1}^{T} \Sigma_{j=1}^{J} C_j^R R_{jt} - \Sigma_{t=1}^{T} C_t^H H_t - C^B B - \Sigma_{t=1}^{T} [C_t^F F_t + P_t^V V_t + P_t^S S_t] \quad (1)$$

where the variables are as defined below:

R_{jt} = an AUM[a] of the j^{th} forage resource (e.g., range, pasture, or grazing permit) in the t^{th} season.

C_j^R = the cost per AUM on the j^{th} forage resource. This cost is assumed to be the same over all the seasons that a particular resource is used.

H_t = one ton of alfalfa hay purchased from another ranch enterprise or from off-ranch sources in the t^{th} season.

C_t^H = the cost per ton in season t.

B = the number of cows in the breeding herd.

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[a] AUM = animal unit month. The amount of forage required to maintain a 1000 lb. cow for one month.

C^{a} = the cost per cow per year excluding costs for range, pasture, grazing allotments, and hay costs and adjusted for the sale of cull cows and cull bulls and including the costs for a calf up to weaning (adjusted for conception and death rates).

F_t = the number of calves fed during the t^{th} season.

C_t^f = the cost per calf for feeding in the t^{th} season excluding costs for range, pasture, grazing allotments, and hay costs.

V_t = the number of calves fed sold at the end of the t^{th} season.

P_t^v = the calf price per head received at the end of the t^{th} season.

S_t = the number of stockers fed during the t^{th} season.

P_t^s = the net income per stocker received at the end of the t^{th} season after adjusting for all costs excluding range, pasture, grazing allotments, and hay costs.

The livestock cannot consume more that the total forage available in each range, pasture, or allotment. The forage may be produced in each season, carried over from the previous season, or carried to the next season:

$$R_{jt} - T_{jt-1,t} + T_{jt,t+1} \leq A_{jt} \tag{2}$$

where all variables are as previously defined and:

T = one AUM carried over from the previous season to the current season or from the current season to the next season and

A = is the amount of the j^{th} forage resource (measured in AUMs) produced in the t^{th} season. On the valley range, there is assumed to be 400 AUMs of standing, dry forage, from the summer. It is added to the fall production constraint.

On certain ranges, there may be a limit on the amount of forage that can be transferred from one season to the next season. Specifically, there is a limit of 500 AUMs on the valley range between fall and winter. This limit is written generally as:

$$T_{jt,t+1} \leq T_{jt}^{*} \qquad (3)$$

where T_{jt}^{*} is the maximum number of AUMs which can be transferred from the t^{th} season to the $t+1^{th}$ season on the j^{th} range.

Livestock nutritional needs are met in each season from forage produced that season, forage carried over from the previous season, or hay purchased in that season:

$$\Sigma_{j=1}^{j} \; R_{jt} \; - T_{t,t-1} \; + T_{t+1,t} \; + 2.5H_t \; - Bb_t \; - F_t f_t \; - S_t s_t \; \geq \; 0 \qquad (4)$$

where all variables are as defined previously and:

b_t = the forage requirement per cow in the t^{th} season (AUMs),

f_t = the forage requirement per calf in the t^{th} season (AUMs), and

s_t = the forage requirement per stocker in the t^{th} season (AUMs).

The breeding cow activity, B, produces calves which are kept for replacement heifers, sold at weaning time in the fall, or fed for the fall season:

$$Ba_b \; - F_1 \; - V_1 \; \geq \; 0 \qquad (5)$$

where all variables are as previously defined and:

a_b = the proportion of a calf weaned per cow. Adjustments are made for weaning and replacement rates.

Any calves which are fed during a season are either sold at the end of that season or fed for another season up to the end of the summer when all calves are sold. Adjustments are made for death rates during each season:

$$a_{t-1}F_{t-1} \; - F_t \; - V_t \; \geq \; 0 \qquad (6)$$

where:

a_t = the proportion of a calf produced by feeding 1 calf during the t^{th} season after adjusting for death rates

and other variables are as previously defined.

