Ranch Profitability Given Increased Precipitation Variability and Flexible Stocking

By Christopher T. Bastian, John P. Ritten, and Justin D. Derner

ABSTRACT

Forage and cattle performance relationships with spring precipitation, combined with cattle price variability, were incorporated into a ranch level model to determine if addition of a yearling enterprise to the base cow-calf herd would improve profitability given a 25 percent increase in variability and 50 percent increase in variability over observed (1975-2009) spring precipitation. Our results indicate profitability can be improved by nearly 35 percent through addition of a yearling enterprise to a base cow-calf herd, at the two levels of increased variability in spring precipitation. This adaptive strategy can also stabilize cow numbers across years, thus enhancing long-term sustainability of herd genetics.

Christopher T. Bastian is a Professor with the Dept. Agricultural and Applied Economics at the University of Wyoming. John P. Ritten is Associate Professor with the Dept. Agricultural and Applied Economics at the University of Wyoming. Justin D. Derner is Research Leader and Rangeland Scientist with the High Plains Grasslands Research Station, United States Department of Agriculture, Agricultural Research Service in Cheyenne, Wyoming.

Acknowledgements: This research was funded by a University of Wyoming Agricultural Experiment Station Competitive grant, USDA NIFA award 4120-15634-12MSGAEJR-2012. Opinions expressed herein are those of the authors and not the funding organization (USDA). The authors declare that they have no relevant or material financial interests that relate to the research described in this paper.

Introduction

Ranching is a dynamic business in which short-term (annual) profitability is highly variable as it is impacted by: 1) changing weather and climatic conditions which influence annual variation in forage production; and 2) cyclical market prices. These independent, yet often interacting conditions provide substantial challenges for ranchers trying to make sound decisions for their business. For example, when forage supplies are reduced should herd numbers be reduced, and if so, by how much, and what are the economic ramifications given the current market prices? When forage supplies rebound, should more replacement heifers be retained or breeding livestock purchased (Bastian et al., 2009; Torell et al., 2010)? Collectively, the suite of herd liquidation and restocking decisions during and after drought events can greatly impact the economic viability of cow-calf ranches (Thomas et al., 2015). Projected increasing variability in seasonal precipitation is likely to result in increased frequency and severity of droughts. Such events will likely lead to greater occurrences of herd reductions to match animal demand with forage availability and most often selling at low prices due to greater numbers of animals being sold, negatively impacting the profitability and financial health of cow-calf operations (Ritten et al., 2010a; Ritten et al., 2010b). Therefore, livestock producers need alternative strategies that can help them reduce risks and increase economic returns despite weather and climatic variability coupled with dynamic market prices.

Adaptive management strategies for drought (e.g., Derner & Augustine, 2016) can aid ranchers applying science-informed decision-making when facing both variable precipitation and variable market prices. Although ranchers have a number of strategies in their toolbox to address forage shortages associated with drought (Karchergis et al 2014), the most common strategies are partial herd liquidation and the purchase of additional feed (Bastian et al., 2006). When these strategies are analyzed in ranch-level models coupled with price cycle dynamics, partial herd liquidation has the lowest risk when cattle prices are falling, whereas purchasing feed is profitable when cattle prices are rising (Bastian et al., 2009). Long-term analyses (time horizons of 35 years) indicate that purchasing feed during drought periods can improve long-term profits because added calf sales overcome incurred feed costs compared to herd liquidation and associated costly time lags to rebuild the herd (Ritten et al., 2010c). Ranchers that add a yearling enterprise to the cow-calf enterprise can improve long-term profitability in extended drought events (Ritten et al., 2010b). Although light (conservative) stocking rates can improve individual calf performance and profits under variable forage production from droughts due to less destocking during drought events (Thomas et al., 2015), incorporating a yearling enterprise while reducing the base cow herd number provides more flexibility to match animal demand with forage availability resulting in higher profitability than light stocking rates (Torell et al., 2010). Reductions in profits for cow-calf only operations during dry/drought years due to low forage production and reduced calf gains are not compensated by positive returns during wet years (Hamilton et al., 2016). Thus ranchers need to consider alternative enterprises to mitigate risk associated with precipitation variability.

The strategy of flexible stocking from adding a yearling enterprise to cow-calf operations offers additional opportunities for ranchers in highly variable precipitation environments (Ritten et al., 2010b; Torell et al., 2010). However, the question remains as to whether this added flexibility can overcome both the negative impacts on forage production and cattle performance from increased variability in precipitation. Here, we utilize existing forage production and cattle performance relationships associated with spring precipitation (Derner & Hart, 2007; Derner et al., 2008) in a ranch-level model which also incorporates market price variability and cycles to analyze whether adding a yearling enterprise to the base cow-calf operation can improve profitability and reduce risks under three levels of spring precipitation variability (historical precipitation, 25% variability increase, and 50% variability increase).

Methods

We develop a multi-period, linear programming model of a case ranch based on characteristics of operations found in southeastern Wyoming. This model incorporates relationships between spring precipitation, forage production, cattle performance, and price cycle dynamics to estimate long term profitability for the case ranch given different precipitation profiles (average spring precipitation, historical precipitation, 25% increase in precipitation variability, and 50% increase in precipitation variability). We utilize data related to precipitation, forage production, and cattle performance from research conducted at the US Department of Agriculture (USDA) – Agricultural Research Service (ARS), High Plains Grasslands Research Station (HPGRS) located in Laramie County in southeastern Wyoming. Given the relationships estimated from the USDA ARS data, we analyze the impact of adding a yearling enterprise to the base cow-calf ranch given the different precipitation profiles coupled with 100 iterations of different cattle price conditions for each profile. See the appendix at the end of the article titled "Model Specifics" for more technical details about model development, land characteristics of the ranch, estimated precipitation profiles, precipitation impacts on forage, precipitation impacts on cattle performance, and the incorporation of cattle price dynamics into the analysis.

