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Choosing Optimum Stocking Rates for Western North Dakota Rangeland

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HIGHLIGHTS

This study examines the use of statistical decision theory in guiding stockmen's adjustments to fluctuating range forage supplies in western North Dakota. Range forage production in the Northern Great Plains is highly variable. Various means by which ranch managers can adjust to fluctuating forage production are examined. The factors affecting range forage production are also examined.

The relationship of range forage production to climatic variables was studied through the use of correlation and regression analysis. Range forage production in western North Dakota was found to be strongly influenced by precipitation during the growing season and also by precipitation during the previous fall and winter.

Bayesian statistical methods were applied to select the best of four alternative stocking rates under varying precipitation conditions.

Stocking rates were evaluated according to the criterion of minimizing losses resulting from over and underutilization of range forage. The amount of precipitation occurring prior to the start of the grazing season (May 1) was found to be a useful guide in determining the most favorable stocking rate. However, the potential benefits from developing more accurate techniques for forecasting range production are substantial.

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INTRODUCTION

Risk and uncertainty are dominant characteristics of range livestock production in western North Dakota. Many production and marketing decisions made by cattlemen are complicated by uncertainty concerning range productivity. Uncertainty concerning cattle prices also contributes to the complexity of their decisions, but is not analyzed in this study. Cattlemen have long faced the problem of adjusting stocking rates to fluctuating range forage production, and numerous "rules of thumb" have been suggested to aid in resolving the problem. Statistical decision theory may offer a new approach to resolving the stocking rate problem. This report will examine the usefulness of statistical decision theory in guiding adjustments in response to an uncertain forage supply in western North Dakota.

Objectives of the Study

The specific objectives of the study are to:

1. Determine factors which lead to fluctuations in range forage production.

2. Develop decision rules to guide managers in adjusting livestock numbers to a fluctuating forage supply.

3. Estimate the potential benefits from improved techniques of predicting forage production in advance of the grazing season.

Area of Study

The study deals with the area which Dietrich identifies as western North Dakota, a 16-county area with about 14 million acres of agricultural land[1] (see Figure 1). In 1964 approximately 7.7 million acres in this area were used for grazing livestock. Of this, approximately 7.3 million acres, or 95 percent, are native pasture and rangeland. Beef cattle and wheat are the leading sources of agricultural income in the area.

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[1]The state is divided into four areas according to pasture production potential. For a thorough discussion, see Dietrich, Irvine T., Pasture Balance for Western North Dakota, Extension Service, North Dakota State University, Fargo, North Dakota, 1965.

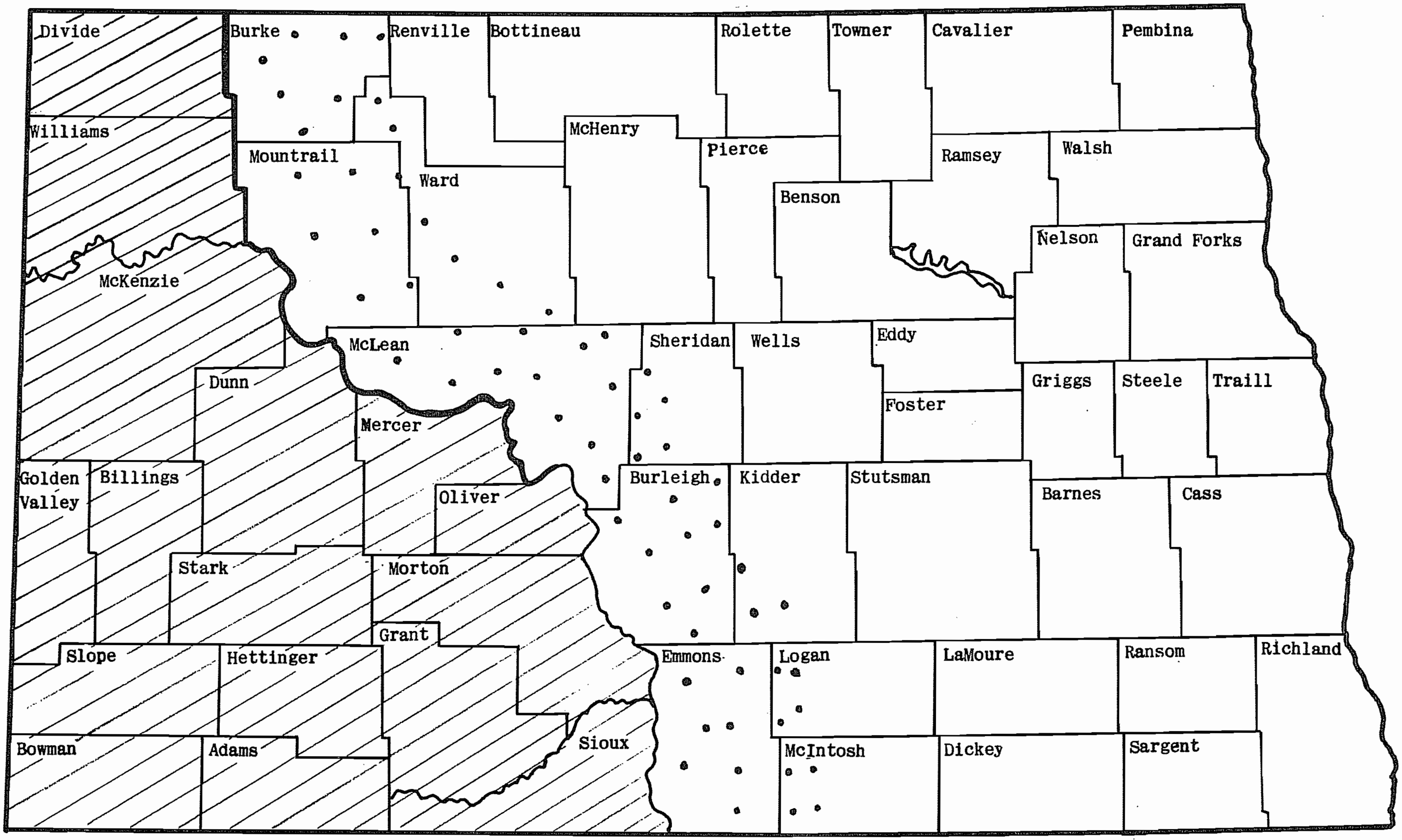

Figure 1. Western North Dakota, Area of Study.