Cow-and-calf costs are adapted from a budget by Drake (1985). All range, pasture, and hay costs and the value of weaned calves are taken out of the value for the LP objective function because they are accounted for elsewhere in the LP. The value of the cull cows and bulls are included since they are not included elsewhere in the LP model.

The pasture and range costs ($/AUM) are adapted from grazing cost surveys. These costs are decreased because some costs are counted in the total ranch budget, such as regular trucking, management, feed, and other costs that would be incurred regardless of what pasture or range was used and they are included in the cow/calf costs. The resulting cost is that cost associated with using a particular pasture or range. That is, those costs that are incurred only due to using that range or pasture.

The range and pasture costs are expressed as $ per AUM even though rents and leases are usually for the total amount. That is, the total cost is due even if all the available AUMs are not used. The lease cost is expressed as a cost per AUM and not as the total cost to reflect the reality of subleasing which keeps the cost per AUM down to the average even though one rancher may not use the entire allotment.

Hay costs are estimated from the hay market.

The value of a calf at the beginning of each season is estimated from estimated weights and historical price data for each season. The prices are the average prices for 1976 through 1983 as reported by the

Federal-State Market News Service (1982 and 1983). Calf weights are based on a weaning weight of 450 lbs. at the beginning of summer and expected average daily gains of 1.5, .5, .5, and 2 lbs. per day for the summer, fall, winter, and spring seasons, respectively.

The cost of feeding a calf is based on the stocker budget by Nelson (1980). Pasture, hay, range and supplementation costs are taken out because those costs are accounted for elsewhere in the LP model. The interest costs are recalculated to include the lost opportunity of selling instead of feeding a calf. This cost is expressed as a cost per day which is used to estimate the feeding cost per season for raised calves.

The return from purchasing and feeding a stocker is also adapted from Nelson's (1980) budget. The purchased stocker activity is limited to the spring season on valley rangeland. The costs are estimated on the basis of buying a 500 lb.-stocker on March 15 and selling a 656 lb.-stocker on June 1 on the basis of a 2 lb. A.D.G. The stocker prices are also the 1976 through 1983 averages for California as reported by the Federal-State Market News Service (1982 and 1983). The costs for pasture, range, hay, and supplementation are not included in this figure because they are accounted for elsewhere in the LP model.

Results. Initially, the LP model was solved to determine the sizes of the cow herd and stocker operations to be analyzed further. Under conditions of poor, average, and high forage production, the model maintained the cow herd at 135 cows and selected a stocker herd size of 316, 1,030, and 1,830 head, respectively. To analyze the effect of conservative management, the stocker herd sizes of 721, 824, and 927 head are added to the list of operation sizes. These three sizes represent 70 percent, 80 percent, and 90 percent of the stocker herd size in an average year. The cow herd is maintained at 135 cows with all stocker herd sizes.

After selecting the herd sizes to be analyzed, the model is solved to estimate the returns for each operation size under different weather and forage conditions. With three forage production levels in three seasons, there are 27 combinations of forage production that may occur. The joint probability of each combination occurring is calculated from the probabilities estimated in the previous section of this paper (Table 4).

The expected returns from each of the six herd sizes range from $42,574 to $56,953 for the ranch (Table 5). The herd size for average forage production in all seasons (135 cows and 1,030 stockers) produced the highest return of $56,953. The herd size for poor forage production in all seasons (135 cows and 316 stockers) has an expected returns of $42,574. The highest stocking rate (135 cows and 1,830 stockers) has an expected return of $51,057 which is the second lowest expected return. The conservatively set herd sizes of 135 cows and 927, 824, and 721 stockers have expected returns between the high and average stocking rates.

Since the stocking rate of 135 cows and 1,030 stockers has the highest expected returns, ranchers whom are not concerned with the income risk due to weather variations will stock at that level. However, many ranchers are concerned with income risk; expected returns are only part of the information they need to make a stocking decision. The variation in the returns under different weather patterns does have an impact on the final decision on stocking rate. The variation in returns can be seen in the standard deviation (Table 5). The standard deviation is a statistical measure of the amount of dispersion of the net returns. A smaller standard

Table 5. Estimated returns from the LP model for six herd sizes under different forage production levels.