We first estimate the model across the three precipitation profiles (historical, 25% increase, and 50% increase) and price observations (100 iterations of the Monte Carlo simulations for each 35 year precipitation profile) for the cow-calf only operation. Then, we estimate the model assuming the ranch can decide to retain calves for a yearling enterprise given the precipitation and price iterations previously described. To fully understand the impact of spring precipitation variability alone, we run these same operation types (cow-calf only versus cow-calf-yearling) assuming average precipitation for the study period occurs every year, i.e., no variability in precipitation as every year the ranch is assumed to receive average precipitation in the spring, but allow prices to vary in the same way as before. We analyze these data from the model runs (average precipitation, historical precipitation, 25% increase, and 50% increase) to achieve our research objective.

Results

Model results reveal that profitability for the case ranch with cow-calf herd only is 45 percent less with historical precipitation than if the ranch received average precipitation each year (Figure 3). What causes this? Destocking during dry years, when prices are unfavorable, coupled with the production lag associated with rebuilding the cow herd through greater heifer numbers retention, has a very negative impact on ranch profitability. Dry years hurt profitably by liquidating breeding stock (or purchasing additional feed), and the ranch can lose out on sales in subsequent years as it tries to build herd numbers through retaining more heifer calves rather than selling them. Ranches also can lose out in wet years due to the inability to rapidly increase cow numbers to take advantage of additional forage production.

If steer calves are retained as a separate yearling enterprise to provide flexibility in stocking for the operation, then ranch-level profitability is increased. Added flexibility from utilizing yearlings to match animal demand with forage availability improves long-term profitability by over 23 percent, compared to the case ranch with cow-calf herd only. Even though profitability is improved long-term, it is important to note that not every year is profitable, regardless of strategy. For example, cattle price cycles independently without the influence of weather and climatic variability caused roughly eight percent of years to be unprofitable for the cow-calf operation. Addition of the variability in historical precipitation compared to just using average spring precipitation nearly doubles the probability of negative profits to 15.7 percent for the cow-calf operation, and the percentage is only slightly less for the cow-calf plus yearling operation at 13.7 percent (Table 1). This suggests the variability in spring precipitation compounds the price variability impacts on ranch-level profit variability.

The impact on profitability associated with flexible stocking from the yearling enterprise becomes even more pronounced with increasing variability in spring precipitation. For example, increasing spring precipitation variability by 25 percent results in decreasing cow-calf only profits by an additional 19 percent compared to historical precipitation variation (Table 2), but the addition of a yearling operation to the cow-calf ranch in this precipitation profile increases long-term profitability by 35 percent compared to cow-calf only operations. This percentage increase in profitability for the cow-calf plus yearling operation compared to cow-calf alone is consistent for the 50 percent increase in spring precipitation variability as well, even though net present value of profits drops by an additional 4 percent when the variability doubles.

Matching animal demand to forage availability with the flexible stocking offered by adding a yearling enterprise to the cow-calf herd operation is the primary reason for increased profitability compared to traditional cow-calf operations only. For example, optimal cowherd numbers (represented by Animal Unit Years in Figure 4) decrease by 50 percent when historical spring season precipitation is used in the model over the 35 years compared to the scenario using the average spring precipitation value across all years (Figure 4). This decrease in optimal cow numbers occurs as replacement only occurs from within the herd through retaining replacement heifers, and cow numbers rarely have time to fully recover to pre-drought numbers before liquidation begins again in response to the next drought or extended dry period. Using yearlings as a "flex" strategy provides more timely responses to effectively match forage availability with animal demand. Yearlings can be moved to feedlots or other geographic areas, or sold during dry periods, with the base cow herd still producing a stable number of calves for sale or retainment of heifers for replacement. Therefore, the addition of a yearling enterprise to the cow-calf only operation will result in a smaller base herd of cows compared to the cow-calf only operation, but this cowherd is more stable over time thereby lessening impacts of liquidating valuable individual herd genetics. This stability in breeding livestock, coupled with the flexibility to increase or decrease numbers of yearlings more quickly than calf numbers, results in a 23 percent increase in total animal units supported by the ranch compared to the cow-calf only operation facing historical variability in spring precipitation (Figure 4).

It is interesting to note, that while profitability is increased with adding a yearling enterprise to a cow-calf only operation with more variable spring precipitation, our results do not suggest a decrease in profit variability (Table 2). Standard deviations are higher for the cow-calf plus yearling operation compared to the cow-calf only operation across all three precipitation profiles, although standard deviations are relative to the mean, and the means are substantially higher for the cow-calf plus yearling operations. Coefficients of variation indicate slightly less variability for the cow-calf-yearling operation compared to the cow-calf operation for the historical precipitation profile (0.093 versus 0.117), but this relationship is reversed, i.e., higher variability for the cow-calf-yearling operation, for the 25 percent and 50 percent increase profiles. These results do not demonstrate reductions in risk for ranchers, as measured by profit variability, for the cow-calf plus yearling operation compared to the cow-calf only operation when influenced by increased spring precipitation variability.

Conclusions

We utilize existing forage and cattle performance relationships associated with spring precipitation in a ranch-level model combined with incorporation of cattle market price variability. Our analysis of adding a yearling enterprise to a cow-calf only ranch operation suggests that profitability can be improved by nearly 35 percent with increased levels of spring precipitation variability (25% and 50% increase in standard deviation). Adding yearlings enables more effective matching of forage availability to animal demand which provides opportunities to utilize "extra" forage produced in above-average years while minimizing overutilization in below-average years. The second benefit of including yearlings into a cow-calf only operation is that the ranch has a more stable, albeit smaller, number of base cows. This benefits ranchers by not having to liquidate valuable individual herd genetics in dry/drought years.