Procedures

The relationship of range forage production to climatic variables was studied through the use of correlation and regression analysis on forage yield data from experiments conducted at the Dickinson Branch Experiment Station.[2] Monthly precipitation data from the Dickinson weather station for 77 years (1893-1969) were used in developing precipitation probabilities. The forage yield-precipitation relationships were generalized through the development of a forage production response equation similar to the equation developed by Sneva and Hyder[3] for the Intermountain Region.

Bayesian statistical methods were used to select the best of four alternative stocking rates under varying precipitation conditions. Three different levels of knowledge were assumed. First, the decision maker was assumed to know only the long-term probabilities of different levels of annual precipitation. Second, it was assumed that the decision maker gained additional knowledge (by observing preseasonal precipitation levels) which enabled him to revise the precipitation probabilities for the current year. Third, in order to estimate the potential value of more reliable predictive techniques, the amount of annual precipitation was assumed to be known with certainty before the start of the grazing season. The best stocking rate strategy was determined under each of the three knowledge situations, and the losses resulting from over or underutilization of pasture were compared for the three different knowledge situations.

VARIABILITY OF RANGE FORAGE PRODUCTION

The phenomenon of extreme variability of range and pasture production in the Northern Plains Region has long been noted. Rogler and Haas report that between 1920 and 1944 forage yields at the Northern Plains Field Station, Mandan, ranged from 1,034 pounds per acre in the most favorable year to no measurable yield in the worst year.[4] Smoliak reports similar variability in forage yields in southeastern Alberta where, during the period 1930-1953, forage production per acre ranged from a low of 90 pounds per acre in 1949 to a high of 825 pounds per acre in 1942.[5]

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[2]Data were obtained from the Annual Reports of the Dickinson Station.

[3]Sneva, Forrest A. and D. N. Hyder, "Estimating Herbage Production on Semiarid Ranges in the Intermountain Region," Journal of Range Management, Vol. 15, 1962, pp. 88-93.

[4]Rogler, George A. and Howard J. Haas, "Range Production as Related to Soil Moisture and Precipitation on the Northern Great Plains," Journal of the American Society of Agronomy, Vol. 39, No. 5, May, 1947, pp. 378-389.

[5]Smoliak, S., "Influence of Climatic Conditions on Forage Production of Short-Grass Rangeland," Journal of Range Management, Vol. 9, 1956, p. 89.

Since 1922, monthly estimates of the "range feed condition" have been published by the United States Department of Agriculture for the 17 western states.[6] These estimates, which are based on information obtained from crop reporters, provide another measure of range production variability. The crop reporters are asked to report range condition based on the following scale: 100 and over, excellent condition; 90-99, very good condition; 80-89, good; 70-79, fair; 60-69, poor; 50-59, bad; and below 49, very bad. Range condition in North Dakota has ranged from a low of 40 in June of 1934 to a high of 96 which was attained in July of both 1942 and 1953. Monthly range condition estimates for North Dakota for the years 1923-1970 are presented in Appendix Table 1.

Ranch managers in western North Dakota are aware of the variation in range forage production or carrying capacity from year to year. Because the variations are often substantial, the number of livestock which is pastured must often be adjusted. A survey of western North Dakota ranch managers in 1968 revealed that variation in range carrying capacity was the most important factor causing adjustments in cattle numbers. Sixty-one percent of the 46 respondents cited range carrying capacity as the most important factor causing adjustment in cattle numbers. Another 20 percent listed winter forage supply as the most important factor.[7]

ADJUSTING RANCH OPERATIONS TO FLUCTUATING RANGE PRODUCTION

The managerial problem of adjusting ranch opeartions to fluctuating range forage production has two aspects. First, there is the problem of taking advantage of those years in which range production is substantially above average. If the forage produced cannot be effectively utilized, a substantial opportunity cost is incurred. On the other hand, the dramatic reductions in forage production often associated with drought pose a dilemma to the ranch manager. To bring grazing needs into line with available forage, large portions of the breeding herd may have to be sold. Supplemental feeding is a possible alternative to herd reduction, but may lead to high costs for purchased feed.

Plath and Gray studied how Oregon ranchers adjusted to drought conditions in 1955.[8] Ranchers who were able to lease more land suffered least financially from the drought. Buying hay and concentrates to maintain the herd led to substantial increases in cash costs, resulting in large reductions in net ranch income. Reducing the breeding herd to meet the feed shortage resulted in a major decrease in receipts and net income.

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[6] Statistical Reporting Service, USDA, Range Livestock and Feed Condition, Washington, D.C., periodical.

[7] Unpublished survey data collected by Professor Edward V. Dunn, Department of Agricultural Economics, North Dakota State University.

[8] Plath, C. V. and James R. Gray, Drought Practices Used by Cattle Ranchers, Circular of Information 591, Oregon Agricultural Experiment Station, Oregon State College, Corvallis, Oregon, 1958.

Another method of adjusting ranch operations to a fluctuating forage supply is the maintenance of feed reserves. Extra winter feed can be harvested and stored in years of high forage production. The feed reserve is then available for use in unfavorable years. The maintenance of feed reserves is not without cost, however. In a study of livestock farms in central Nebraska, Langemeier and Finley found that a policy of maintaining feed reserves resulted in a more stable farm income over time.[9] However, the cost of maintaining feed reserves was found to be substantial, and the feed reserve policy reduced the average level of farm income over time. The researchers concluded that, while feed reserves tended to stabilize farm income, adjustment of livestock numbers to changes in forage supply would be preferred if a high average level of income were the primary objective.