		TOTAL RETURNS FOR RANCH					
	Forage	number of stockers*					
Probability	Year**	316	721	824	927	1030	1830
.06	P-P-P:	$32513	$28098	$26976	$25853	$24730	$16010
.15	P-P-A:	34487	47805	51193	54166	53920	45200
.05	P-P-H:	34487	47805	51193	54580	57967	59795
.04	P-A-P:	38351	33936	32814	31691	30568	21848
.10	P-A-A:	40325	53643	57031	60004	59758	51038
.03	P-A-H:	40325	53643	57031	60418	63805	65633
.02	P-H-P:	43689	39774	38652	37529	36406	27686
.04	P-H-A:	46163	59481	62869	65828	65429	56876
.01	P-H-H:	46163	59481	62869	66256	69643	71471
.05	A-P-P:	43689	39774	38652	37529	36406	27686
.13	A-P-A:	46163	59481	62869	65828	65429	56876
.04	A-P-H:	46163	59481	62869	66256	69643	71471
.04	A-A-P:	47520	45612	44490	43367	42244	33524
.09	A-A-A:	48476	61795	65182	68368	70331	62714
.03	A-A-H:	48476	61795	65182	68569	71956	77309
.02	A-H-P:	49330	51450	50328	49205	48082	39362
.04	A-H-A:	50286	63605	66992	70178	72167	68552
.01	A-H-H:	50286	63605	66992	70379	73766	83147
.006	H-P-P:	50235	54369	53246	52124	51001	42281
.015	H-P-A:	50337	63655	67042	70429	73072	71471
.005	H-P-H:	50337	63655	67042	70429	73816	86066
.004	H-A-P:	50337	59275	58875	57962	56839	48119
.010	H-A-A:	50337	63655	67042	70429	73816	77309
.003	H-A-H:	50337	63655	67042	70429	73817	91737
.002	H-H-P:	50337	61675	63664	63377	62677	53957
.004	H-H-A:	50337	63655	67042	70429	73816	83147
.001	H-H-H:	50337	63655	67042	70429	73817	96639
EXPECTED RETURNS =		42,574	52,003	54,308	56,404	56,953	51,057
STANDARD DEVIATION=		5,482	9,948	11,493	13,104	14,645	21,588

* Herd size includes 135 cows in addition to the stockers.

**The type of forage production in the valley range by season: fall, winter, and spring, respectively. P=poor, A=average, & H=high.

deviation is preferred to a larger deviation. The stocker herd of 1,030 head is preferred to the herd of 1,830 because the 1,030 herd has a larger expected return and a smaller standard deviation. However, this measure is not sufficient to show the optimal herd size because as the herd size decreases from 1,030 to 316 stockers, both the expected return and the standard deviation decrease thus providing no conclusive answer to the optimal herd size. Comparing the herd sizes by either a graph of expected returns and standard deviations (i.e., E-V analysis) or by their coefficient of variation (CV = standard deviation/expected return) does not provide any new information for choosing the optimal head size.

Another method to evaluate this risk of low versus high returns is in terms of stochastic dominance. This involves comparing the distribution of net returns and the probability of each return for each herd size. This is usually done by comparing the cumulative probability curves for net returns (Figure 1).

A herd size clearly dominates another herd size if at each level of cumulative probability the first herd size always has a higher net return. This is stochastic dominance of the first degree. Graphically, the dominating cumulative probability curve will lie completely to the right of the dominated curve. In terms of first degree stochastic dominance, no herd size dominates another (Figure 1). That is, no one curve lies neither completely to the right nor completely to the left of the others. All the curves cross each other at some point.