Understanding the variable nature of both cattle market prices and forage production is important for ranchers regarding science-informed decision-making for long-term economic sustainability. Increasing long-term profitability through adding yearlings to the traditional cow-calf only ranch enterprise is achieved through more effectively matching available forage with animal demand as the yearlings provide flexibility on the demand side. It is important to note that although profitability over the long-term is markedly enhanced with adding yearlings to a cow-calf operation, risk to the rancher is not reduced as profit variability among years remains similar and the likelihood of negative returns in any given year is only slightly lower. In addition to greater profitability potential over the long-term, adding yearlings to a cow-calf only operation results in the base cow herd being smaller, but more stable with time thereby enhancing long-term sustainability of individual herd genetics.

Endnotes

1. Bastian et al. (2005) indicate that while variations across counties do exist, this region is relatively homogeneous in terms of livestock production, average productivity of range resources, and average ranch carrying capacity. Average carrying capacity of ranches sold (n=147) in

these counties for this region ranged between 159 and 162 Animal Units during their study period of 2002-2004 while our case ranch has range forage production to carry about 150 AU not including hay production (Bastian et al,. 2005). While the average operations across the counties are similar, as expected, heterogeneity does exist. For example, operations ranged from 1 to 19 head per operation for 2012 to operations with over 500 head in the counties for the study area for our analysis (NASS 2012). However, given the objective of the study, we model our case ranch based on average characteristics for the region of interest which results in an operation that has a relatively representative carrying capacity.

2. Costs per ton of alfalfa hay produced, using Hewlett and Bastian (1992) ($127/ton), are similar to costs per ton estimated for Nebraska for 2014 ($126/ton) (Klein et al., 2014a; Klein et al., 2014b).

References

Bastian, C. T., P. Ponnamaneni, S. Mooney, J. P. Ritten, W. M. Frasier, S. I. Paisley, M. A. Smith, and W. J. Umberger. 2009. "Range Livestock Strategies Given Extended Drought and Different Price Cycles," *Journal of the American Society of Farm Managers and Rural Appraisers* 72: 153-163.

Bastian, C. T., S. Mooney, A. M. Nagler, J. P. Hewlett, S. I. Paisley, M. A. Smith, W. M. Frasier, and W. J. Umberger. 2006. "Cattle Ranchers Diverse in Their Drought Management Strategies," *Western Economics Forum* 5,2: 1-8.

Bastian, C. T., Freeburn, S. L., Hewlett, J. P., 2005. Wyoming farm, ranch & rural land market: 2002-2004. Agr. Exp. Sta. Bull. B-1168. University of Wyoming.

BLM (Bureau of Land Management). 2014. "Wyoming Surface and Mineral Status." http:www.blm.gov/wy/st/en/resources/public_room/gis/datagis/state/state-own.html

Derner J. D. and D. J. Augustine. 2016. "Adaptive Management for Drought on Rangelands." *Rangelands* 38: 211-215.

Derner, J. D., R. H. Hart, M. A. Smith, and J. W. Waggoner. 2008. "Long-term Cattle Gain Responses to Stocking Rates and Grazing Systems in Northern Mixed-grass Prairie," *Livestock Science* 117: 60 - 69.

Derner, J. D., and R. H. Hart. 2007. "Grazing-induced Modifications to Peak Standing Forage Crop in Northern Mixed-grass Prairie," *Rangeland Ecology and Management* 60: 270 -276.

Eisele, K.L., J P. Ritten, C.T. Bastian, and S.I. Paisley. 2011. "Enterprise Budget for Beef Cattle: Cow-Calf Production; 200 Head, Southeastern Wyoming." Extension Bulletin. B-1217. University of Wyoming.

Gray, S.T., C. Fastie, S. T. Jackson, and J. L. Betancourt. 2004. Tree-ring Based Reconstructions of Precipitation in the Bighorn Basin, Wyoming since A.D. 1260. *Journal of Climate*, 17:3855-3865.

Hamilton, T. W., J. P. Ritten, C. T. Bastian, J. D. Derner, and J. A. Tanaka. 2016. "Economic Impacts of Increasing Seasonal Precipitation Variation on Southeast Wyoming Cow-Calf Enterprises," *Rangeland Ecology and Management* 69: 465-473.

Hewlett, J.P., and C. Bastian. 1992a. "Crop Enterprise Budget: Alfalfa Baled, Wheatland Area." Cooperative Extension Service. MP-72.1. University of Wyoming.

Hewlett, J.P., and C. Bastian. 1992b. "Crop Enterprise Budget: Alfalfa Establishment, Wheatland Area." Cooperative Extension Service. MP-72. University of Wyoming.

Kachergis, E., J. D. Derner, B. B. Cutts, L. M. Roche, V. T. Eviner, M. N. Lubell, and K. W. Tate. 2014. "Increasing Flexibility in Rangeland Management During Drought." *Ecosphere* 5: 1-14

Klein, R.N., R.K. Wilson, and J. Johnson. 2014. "2014 Budget 38. Grass Hay, Large Round Dryland." Crop Budgets, Nebraska. Lincoln, NE: U.S. Lincoln Extension, Institute of Agriculture & Natural Resources, Department of Agriculture-Agriculture Research Service.

Klein, R.N., R.K. Wilson, and J. Johnson. 2014a. "2014 Budget 6. Alfalfa, Established Spring Seed, Pivot Irrigated." Crop Budgets, Nebraska. Lincoln, NE: U.S. Lincoln Extension, Institute of Agriculture & Natural Resources, Department of Agriculture-Agriculture Research Service.