Ranchers generally are extremely reluctant to sell a major portion of their breeding herds during drought periods because such a sale would disrupt their long-term breeding program. Yet, an adjustment in grazing during drought is needed to protect the range. Heavy grazing tends to reduce the yields in future years, and very heavy grazing over extended periods can have long-term detrimental effects.[10] Given these considerations, the stockman's alternatives in adjusting to fluctuations in range production appear rather limited. Supplemental feeding is an alternative, but the expense may be substantial. The number of animals on the ranch could be reduced through heavier or earlier culling of cows although the reduction that can be achieved while keeping the breeding herd intact may be quite limited.

Use of the cow-yearling production system has been suggested as a means of achieving greater flexibility in adjusting cattle inventories.[11] The usual production practice with this system is to winter the calves, summer them on grass, and sell as long yearlings. However, if winter feed is scarce, the calves can be sold after weaning. If range prospects are bleak in the spring, the calves can be sold then rather than summered. Obviously, price expectations will also enter into such sales decisions.

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[9]Langemeier, Leon E. and Robert M. Finley, "The Use of Hay Reserves as a Method of Stabilizing Farm Income," Management Strategies in Great Plains Farming, Great Plains Council Publication No. 19, Lincoln, Nebraska, 1961.

[10]For further discussion of drought adjustment, see Boykin, Calvin C., Cattle Ranch Adjustments to Drought in the Southern Plains, Departmental Information Report 64-2, Department of Agricultural Economics, Texas A&M University, College Station, 1964.

[11]Boykin, Calvin C., "Profitability and Flexibility of Two Range Cattle Systems in the Rolling Plains of Texas," Journal of Range Management, Vol. 20, 1967, pp. 375-379.

A recent survey of ranch managers in western North Dakota indicated that adjusting the livestock inventory was a more common way of adjusting to lower range production than supplemental feeding.[12] Fifty percent of the respondents ranked heavier culling of cows as their most important adjustment technique. Another 27 percent ranked pruchase or sale of calves and yearlings as the most important method of adjustment. Supplemental feeding was rated as most important by 19 percent of respondents. Other adjustment techniques used included renting more land and varying the amount of hay harvested.

Adjustments are more difficult when abnormal weather conditions affect wide areas. If an entire range area is dry in a particular year, heavy marketings of young animals and cull cows may be expected. In addition, substantial increases in the demand for rented pasture seem likely under drought conditions. On the other hand, in an abnormally favorable forage year there might be a substantial demand for stocker cattle to utilize the extra forage.

FACTORS AFFECTING RANGE FORAGE PRODUCTION

A number of researchers have studied the response of range forage plants to various environmental forces. In an early study in New Mexico, Nelson found a high correlation between precipitation in the current growing season and the height growth of stands of black grama.[13]

Craddock and Forsling studied spring-fall sheep ranges in southern Idaho over the period 1924-1932.[14] Annual precipitation explained 56 percent of the variation in the number of days of sheep grazing on moderately grazed pastures. A smaller percentage of the variation was explained on severely overgrazed pastures.

Sarvis reported on experiments conducted in North Dakota from 1916 through 1940. Pasture output was measured as pounds of beef produced per acre.[15] Annual precipitation explained 41 percent of the variation in beef production per acre.

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[12]Unpublished survey data collected by Professor Edward V. Dunn, Department of Agricultural Economics, North Dakota State University.

[13]Nelson, Enoch W., The Influence of Precipitation and Grazing on Black Grama Range, Technical Bulletin 409, USDA, Washington, D.C., 1934.

[14]Craddock, G. W. and C. L. Forsling, The Influence of Climate and Grazing on Spring-Fall Sheep Range in Southern Idaho, Technical Bulletin 600, USDA, Washington, D.C., 1938.

[15]Sarvis, J. T., Grazing Investigations on the Northern Great Plains, Bulletin 308, Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota, 1941.

Rogler and Haas examined the relationship of soil moisture and precipitation to range forage production in the Northern Plains.[16] Available soil moisture was measured in the fall and correlated with forage production for the following growing season. A correlation coefficient of 0.72 was obtained between forage yield and available soil moisture in the surface three feet of soil. The correlation coefficient between yield and soil moisture in the surface six feet was 0.74.[17] An important factor influencing yields (in addition to soil moisture) was current season precipitation. The highest correlation (0.76) was obtained when precipitation for the period April through July was used as the independent variable.

Smoliak examined the influence of a series of meteorological factors on forage yields in southeastern Alberta.[18] He found that increases in seasonal mean temperature, hours of bright sunlight, and wind mileage all tended to decrease forage production. Greater precipitation in May and June tended to increase production in the current year.

A FORAGE RESPONSE FUNCTION FOR WESTERN NORTH DAKOTA

The results of previous studies indicate that precipitation is a dominant force influencing range forage production. In the present study the correlation of range forage yields with precipitation in different periods was examined. The range forage yield data were obtained from experiments conducted at the Dickinson Branch Experiment Station in western North Dakota.[19] Weather data also were obtained from the Dickinson Station.

Yields from native range sites and crested wheatgrass were found to be highly correlated with growing season precipitation. Correlations were generally improved when precipitation from the previous fall and winter was added to growing season precipitation. When forage yields from 11 different sites or plots were correlated with precipitation for the period October through September (12 months), the correlation coefficients ranged from 0.27 to 0.97. Thus, the variations in precipitation accounted for from 7 to 94 percent of the variations in forage yield.

Correlation coefficients and regression equations describe the relationship between precipitation and forage yield for a particular species or a particular site. They may not provide an adequate means for predicting forage production on other sites, however. Sneva and Hyder

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[16] Rogler and Haas, op. cit., pp. 378-389.

[17] Ibid., p. 380.

[18] Smoliak, op. cit., p. 89.