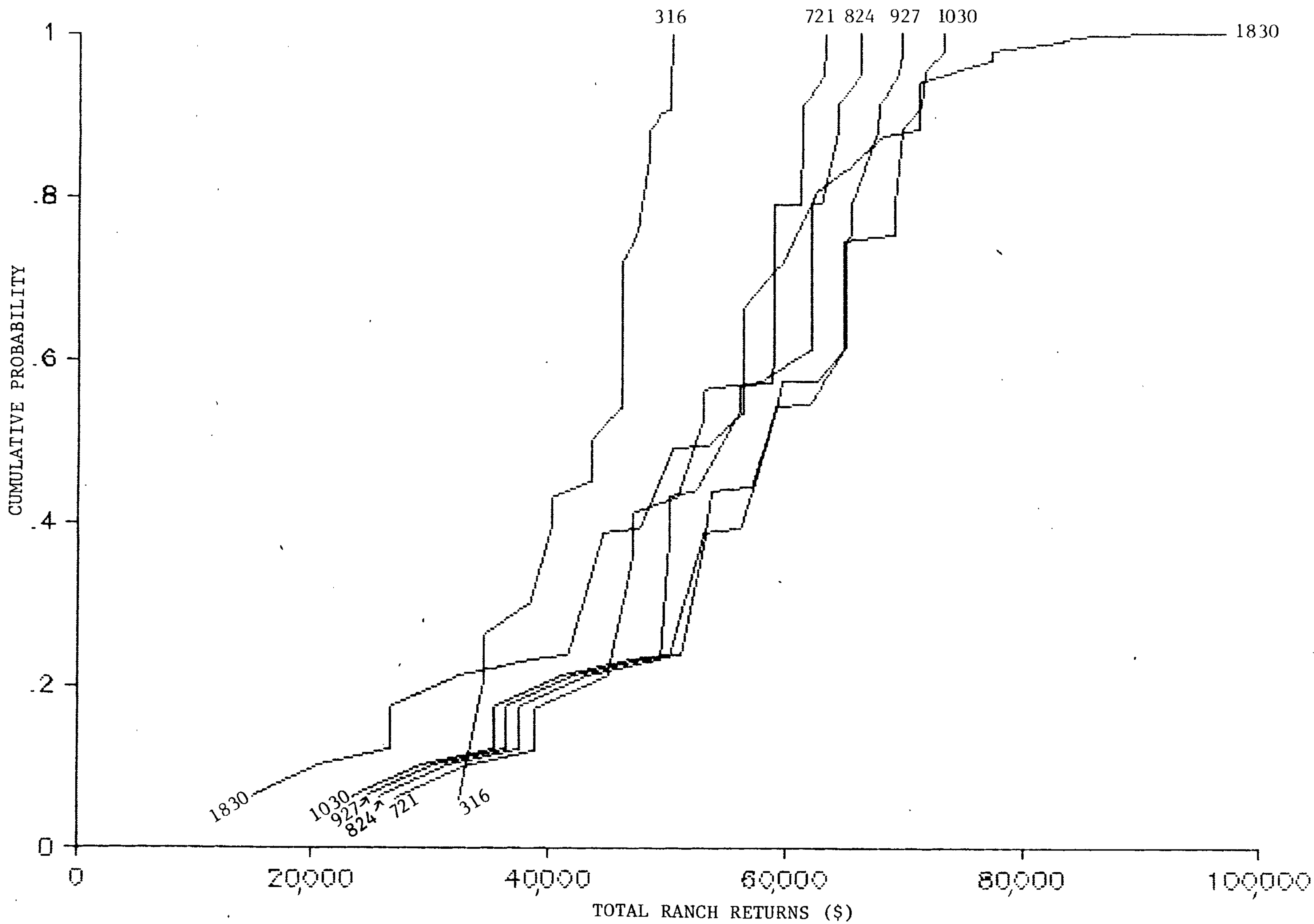

FIGURE 1. Cumulative distribution curves of total ranch returns for six herd sizes each with 135 cows and 316, 721, 824, 927, 1,030 Or 1,830 stockers.

Second-degree stochastic dominance may be helpful in providing a more specific answer to the stocking rate question. This technique will work for ranchers who are risk averse, but not for risk lovers. It allows the exclusion of alternatives which involve more risk than other alternatives and which ranchers who are more averse to poor returns would not consider. (For people who like the potential reward of a large return regardless of the risk involved, second-degree stochastic dominance does not work.) For one herd size to dominate a second herd size in terms of second-degree stochastic dominance, the total area under its cumulative probability curve must be less than or equal to the area under the second curve <u>and</u> at no point can the area under the first curve be greater than the area under the second curve.