Klein, R.N., R.K. Wilson, and J. Johnson. 2014b. "2014 Budget 10. Alfalfa, Large and Small Square, Pivot Irrigated." Crop Budgets, Nebraska. Lincoln, NE: U.S. Lincoln Extension, Institute of Agriculture & Natural Resources, Department of Agriculture-Agriculture Research Service.

NASS (National Agricultural Statistics Service). "Wyoming 2012 Agricultural Statistics." U. S. Department of Agriculture, U. S. Government Printing Office, Washington, D.C.

Ritten, J. P., W. M. Frasier, C. T. Bastian, and S. T. Gray. 2010a. "Optimal Rangeland Stocking Decisions Under Stochastic and Climate Impacted Weather," American Journal of Agricultural Economics 92: 1242-1255.

Ritten, J. P., C. T. Bastian, S. I. Paisley, and M. A. Smith. 2010b. "Long Term Comparison of Alternative Range Livestock Management Strategies Across Extended Droughts and Cyclical Prices," *Journal of the American Society of Farm Managers and Rural Appraisers* 73: 243-252.

Ritten, J. P., W. M. Frasier, C. T. Bastian, S. I. Paisley, M. A. Smith, and S. Mooney. 2010c. "A Multi-period Analysis of Two Common Livestock Management Strategies Given Fluctuating Precipitation and Variable Prices," *Journal of Agricultural and Applied Economics* 42: 177-191.

Rosenthal, R.E. 2008. *GAMS: A User's Guide*. Redwood City, CA. The Scientific Press.

Strauch, B. A. Profitability and Business Risk of Fall Versus Spring Calving in Wyoming. (MS Thesis, University of Wyoming, 2008).

Thomas, M. G., A. H. Mohamed, M. N. Sawalhah, J. L. Holecheck, D. W. Bailey, J. M. Hawkes, P. Luna-Nevarez, F. Molinar, and G. Khumalo. 2015. "Long-term Forage and Cow-calf Performance and Economic Considerations of Two Stocking Levels on Chihuahuan Desert Rangeland," *Rangeland Ecology and Management* 68: 158-165.

Torell, L. A., N. R. Rimbey, O. A. Ramirez. 2010. "Economics of Flexible Versus Conservative Stocking Strategies to Manage Climate Variability Risk," *Rangeland Ecology and Management* 63: 415-425.

Torell, L.A., N.R. Rimbey, and J.A. Tanaka. 2013. "Ranch-Level Economic Impacts of Altering Grazing Policies on Federal Land to Protect the Greater Sage-Grouse." *Journal of Rangeland Applications*. 1: 1-13.

Volesky, J. D., D. C. Adams, and R. T. Clark. 2002. "Windrow Grazing and Baled-hay Feeding Strategies for Wintering Calves," *Journal of Range Management* 55: 23-32.

Figure 1. Conceptualizaion of Multi-period Linear Programming Model (Torell et al., 2013)