[19] The forage yield data were derived from research conducted by Dr. Warren C. Whitman, Department of Botany, North Dakota State University. The author accepts full responsibility for any errors in interpreting the data.

suggest a method for applying the precipitation-forage yield relationships to a wider area.[20] Their method is based upon expressing the actual yields and amounts of precipitation from different experimental areas in terms of the median precipitation and associated level of forage yield for the area. The first step is to estimate the relationship between precipitation and forage production for each area (plot or site). Next, the level of forage production associated with the median level of precipitation is estimated. This level of production can be called the "median yield."

Precipitation data from various sites are converted to percentages of the median precipitation for the site. Yields from each site are converted to percentages of the median yield for that site. The converted yield and precipitation data can then be pooled and used to estimate a common forage response function.

A forage response function was estimated by least-squares regression analysis using data from 11 sites converted as explained above.[21] The function estimated was:

$$Y = -68.86 + 1.69X$$

where Y = forage yield as a percentage of median yield, or forage yield index.

X = October-September precipitation as a percentage of median annual precipitation or precipitation index.

The correlation coefficient (r) was 0.72, indicating a relatively high degree of positive linear association between the variables. The slope coefficient (1.69) indicates that an increase of the precipitation index by 1 percentage point (e.g., from 101 to 102) will result in an increase in the forage yield index of 1.69 percentage points. There were 96 total observations used to estimate the function. The slope and intercept coefficients of the regression equation were both significantly different from zero by the t-test. The coefficient of determination (r^2) was 0.52, indicating that 52 percent of the variation in the dependent variable (Y) can be statistically accounted for by variations in the independent variable (X).

The forage response equation can be used to predict the changes in forage production associated with given changes in precipitation from year to year. The equation is used in this manner in the next section of this report.

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[20]Sneva and Hyder, op. cit., p. 88.

[21]The raw yield data from which the function was derived are presented in Appendix Tables 3 and 4. The raw precipitation data are presented in Appendix Table 2.

USE OF STATISTICAL DECISION THEORY TO DETERMINE OPTIMUM STRATEGIES

Bayesian decision theory provides the basic framework for this analysis. The Bayesian model provides a method of determining the optimum strategy to be followed in an uncertain decision-making framework. The essential element of the Bayesian method is the relative frequencies (probabilities) of each possible state of nature (e.g., quantity of precipitation). These probabilities may be determined objectively from historical data. The probabilities then are used as weights in determining the weighted average net income for each course of action (e.g., stocking rate) considered.[22]

Calculating Precipitation Probabilities

Monthly precipitation data were obtained from the Dickinson, North Dakota, weather station for 77 years (1893-1969). Median annual precipitation for October through September for the period was 15.5 inches. Four levels of annual precipitation were established. A "drought" level was established at less than 12 inches, a "below normal" level at 12 to 14 inches, a "normal" level at 14 to 17 inches, and an "above normal" level at 17 inches and above. The frequencies with which the four precipitation levels occurred are indicated in Table 1.

TABLE 1. FREQUENCIES OF ANNUAL PRECIPITATION LEVELS, DICKINSON, NORTH DAKOTA, 1893-1970

Level	Amount[a] (inches)	Years Observed	Relative Frequency
Drought	0 to 11.99	11	.142
Below Normal	12.0 to 13.99	11	.142
Normal	14.0 to 16.99	30	.389
Above Normal	17.0 or more	25	.323

[a]Annual precipitation is computed for the months of October through September.

SOURCE: See Appendix Table 2.

[22]Dean, G. W., A. J. Finch, and J. A. Petit, Jr., Economic Strategies for Foothill Beef Cattle Ranchers, Bulletin 824, California Agricultural Experiment Station, University of California, Davis, California, 1966, p. 23.

Estimating Forage Production

Forage production estimates are based upon recommendations for range in good condition in western North Dakota. Assuming a six-month grazing season (May-October), such range can be expected to produce 0.364 animal unit months (AUM) of grazing annually per acre under normal conditions.[23] This level of production was assumed to be associated with the median level of precipitation. The forage response function described previously was used to estimate forage production for the four precipitation levels.

To convert the forage production values to terms more meaningful to a ranch manager, a ranch was assumed to have 1,000 acres of native rangeland. Four alternative stocking rates were considered, ranging from 0.15 AUM per acre to 0.55 AUM per acre. Table 2 shows the forage production, forage requirements, and surplus or deficit of forage for the different stocking rates and precipitation levels.

TABLE 2. FORAGE PRODUCTION, FORAGE REQUIRED, AND FORAGE SURPLUS OR DEFICIT FOR FOUR ALTERNATIVE STOCKING RATES AND FOUR LEVELS OF PRECIPITATION, 1,000 ACRES OF NATIVE RANGE, WESTERN NORTH DAKOTA

Level of Annual Precipitation[a] (inches)	Forage Production (AUM)	Forage Surplus or Deficit — Stocking Rates: 150 AUM	260 AUM	360 AUM	550 AUM
0 to 11.99	145.53	-4.47	-114.47	-214.47	-404.47
12.0 to 13.99	264.85	+114.85	+4.85	-95.05	-285.15
14.0 to 16.99	363.89	+213.89	+103.89	+3.89	-186.11
17.0 or More	554.59	+404.59	+294.59	+194.59	+4.59
AUM's of Forage Required		150	260	360	550

[a]Annual precipitation is computed for the months of October through September.

When the rate of stocking is too heavy and there is a forage deficit, additional costs may be incurred through renting more land or purchase of supplemental feeds. The sale of some breeding livestock may also be necessary. On the other hand, when the stocking rate is too light in relation to the level of forage production, the large amounts of range forage not utilized represent a substantial opportunity cost to the ranch operator. Table 3 shows the dollar cost magnitude of the losses associated with the range forage surpluses and deficits shown in Table 2.

[23]Dietrich, op. cit., p. 2.