Graphically, second-degree stochastic dominance may be easy or hard to determine. It depends upon the points at which the curves cross and the relative slopes of the curves. Of the six herd sizes (Figure 1), the largest herd size may be dominated, but that is hard to determine visually. To make an accurate assessment, the areas under the curves are needed (Table 6). Of the six herd sizes, only the largest herd size is dominated in terms of second-degree stochastic dominance by the medium herd sizes (135 cows with 721, 824, 927 and 1,030 stockers). The area under the largest herd size curve is calculated to be 46,943 which is larger than the total areas under the curves for the medium sizes. Also, the area under the curves for the medium sizes is always less than that of the largest size curve. This second condition can also be seen in that they start to the right of the largest size curve. The curve for the smallest herd size starts to the right of the largest size, but its total area is larger than the curve for the largest size, so we cannot say whether the smallest size dominates the largest or vice versa.

Table 6. Summary of area under cumulative probability curves at selected levels of net returns.

Stocker level	Area under curve at: 34,000	50,000	60,000	74,000	98,000
316	89	7457	17426	31426	55426
721	357	3287	8535	21997	45997
824	469	3084	7569	19692	43692
927	581	3335	6837	17596	41596
1030	693	3594	6998	17047	41047
1830	2027	6373	11723	23340	46943

Technically, the smallest herd size (135 cows and 316 stockers) can not be eliminated in terms of second degree stochastic dominance. The curves for the medium sizes have smaller total areas under them, but at low levels of returns, the curve for the medium sizes have larger areas. This violates the second part of the terms of second-degree stochastic dominance. However, since the smallest herd size has the lowest expected return (almost $10,000 less than the next larger size) and its curve lies to the right of the other curves only at low levels of ranch returns, we would expect only a very risk-averse individual would choose this herd size.

The medium herd sizes (135 cows with 721, 824, 927, and 1,030 stockers) were selected on the basis of average conditions and conservative management. Their cumulative probability curves lie close together at lower levels of income, but separate after they cross each other. The herd size with 1,030 stockers does have the smallest total area; however, it violates the terms of second-degree stochastic dominance by having larger area underneath it at low levels of return (e.g., $34,000, Table 6). The herd size with 721 stockers has a smaller area at low return levels, but its total area is larger than the curves for other medium herd sizes. Thus, second-degree stochastic dominance also does not allow us to specify the optimal herd size.

To make a final decision on the stocking rate, a rancher must balance his/her preferences for returns versus risk. To quantify this relationship, a utility function needs to be estimated. Based on our knowledge of ranchers, their risk preferences, and their management decisions, a quadratic utility function is assumed to adequately represent the typical rancher's response to risk. Thus, utility can be expressed as a function of the expected returns and the variance of those returns (Anderson, et al.):

$$U = E(R) + b[E(R)]^2 + b\,V(X) \qquad (7)$$

where U = the rancher's utility level; E(R) = expected returns; V(X) = variance of those returns; and b = risk coefficient relating variance and change in expected returns back to the actual level of the expected return. Since most ranchers are risk averse, the coefficient, b, should be negative. This coefficient is often specified in the range of -.01 to -.005 (Anderson, et al.). The closer this coefficient is to zero, the less risk averse the person is. A value of zero would indicate risk neutrality.

The expected returns and the standard deviations of those returns (Table 7) and different values of the coefficient are used to estimate the rancher's utility for each herd size (Table 7). At very small levels of the coefficient (-.000008), the stocking rate with the maximum utility changes from 1,030 stockers (plus 135 cows) to 927 stockers. A slightly more negative coefficient (-.00001) shifts the optimal rate to the smallest herd: 135 cows and 316 stockers. These coefficient values are relatively small. Normally, this coefficient is thought to be in the range of -.01 to -.005 (Anderson, et al.). Since most ranchers do not stock at the lower rates, these results indicate that ranchers are not very risk averse. However, these results may be due, in part, to using data generated by a linear programming model. The simplistic utility function may also lack the detail needed to see differences in utility levels. These results do not provide a general answer to the stocking rate design, but they do indicate that ranchers may be close to being risk neutral in their stocking rate decision.