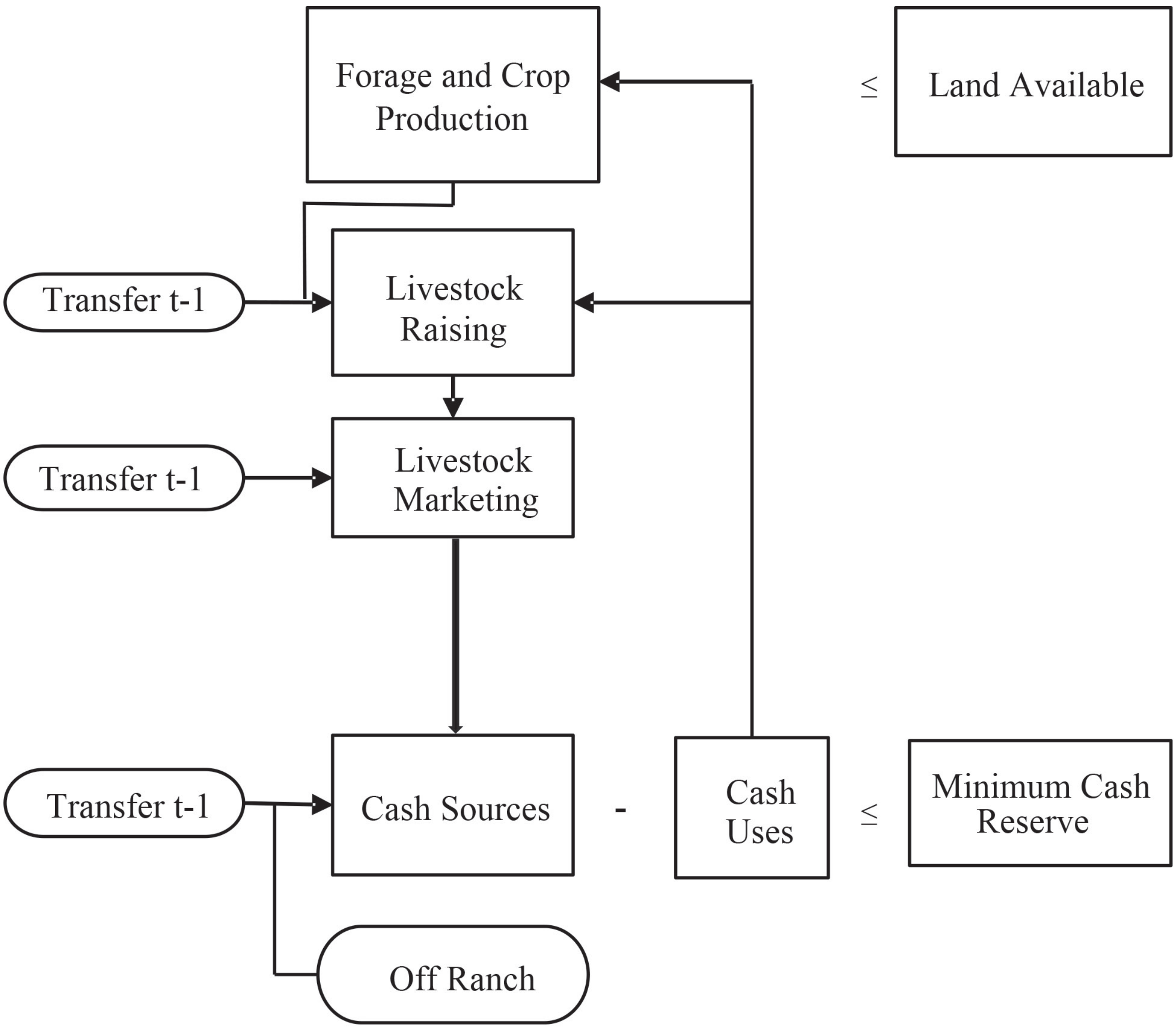

Figure 2. Precipitation Data Profiles Used in Analysis

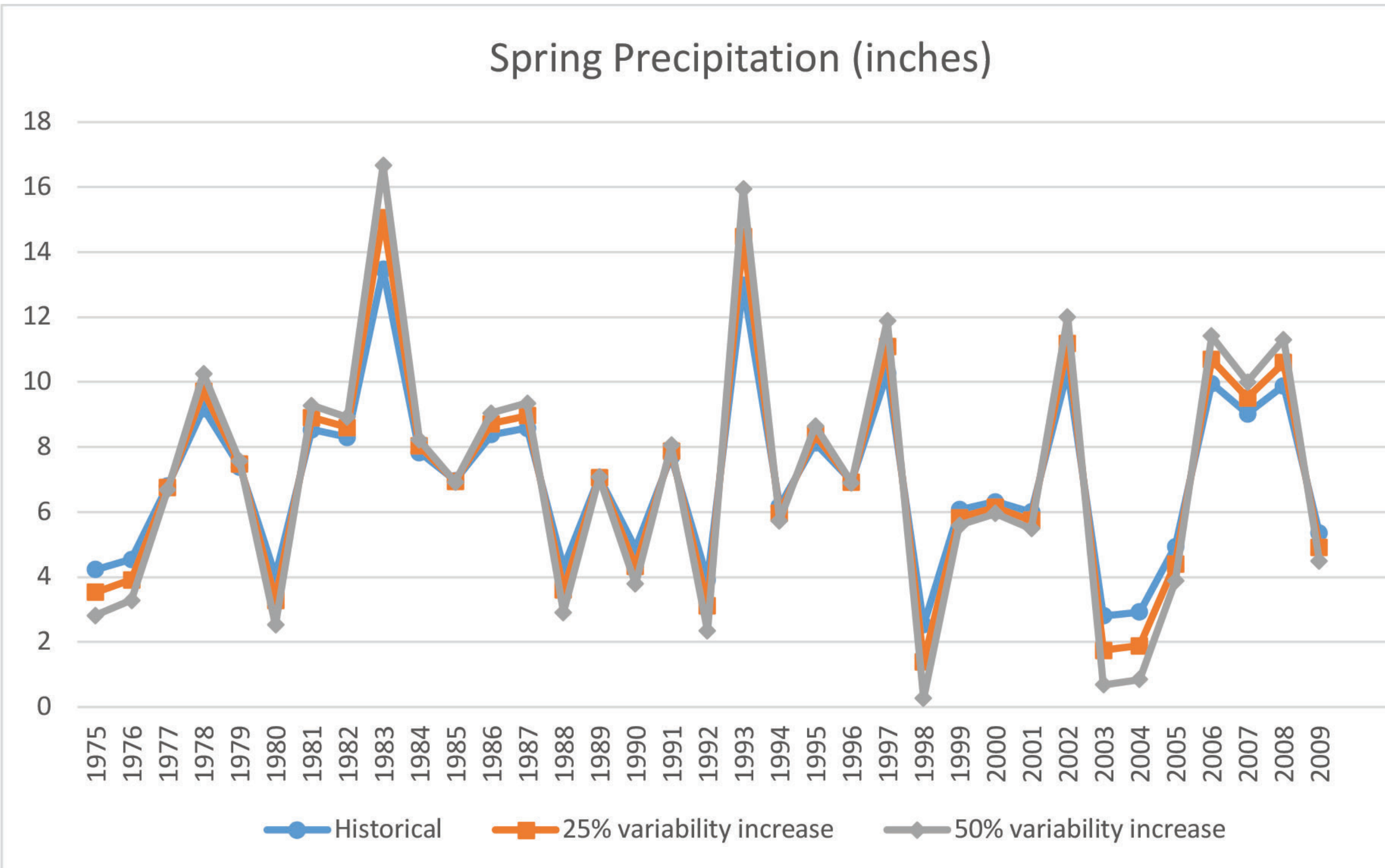

Figure 3. Distribution of Net Present Value from Ranching Operations over a 35-Year Horizon across 100 Price Scenario Iterations