TABLE 3. DOLLAR LOSSES INCURRED WITH FOUR ALTERNATIVE STOCKING RATES AND FOUR LEVELS OF PRECIPITATION, 1,000 ACRES OF NATIVE RANGE, WESTERN NORTH DAKOTA[a]

Level of Precipitation	Long-Run Probability	Stocking Rates			
		150 AUM	260 AUM	360 AUM	550 AUM
(inches)		(dollars)			
0 to 11.99	.143	12.07	309.07	579.07	1,092.07
12.0 to 13.99	.143	246.93	10.43	256.64	769.91
14.0 to 16.99	.390	459.86	223.36	8.36	502.50
17.0 or More	.324	869.87	633.37	418.37	9.87
Long-Term Loss[b]	1.000	498.22	338.01	258.32	465.44

[a]The outcome for each combination of stocking rate and level of precipitation is compared with the ideal of exact utilization of the available forage. Because exact utilization is not achieved by any combination, all figures in the table are termed losses. Excess forage was valued at $2.15 per AUM. Forage shortages were expected to lead to costs of $2.70 per AUM. Both values were based on pasture rented rates.

[b]Long-term loss for each stocking rate was calculated as the sum of the loss at each level of precipitation times the long-run probability of that level. It is the average annual loss which would occur if the stocking rate were employed over a long period of time.

Analysis and Results

The probabilities of occurrence of the October-September precipitation levels and the calculated losses associated with the stocking rates for each level can be utilized to provide two solutions to the problem of choosing an appropriate stocking rate. The first solution assumes that only the long-run (or *a priori*) probabilities associated with the different precipitation levels are known. These long-run probabilities, as shown in Table 3, are simply the relative frequencies with which these levels of precipitation have occurred historically. These probabilities can be multiplied by the potential loss of each stocking rate for each precipitation level and summed for each stocking rate to compute the long-term probable loss for each stocking rate. The long-term probable losses for each stocking rate are shown as the bottom line of Table 3. The stocking rate of 360 AUM (0.36 AUM/acre) produces the smallest long-term probable loss and is the most favorable of the stocking rate alternatives in this solution. If a ranch manager desires to maintain his herd size and stocking rate at a constant level from year to year, the best size of herd to maintain will be that which most effectively utilizes the range forage produced at the normal (median) precipitation level.

The key question to be examined is whether the probable loss obtained when only long-run (*a priori*) probabilities are used can be reduced by using available information to predict range production in advance of the grazing season. Because the grazing season in western North Dakota typically begins in May, it is assumed that the stocking rate decision must be made by May 1. Therefore, a ranch manager can use information about fall, winter, and early spring precipitation in making the stocking rate decision. The information concerning preseasonal precipitation can be used to modify the long-run precipitation probabilities. The "modified" probabilities reflect the probability of different levels of annual precipitation given that a particular level of October through April precipitation has been observed on May 1.[24] Table 4 presents the probabilities of observing the four different levels of annual precipitation given that specified levels of October-April precipitation have been observed. These probabilities were developed using the Bayesian technique discussed in Appendix Table 5.

TABLE 4. PROBABILITIES OF OBSERVING FOUR DIFFERENT LEVELS OF ANNUAL (OCTOBER-SEPTEMBER) PRECIPITATION, GIVEN VARIOUS LEVELS OF OBSERVED (OCTOBER-APRIL) PRECIPITATION, DICKINSON, NORTH DAKOTA[a]

Observed Precipitation (October-April)		Total Annual Precipitation			
Level	Probability of Observation P(Z)	0-11.99"	12-13.99"	14-16.99"	17" and Over
0-2.99"	.194	.402	.134	.263	.201
3-3.99"	.195	.200	.262	.456	.067
4-4.99"	.195	.133	.200	.400	.267
5" and Over	.414	.000	.063	.403	.531

[a]For details concerning the development of the probabilities shown in this table, see Appendix Table 4.

The modified probabilities can be used by a decision maker to determine which of several alternative actions will minimize expected loss or maximize expected profit. More specifically, the modified probabilities from Table 4 can be multiplied by the appropriate loss figures in Table 3 to calculate probable net losses. These probable losses are presented in Table 5.

Examination of Table 5 indicates that a stocking rate of 150 AUM (0.15 AUM/acre) is best (produces the smallest probable loss) for levels of October through April precipitation less than three inches. For observed precipitation levels between 3.0 and 4.99 inches, a stocking rate of 260 AUM is best, and for observed precipitation levels in excess of five inches, a

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[24]The "modified" probabilities are also sometimes referred to as <u>a posteriori</u> probabilities. Detailed discussion of the calculation of these probabilities may be found in Halter, A. N. and G. W. Dean, <u>Decisions Under Uncertainty With Research Applications</u>, South-Western Publishing Company, Cincinnati, Ohio, 1971, pp. 106-130.

stocking rate of 550 AUM (0.55 AUM/acre) is most satisfactory. The average loss to be expected from following this strategy for a number of years is $232.20,[25] an improvement of $24.85 or 9.8 percent from the solution obtained using the long-run probabilities only.

TABLE 5. EXPECTED NET LOSSES CALCULATED USING A POSTERIORI PROBABILITIES[a]

Observed Precipitation, October-April	Stocking Rates			
	150 AUM	260 AUM	360 AUM	550 AUM
(inches)	(dollars)			
0-2.99	333.72	335.09	467.20	662.78
3-3.99	496.09	99.86	301.65	426.99
4-4.99	353.47	214.89	243.39	241.69
5 and Over	676.32	649.93	502.87	256.25

[a]The probable losses in this table are developed through the use of the losses from Table 3 and the modified probabilities from Table 4. The probable loss from each stocking rate for a particular level of October-April precipitation is computed by multiplying the "modified" probabilities of occurrence of the different levels of annual precipitation for each level of observed precipitation by the losses which would result from the stocking rate in question if the different levels of annual precipitation did occur. For example, the probable loss from a stocking rate of 260 AUM given an observed level of October-April precipitation of 3.0-3.99 inches is obtained by multiplying the elements of the second row of Table 4 by the corresponding elements of the second column of Table 3. Thus, $309.07 (.200) + $10.43 (.262) + $223.36 (.456) + $633.37 (.067) = $99.86.