Table 7. Estimated utility levels using a quadratic utility function.

Coefficient Level (b)	Stocker Level					
	316	721	824	927	1,030	1,830
- .000001	40,731	49,199	51,227	53,051	53,495	47,984
- .000005	33,361	37,986	38,901	39,638	39,662	35,693
- .000008	27,833	29,577	29,656	29,579	29,288	26,474
- .00001	24,148	23,970	23,494	22,873	22,372	20,329
- .0001	-141,683	-228,322	-253,837	-278,906	-288,861	-256,226

SUMMARY AND CONCLUSIONS

The "conventional wisdom" in managing California rangeland is to stock the range at 80 percent of the average forage production. The stocking rate decision was evaluated with iterative solutions of a linear programming model for a ranch based in the western foothills of the Northern Sierra Nevada. A herd size of 135 cows and 1,030 stockers was chosen based on average forage production. To reflect conservative management, the stocker herd was decreased to 927, 824, and 721 stockers (90 percent, 80 percent, and 70 percent of 1,030 stockers). The relationship between weather variability and forage production was estimated on the basis of historical data and subjective field experience. The LP model was solved for these variations with the stocking rate fixed at the above rates. Since the stocking rate for average forage production has a higher expected return than these conservative stocking rates, the "conventional wisdom" is not risk-neutral, but risk-averse to some degree.

To evaluate the impact of income variance, the choice of herd size was analyzed by the mean-variance tradeoff, stochastic dominance analysis, and utility estimation. Both the mean-variance tradeoff and second-degree stochastic dominance eliminated the highest stocking rate, but did not provide enough information to rank the other stocking rates. Using a quadratic function to estimate utility showed that ranchers who were averse to risk would stock at rates lower than the conventional wisdom. The conventional wisdom of stocking at 80 percent of the average range forage production was shown to be close to risk neutrality.

Further research is needed in the specification of the utility function, the estimation of the returns, and the measurement of risk attitudes of ranchers.

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APPENDIX: Example LP Matrix for Average Weather Conditions.

LP MATRIX		Range and pasture: FALL PASTURE	USFS LEASE	FALL VALLEY	WINTER VALLEY	SPRING VALLEY	IRRIGATED PASTURE	Carry over: Fall to Winter	Winter to Spring	Buy Hay (tons): Fall	Winter	Spring	Cow/calf	Sell Calf Summer	Feed Calf Summer	Sell Calf Fall	Feed Calf Fall	Sell Calf Winter	Feed Calf Winter	Sell Calf Beg. of Spring	Feed Calf Spring	Sell Calf End of Spring	Stockers		
Objective Function	$	-9.86	-9.86	-.81	-.81	-.81	-.81	.00	.00	-75.00	-75.00	-75.00	45.46	289.58	-17.27	377.01	-15.70	423.15	-13.58	452.34	-15.27	550.79	34.10		
Range																									
FALL PASTURE	AUMs	1						0	0															<=	1000
USFS LEASE	AUMs		1					0	0															<=	2000
FALL VALLEY	AUMs			1				1	0															<=	900
WINTER VALLEY	AUMs				1			-1	1															<=	300
SPRING VALLEY	AUMs					1		0	-1															<=	2000
IRRIGATED PASTURE	AUMs						1	0	0															<=	1000
CARRY FALL TO WINT	AUMs							1																<=	500
Forage																									
Summer	a.u.m's		1				1						-6.10		-2.20									>=	0
Fall	a.u.m's	1		1						2.5			-4.60				-2.01							>=	0
Winter	a.u.m's				1						2.5		-3.65						-1.70					>=	0
Spring	a.u.m's					1						2.5	-3.90								-1.38		-1.5028	>=	0
Cow-Calf	Head												1											>=	0
Calves:																									
Summer	Head												.6	-1	-1									>=	0
Fall	Head														.98	-1	-1							>=	0
Winter	Head																.98	-1	-1					>=	0
Spring	Head																		.98	-1	-1			>=	0
Summer, end of	Head																				.98	-1		>=	0
Stockers	Head																						1	>=	0