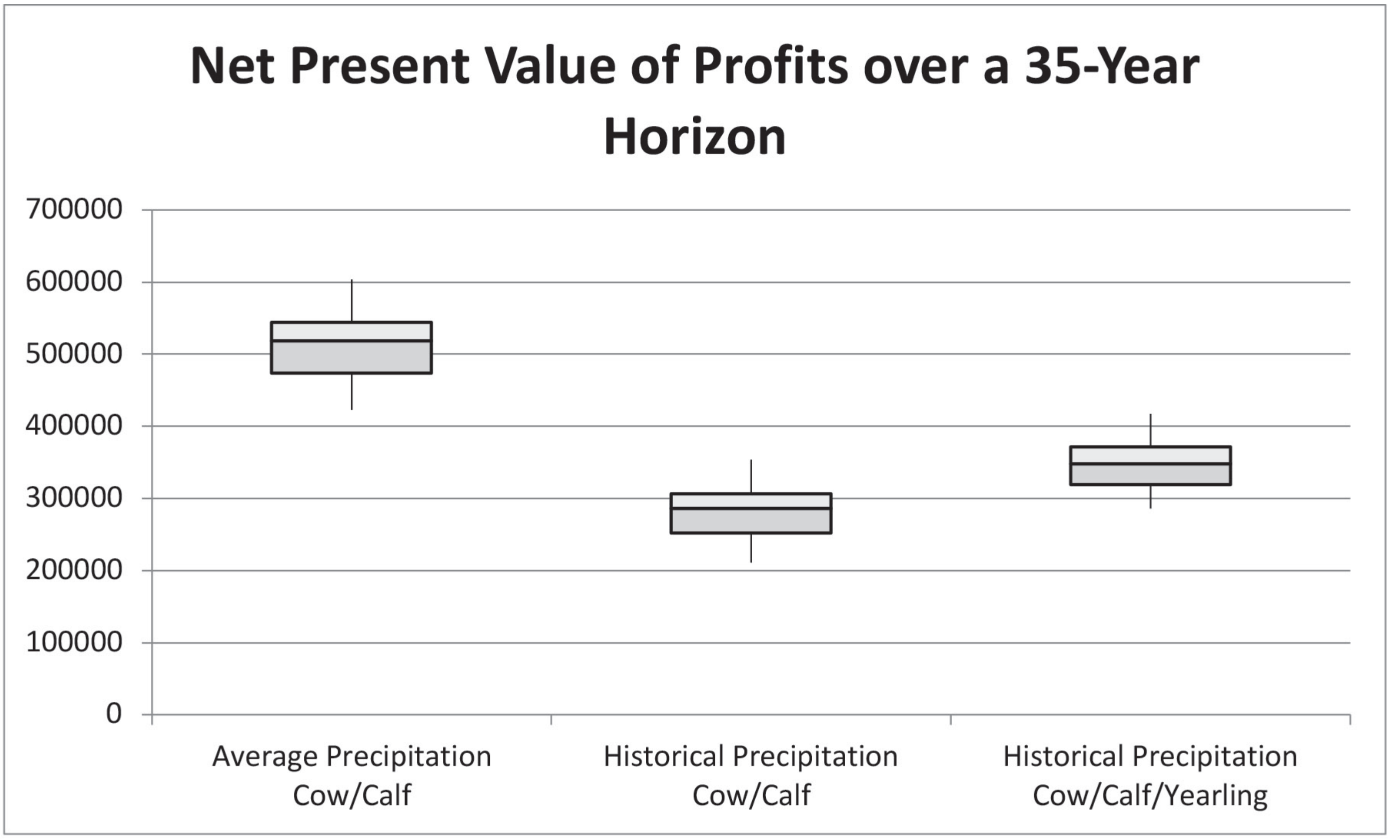

Figure 4. Distribution of Animal Unit Years (AUYs) from Ranching Operations over a 35-Year Horizon across 100 Price Scenario Iterations