Statistical decision theory can be employed to estimate the potential benefit from more accurate weather-predicting techniques. Specifically, the Bayesian model can be used to show the expected loss if a perfect weather predictor were available. If, for example, the observed levels of October-April precipitation served as perfect predictors of the level of annual precipitation, the diagonal elements of the modified probabilities matrix (Table 4) would become ones (1.0) and the other elements would become zeros. Under such circumstances, the decision maker could select the stocking rate corresponding most closely to the known level of carrying capacity. The long-term loss under such circumstances would be computed by multiplying the diagonal elements of the loss matrix (Table 3) by the long-run probabilities (Table 3). The long-term loss, always using the most appropriate stocking

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[25]This is obtained by multiplying the underlined values from Table 5 by the appropriate P(Z) value shown in Table 4. Thus, $333.72 (.194) + $99.86 (.195) + $214.89 (.195) + $256.25 (.414) = $232.20.

rate and assuming observed precipitation to be a perfect predictor of annual precipitation, is $19.02.[26] This loss is much less than the long-term losses associated with the previous solutions.

CONCLUSIONS AND IMPLICATIONS

The preceding analysis indicates the importance of precipitation as a variable affecting range forage production. Both precipitation occurring during the growing season and precipitation prior to the growing season have an influence on forage yields. The amount of precipitation occurring to the start of the grazing season (May 1) can be a useful guide in determining the most appropriate stocking rate although preseason precipitation is not a highly accurate predictor of range forage yields. The potential benefits from developing more accurate techniques for predicting precipitation, and from it range forage production, would be substantial.

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[26]The long-term loss is computed as follows: ($12.07)(.142) + ($10.43)(.142) + ($8.36)(.389) + ($9.87)(.323) = $19.02. If the state of nature could be predicted perfectly, the optimal stocking rate could be selected for each state. The limited number of alternative stocking rates considered in this analysis, however, results in an imperfect matching of stocking rate to forage production. Thus, a small loss would be incurred, under the conditions assumed in this analysis, even with perfect prediction.

APPENDIX

APPENDIX TABLE 1. RANGE FEED: CONDITION, NORTH DAKOTA, BY MONTHS, 1923-1970

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1923	88	83	88	87	84	88	86	85	84	86	85	84
1924	89	87	88	91	83	77	90	88	87	87	87	87
1925	88	84	77	87	89	84	96	87	80	87	84	87
1926	86	87	86	84	72	78	81	71	76	78	74	71
1927	70	87	64	69	75	88	92	96	94	90	90	87
1928	73	77	81	86	79	76	90	96	90	87	85	83
1929	84	77	76	80	82	84	89	72	69	75	78	78
1930	70	70	70	76	80	88	92	74	75	73	78	74
1931	75	79	79	75	74	66	62	60	72	72	74	70
1932	70	63	63	63	72	86	92	86	77	77	73	77
1933	76	70	68	72	76	87	73	73	66	66	65	66
1934	61	57	64	64	60	40	58	49	48	47	49	47
1935	49	46	48	48	56	72	88	90	87	84	82	77
1936	74	64	62	71	73	71	52	46	57	62	57	56
1937	56	51	52	53	58	66	78	77	71	68	69	67
1938	65	62	61	70	72	83	80	85	77	71	74	73
1939	74	75	69	75	74	75	87	79	75	75	77	80
1940	77	74	75	74	77	88	86	83	84	81	82	81
1941	82	74	74	80	82	90	95	89	87	91	90	86
1942	86	87	83	83	87	92	96	93	90	89	86	85
1943	82	74	74	77	81	84	94	91	88	86	84	83
1944	84	84	79	77	80	88	94	88	89	88	86	76
1945	77	73	75	82	77	80	89	89	86	86	84	80
1946	70	70	71	82	81	76	78	80	74	81	80	75
1947	74	74	74	76	74	83	95	91	87	85	87	74
1948	73	69	68	72	80	84	88	91	87	79	81	79
1949	74	61	60	69	77	84	82	81	77	73	75	77
1950	69	62	63	69	65	81	90	89	86	85	83	75
1951	72	66	71	74	77	82	87	81	86	86	83	78
1952	69	66	66	65	77	67	67	81	75	72	68	67
1953	70	72	72	72	71	86	96	91	83	81	80	77
1954	74	68	78	75	78	81	91	82	85	84	81	79
1955	79	74	71	73	79	81	90	86	81	79	77	65
1956	63	63	64	69	68	80	82	83	78	77	74	73
1957	75	68	72	74	78	86	90	84	84	83	82	79
1958	79	77	75	77	77	70	79	82	73	71	71	60
1959	63	65	66	70	65	74	80	69	66	67	68	64
1960	62	61	63	65	67	84	92	78	79	78	72	69
1961	66	64	66	69	68	76	56	63	59	72	70	64
1962	59	59	57	61	64	86	94	92	89	85	80	79
1963	75	72	76	75	80	86	89	84	80	77	73	72
1964	70	70	70	68	72	80	89	84	79	79	74	68
1965	62	60	63	66	70	86	92	90	84	83	80	73
1966	73	70	70	74	71	81	88	85	85	77	74	73
1967	72	67	67	71	70	82	82	67	65	69	69	68
1968	63	65	66	68	70	78	88	84	84	85	80	75
1969	66	60	58	69	77	80	79	88	76	72	72	71
1970	66	65	69	70	71	83	91	81	75	77	73	66
Median	73.00	69.50	70.00	72.50	75.50	81.50	88.50	84.00	80.00	79.00	78.00	75.00
Mean	71.70	69.40	69.80	72.80	74.40	79.60	84.90	81.40	78.90	78.40	77.10	74.10
Standard Deviation	11.18	8.97	8.54	8.19	7.05	9.10	10.60	10.84	9.43	8.44	8.07	8.28
Coefficient of Variation[a]	0.16	0.13	0.12	0.11	0.095	0.11	0.12	0.13	0.12	0.11	0.10	0.11

[a]Computed by dividing the standard deviation by the mean.

SOURCE: North Dakota Crop and Livestock Reporting Service, Statistical Reporting Service, USDA, Fargo, North Dakota.

APPENDIX TABLE 2. PRECIPITATION BY MONTHS AND ANNUAL, DICKINSON, NORTH DAKOTA, 1892-1969

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Annual
1969	0.66	0.36	0.25	0.72	1.32	6.13	4.40	0.52	0.31	0.86	T	0.84	16.37
1968	0.44	0.11	0.28	0.84	1.92	3.19	0.50	3.97	0.67	0.79	0.45	1.15	14.31
1967	0.51	0.48	0.27	3.87	2.79	1.63	0.72	0.41	2.48	0.61	0.15	0.32	14.24
1966	0.32	0.18	0.70	0.82	2.16	4.94	2.19	3.41	0.93	0.48	0.27	0.29	16.69
1965	0.41	0.24	0.21	3.41	6.07	4.25	3.08	1.64	1.63	T	0.41	0.28	21.63
1964	0.28	0.07	0.23	1.38	1.86	6.12	4.42	2.87	0.62	0.01	0.54	0.34	18.74
1963	0.37	0.46	1.79	3.79	3.69	4.24	1.86	1.04	1.35	0.20	T	0.15	18.94
1962	0.34	0.15	0.99	1.12	6.18	2.07	3.22	2.52	0.75	0.55	0.28	0.17	18.34
1961	0.05	0.59	0.50	1.89	1.44	2.82	1.66	1.68	3.05	0.11	T	0.11	13.90
1960	0.13	0.12	0.58	0.35	2.33	3.06	0.58	2.16	0.14	0.02	0.72	0.14	10.23
1959	0.24	0.84	0.11	0.16	1.94	3.08	0.97	0.54	4.54	0.33	0.52	0.18	13.45
1958	0.13	1.01	0.16	0.57	0.45	3.26	3.86	0.57	0.06	0.65	1.35	0.11	12.18
1957	0.41	0.21	0.32	2.59	2.10	6.61	3.46	1.49	1.98	1.94	0.88	0.16	22.15
1956	0.44	0.12	0.57	0.22	2.90	1.17	3.01	2.55	0.76	0.43	0.50	0.03	12.70
1955	0.29	0.70	0.15	1.91	2.45	4.70	1.08	0.81	1.53	0.18	0.72	0.13	14.65
1954	0.46	0.86	1.31	0.49	1.67	2.84	0.59	6.82	0.66	0.39	0.11	0.13	16.33
1953	0.17	0.27	1.28	3.50	3.47	3.99	2.48	1.78	0.22	1.93	0.07	0.23	19.39
1952	0.48	0.67	0.73	T	0.42	3.80	1.85	3.09	0.63	0.04	1.26	T	11.97
1951	0.45	0.90	0.15	0.63	1.58	2.68	2.39	3.05	1.73	2.39	0.21	0.54	16.70
1950	0.77	0.47	1.81	1.37	2.13	2.87	0.68	0.87	1.77	0.87	1.00	0.52	15.13
1949	1.23	0.61	0.61	0.14	1.33	1.21	2.84	0.42	0.42	1.75	0.01	0.20	10.77
1948	0.52	0.82	0.33	1.45	3.20	2.87	3.18	1.42	0.22	0.55	1.14	0.41	16.11
1947	0.33	0.12	0.78	1.70	0.73	8.48	2.15	2.58	0.68	0.61	0.45	0.25	18.86
1946	0.06	0.31	0.63	0.63	2.81	2.75	1.38	0.89	0.96	2.76	0.21	1.11	14.50
1945	0.28	0.24	2.33	1.57	1.20	2.83	1.36	0.63	1.09	0.11	0.31	0.27	12.22
1944	0.55	0.12	0.55	0.65	2.25	7.63	0.65	2.27	2.52	0.11	3.15	0.18	20.63
1943	1.13	0.22	0.77	1.20	1.30	5.05	3.27	2.68	0.19	1.56	0.36	0.05	17.75
1942	0.17	0.77	0.54	2.35	2.90	4.84	2.39	2.52	2.27	0.51	0.17	0.32	19.75
1941	0.18	0.27	0.40	2.05	5.34	10.08	3.73	1.58	5.80	1.20	0.32	0.21	31.16
1940	0.04	0.49	0.71	5.02	1.01	1.53	3.12	0.37	1.86	2.25	0.49	0.23	17.12
1939	0.38	0.58	0.46	1.44	3.22	4.46	1.93	2.49	0.11	0.47	0.01	0.21	15.75
1938	0.99	0.60	0.40	0.62	2.97	4.70	3.12	0.82	0.10	0.74	1.41	0.18	16.65
1937	0.41	0.39	0.61	0.84	1.61	6.32	2.74	1.04	1.00	0.37	0.53	0.42	16.28
1936	0.55	0.42	0.59	0.21	0.61	0.92	0.29	1.23	0.23	0.39	0.49	0.79	6.72
1935	0.39	0.19	1.16	2.29	2.77	2.14	2.93	1.83	0.07	0.01	0.77	0.45	15.00
1934	0.20	0.05	0.69	0.70	0.18	3.88	0.75	0.46	0.53	0.11	0.14	0.22	7.91
1933	0.83	0.35	0.24	0.86	2.56	1.26	2.63	0.72	0.49	0.55	0.60	0.41	11.50
1932	0.90	0.23	0.61	1.95	1.63	5.16	1.02	2.68	0.21	2.12	0.45	0.28	17.24
1931	0.22	0.61	1.08	0.11	1.21	3.46	2.80	2.05	3.02	0.86	0.38	0.37	16.17
1930	0.64	1.29	0.05	1.86	1.23	4.31	0.08	0.55	1.52	1.44	0.45	0.37	13.79
1929	1.82	0.39	2.12	0.60	3.48	2.89	0.54	0.09	1.67	1.40	0.63	1.58	17.21
1928	0.45	0.27	0.37	1.15	1.22	3.39	3.52	3.38	0.50	0.58	0.08	0.39	15.30
1927	0.49	0.16	0.37	2.10	5.67	2.12	2.93	1.29	1.48	0.59	1.09	1.33	19.62
1926	0.45	0.38	0.28	0.46	2.90	1.92	1.16	1.56	1.48	1.00	0.77	0.75	13.11
1925	0.50	0.17	0.35	1.26	0.89	4.31	1.29	1.30	0.46	0.98	0.13	0.55	12.19
1924	0.03	0.19	1.11	1.03	1.12	3.26	2.69	0.77	0.66	3.37	0.12	0.78	15.13
1923	0.30	0.20	0.37	1.55	1.46	4.49	4.67	0.82	4.20	1.12	0.31	0.18	19.67
1922	0.22	1.09	0.37	1.21	1.97	6.57	1.92	0.69	1.28	0.58	1.72	0.58	18.20
1921	0.23	0.35	1.01	1.02	1.78	3.09	1.61	2.73	2.15	0.13	1.05	0.61	15.76
1920	0.79	0.05	0.18	0.89	1.39	4.32	2.76	2.35	1.77	1.11	0.10	0.10	15.81
1919	0.01	0.67	0.51	1.28	2.49	0.52	0.53	0.59	0.70	0.58	0.34	0.16	8.37
1918	0.39	0.25	0.31	2.11	1.67	1.61	1.73	2.99	0.48	0.42	0.10	0.30	12.36
1917	0.60	0.23	0.48	1.18	0.36	2.54	1.40	1.43	0.20	0.22	0.10	0.61	9.25
1916	0.80	0.32	1.19	2.71	2.19	3.77	2.46	1.77	0.73	1.10	0.38	0.98	18.40
1915	0.07	0.15	0.21	0.61	3.67	5.50	3.71	0.45	2.23	1.78	1.15	0.22	19.75