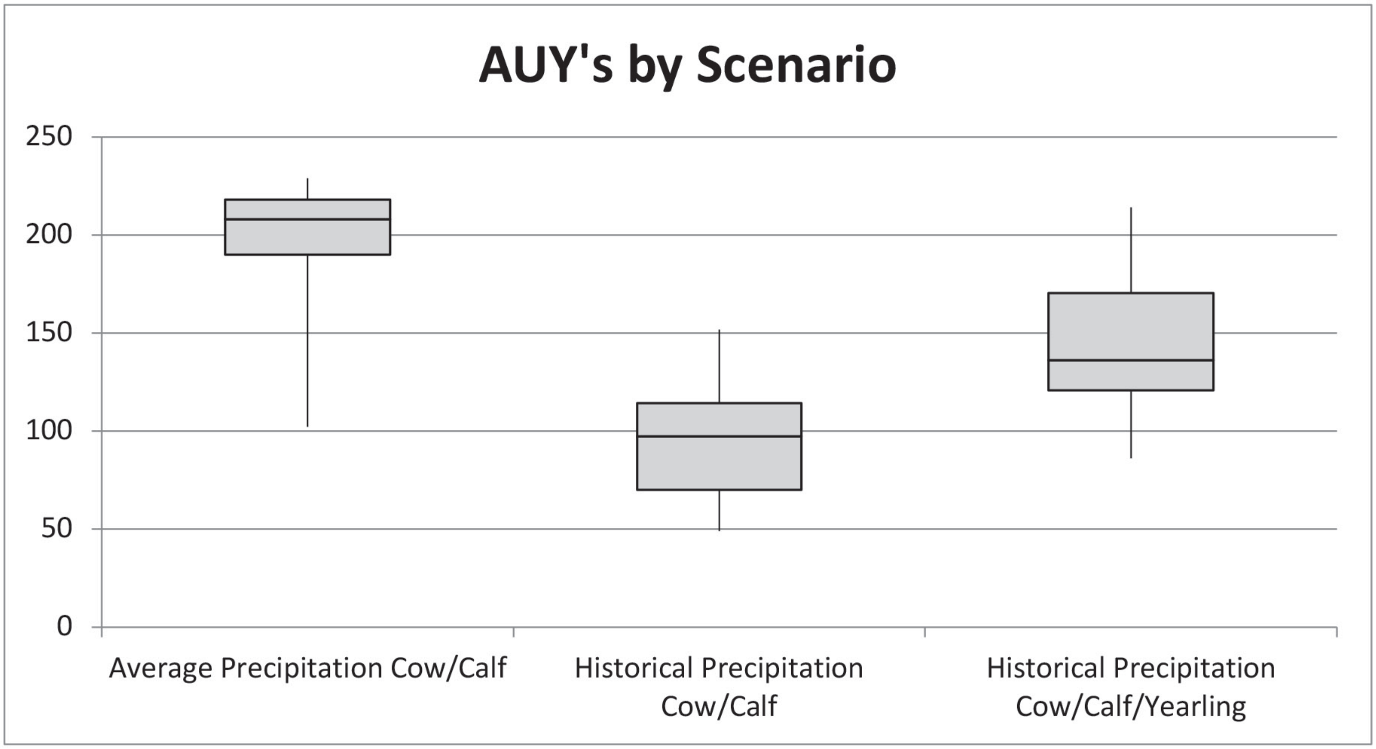

Table 1. Probability of Annual Returns Less than $0

Average Precip. Cow/Calf	Historical Precip. Cow/Calf	Historical Precip. Cow/Calf/Yearling
8.8%	15.7%	13.7%

Table 2. Estimated Net Present Values Across Precipitation Profiles by Operation Type

Net Present Values	Avg. Precip. Cw-Clf	Hist. Precip. Cw-Clf	Hist. Precip. Cw-Clf-Yr.	25% Inc. Cw-Clf	25% Inc. Cw-Clf-Yr	50% Inc. Cw-Clf	50% Inc. Cw-Clf-Yr
Average	$511,866	$281,535	$347,006	$229,418	$310,055	$219,459	$296,510
Std. Dev.	$43,832	$33,050	$32,247	$5,918	$22,415	$5,800	$21,795
Coeff. Of Variation	0.086	0.117	0.093	0.026	0.072	0.026	0.074

Appendix: Model Specifics

Ranch Characteristics, Production Costs, and Prices

Land resources for the case ranch are based on data from a six-county region (Albany, Converse, Goshen, Laramie, Niobrara, and Platte Counties). The total number of acres for each land type by county (BLM, 2014), coupled with the total number of operators in each county according to Wyoming 2012 Agricultural Statistics, were utilized to simulate average land resources for an operation in the region of interest (NASS, 2012). Non-private lands included in the representative ranch include state-owned, and federal lands of the Bureau of Land Management (BLM) and United States Forest Service (USFS). The operation consists of 2,827 acres of deeded rangeland, 308 acres of state land, 205 acres of BLM, 139 acres of USFS, and 205 acres of privately leased pasture. The number of animal unit months (AUMs) available for grazing are 1,385 AUMs from deeded rangeland, 150 AUMs from state-owned land, 100 AUMs from BLM, 68 AUMs from USFS, and 100 AUMs from privately leased lands. The representative ranch also consists of 172 acres of irrigated alfalfa hay land and 225 acres of irrigated meadow hay land. These hayed lands also are assumed to offer the potential for grazing after harvest occurs and provide an additional 410 AUMs of grazing for the case ranch (Strauch 2008). While many operations in the region also have other enterprises such as crops from farming, we focus only on range livestock production and the ability to produce hay for winter feeding in the model to address our research objective.

We base our operation practices and related costs of production for the case ranch on data available from existing budgets and input prices relevant to the study area. Costs of production for meadow hay came from western Nebraska budgets close to the study region (Klein et al., 2014). Costs of production for irrigated alfalfa hay came from Hewlett and Bastian (1992 a,b) as these budgets were developed from producer interviews in the study area which were adjusted to 2012 dollars. Federal and state rangeland grazing costs came from Eisele et al. (2011) and Strauch (2008).[1] Cattle production costs including brood cow, cull cow, replacement heifer, salt/mineral, protein supplement, veterinary, labor, transportation and marketing came from Eisele et al. (2011). Yearling costs were updated from Ritten et al. 2010b. Fixed ranch expenses of $45,000 include facility maintenance, equipment maintenance, depreciation, insurance, taxes, and professional services (Eisele et al. 2011). All costs are deflated to 2012 dollars using the Producer Price Index.

Livestock price series used in analyses are calculated using a Monte Carlo simulation developed by Torell et al. (2013). This allowed us to incorporate the effects of price variability on ranch profitability and management strategies. Prices from the simulation were generated for 35 year time horizons across 100 iterations. This forced the model to be solved over a suite of cattle price levels representing a number of potential cattle cycle dynamics. Prices were normalized so that the mean real 2012 adjusted (deflated using PPI) price for each livestock class (weight and sex), during the appropriate month of sale, was equal to the 1980-2012 mean real price recorded by CattleFax (Torell et al. 2013).

Ranch level model

We incorporate the above data in a multi-period, linear programming model (see Figure 1) similar to that reported in previous research (see Bastian et al., 2009; Ritten et al., 2010 b,c; Torell et al., 2010). We altered the model to represent the case ranch using the land resources, representative costs, and prices described above. We solved the model using the MINOS solver in the Generalized Algebraic Modeling System (GAMS) software (Rosenthal, 2008).

The model maximizes the net present value of profits over a T year planning horizon (in our case we use a 35 year planning horizon for each suite of prices and spring precipitation scenarios which corresponds to available precipitation and production data from the USDA ARS HPGRS site used for this research). The objective function includes a terminal value that takes into account the value of cows after the 35 year planning horizon is completed. If the terminal value was not included, the model would sell all livestock the last year in order to maximize the objective function. This objective function is subject to constraints defining the ranch resources and transfers resources from one year to the next during the T year planning horizon (for example under livestock, heifers moving to cows). The decision variables under the rancher's control include number of animals (liquidation of animals versus restocking of animals) and amount and timing of forage use by land type and season.