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APPENDIX TABLE 3. FORAGE YIELDS FROM SELECTED RANGE SITES, DICKINSON EXPERIMENT STATION, 1946-1957

Year	Forage Yield, Lbs. Per Acre				
	Upland Type	Upland Draw	Lower Draw	Bench Type	Crested Wheatgrass
1957	1,020	2,129	4,831	951	1,353
1956	392	416	773	208	565
1955	903	1,459	2,407	562	801
1954	929	1,157	3,060	637	1,808
1953	1,768	3,009	3,144	1,587	2,383
1952	593	948	1,701	470	657
1951	512	869	597	310	989
1950	710	915	1,226	742	1,262
1949	434	869	941	315	613
1948	776	1,210	1,385	667	1,222
1947	1,432	2,394	2,972	1,039	1,945
1946	924	1,313	1,455	658	937
Average	866	1,391	2,041	679	1,211

SOURCE: Dickinson Experiment Station, 1957 Annual Report, Table 15.

APPENDIX TABLE 4. FORAGE YIELDS FROM SELECTED RANGE SITES, DICKINSON EXPERIMENT STATION, 1964-1969

Year	Forage Yield, Lbs. Per Acre					
	Vebar 0# N	Vebar 33# N	Vebar 67# N	Vebar 100# N	Havre 33# N	Farwell 33# N
1969	1,373	1,701	2,298	2,404	3,157	1,654
1968	975	1,060	1,493	1,315	2,300	1,599
1967	839	1,040	1,442	1,409	2,625	1,491
1966	1,296	1,654	2,413	2,387	2,132	1,806
1965	2,224	2,791	3,720	4,110	3,452	2,036
1964	1,283	1,748	2,375	2,361	2,265	1,873
Average	1,332	1,666	2,290	2,331	2,655	1,743

SOURCE: Dickinson Experiment Station, 1969 Annual Report, Table 4.

APPENDIX TABLE 5. DEVELOPMENT OF A POSTERIORI PROBABILITIES OF TOTAL PRECIPITATION BASED ON OBSERVED PRECIPITATION, MAY 1

Total Precipitation (θ)	Conditional Probabilities $P(Z/\theta)$ — Observed Precipitation, May 1: 0-2.99"	3-3.99"	4-4.99"	5" and Over	A Priori Probabilities $P(\theta)$
0 - 11.99"	.545	.272	.181	.000	.142
12 - 13.99"	.181	.363	.272	.181	.142
14 - 16.99"	.133	.233	.200	.433	.399
17" and Over	.120	.040	.160	.680	.323

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APPENDIX TABLE 5. DEVELOPMENT OF A POSTERIORI PROBABILITIES OF TOTAL PRECIPITATION BASED ON OBSERVED PRECIPITATION, MAY 1 (CONTINUED)

Total Precipitation (θ)	Joint Probabilities $P(\theta)\ P(Z/\theta)$ — Observed Precipitation, May 1: 0-2.99"	3-3.99"	4-4.99"	5" and Over	A Posteriori Probabilities $P(\theta/Z) = \frac{P(\theta)\ P(Z/\theta)}{P(Z)}$ — Observed Precipitation, May 1: 0-2.99"	3-3.99"	4-4.99"	5" and Over
0 - 11.99"	.078	.038	.026	.000	.402	.200	.133	.000
12 - 13.99"	.026	.051	.038	.026	.134	.262	.200	.063
14 - 16.99"	.051	.089	.078	.167	.263	.456	.400	.403
17" and Over	.039	.013	.052	.220	.201	.067	.267	.531
P(Z)	.194	.195	.195	.414				