Major constraints in the model include animal production limitations (including conception/weaning rates, required bull/cow ratios, inter-year transfers) and forage supply (total supply of forage in a year and seasonal use restrictions). The model forage constraints consist of six seasons determined by the ranch activities and land availability (for example federal land permits restrict use to appropriate seasons of use). Aftermath grazing of hay is not available until after harvesting the hay. Forage demand is flexible subject to land class availability. Seasonal forage availability cannot be exceeded by forage demand. Hay is fed when deemed economically feasible by the model but can only be fed November through April. Previous work by Ritten et al. (2010c) and Bastian et al. (2009) suggest providing hay in other seasons as a drought reaction strategy can create short-term financial issues for the ranch that may put it at greater risk of financial loss depending on the price conditions. Therefore, we limit hay feeding to the season that is common for the study area. Additionally, the operation is required to maintain a minimum cash reserve of $500, and the operation has the ability to save cash and transfer it from one year to the next as well as borrow operating funds if needed. All borrowing of short-term funds is required to be paid back during the following year, as is common with operating loans. As costs and prices are in real terms, all debt is also in 2012 dollars. We use a nine percent interest rate on short-term funds which is higher than the discount rate of seven percent (4% real rate plus a 3% risk premium) used to calculate NPV over the planning horizon. These rates are consistent with data from the study period and Hamilton et al. (2016).

Precipitation Variability and Production Relationships Used in the Model

We incorporate spring precipitation variability into the model based on research conducted at the USDA ARS HPGRS. Their research investigates the impact of spring precipitation on both forage productivity and also cattle performance. Derner and Hart (2007) reported on the relationship between spring precipitation and forage production, and the relationship between cattle performance (gain per animal for the grazing season) and spring precipitation was reported by Derner et al. (2008). Here, we update the relationships using their data plus more recent data. Peak standing forage for the case ranch is based on the following estimated (via regression) relationship ($R^2 = 0.44$), $Y_t = [3501.8*P_t/(304.2 + P_t)]$, where Y_t is peak standing crop in kilograms per hectare (Kg/ha) and P_t is the sum of April, May, and June precipitation in year t, reported in millimeters. We estimate the historical forage production for the ranch based on observed precipitation at the USDA HPGRS for the years 1975-2009 and convert it to pounds per acre. We assume a 35 percent utilization rate (based on data from the ARS) of total forage available which represents a light to moderate stocking rate for the area. The available forage for grazing in a given year then impacts the AUMs available for grazing per unit of land for each land type. This defines the model constraints for grazing on an annual basis. In this way the model incorporates forage production variability expected from spring precipitation variability.

Reliable forecasts for changes in spring precipitation specific to the study area are not available. So we model increased variability in precipitation based on observed precipitation (labeled as historical precipitation) from 1975-2009. Using this historical spring precipitation data for the study area, simulated increases in precipitation variation are estimated by keeping the mean precipitation constant but increasing the standard deviation around the mean by 25 percent and 50 percent, following the procedure used in Hamilton et al. (2016), resulting in three precipitation profiles: 1) historical spring precipitation, 25 percent increase in standard deviation of spring precipitation, and 50 percent increase in standard deviation of spring precipitation. These precipitation profiles, graphed in figure 2, are then used to estimate forage yields and incorporated into the model as previously explained. This variability is well within what has been observed for the area based on climatological studies using tree rings. Gray et al (2004) find annual precipitation has varied by more than one full standard deviation since 1260 A. D. in Wyoming.

Spring precipitation impacts on cattle productivity were analyzed based on USDA HPGRS data as well. The impacts of April through June precipitation on calf gains also were estimated via regression for the summer grazing season (approximately 125 days) following the prior work of Derner et al. (2008). As was the case with forage production a hyperbolic relationship is found. The estimated relationship is $G_t = [179* P_t /(11.56 + P_t)]$ ($R^2 = 0.65$). G_t is annual calf gains per head in kilograms, and P_t is again the sum of precipitation reported in millimeters observed at the study area in April, May, and June each year. Resulting weights are then converted to pounds. Weaning weights are impacted by calf gains and this is incorporated into the model via sales weight, which in turn affects revenues via livestock sales. The same precipitation data and two increased variation profiles were used to estimate calf gains and resulting sales weights.

Finally, we incorporate spring precipitation variability on weight gains for retained calves used in the yearling enterprise. Unfortunately, calves were not retained in the studies used for this analysis at the USDA. Rather, lighter weight animals were purchased and then grazed to heavier weights. Specifically, assumptions were made about winter gains for the retained calves in our analysis, and then we utilized the available yearling data from the USDA to estimate gains during the summer given observed precipitation. We added winter gains based on Volesky et al. (2002) who found an average of 0.315 kg gain/day over a 182 day winter feeding period, and added that to the prior year's ending calf weights. Yearling gains, as a function of growing season precipition, were then added to these weights to get final yearling sale weights.

We account for marginal changes in prices as weights change within a weight category in the Monte Carlo price simulation described previously. A price slide regression was used to adjust prices according to the differences in weights as dictated by spring precipitation in a given year. The regression was estimated by Ritten et al. (2010a) and calculates price as a function of weight and corn prices (mean deflated corn prices in 2012 dollars is used to remove impact from varying corn prices). The price slide adjusted prices from the Monte Carlo simulation for the differing livestock categories. Lighter animals received a higher price per cwt and heavier animals received lower prices per cwt. The impact of differences in sale weights from precipitation may also be impacted by a slide in the price per cwt as well. In this way, gross revenues in the model account for both altered sale weights and related price effects.