The Impact of Grazing Management System on Producer Wealth in Alberta

by

Kyle Douglas Wheeler

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Agricultural and Resource Economics

Department of Resource Economics and Environmental Sociology

University of Alberta

Abstract

This project sought to determine the effect of grazing management decisions on operation wealth; specifically, to determine both the wealth maximizing system for producers and to determine the impact on producers who adopt more intensive management systems. Adoption of four grazing management treatments, corresponding to one, eight, 50, and 115 paddocks, were modelled for representative cow-calf operations in three locations, the Boreal Transition (Lac Ste. Anne County), Aspen Parkland (Ponoka County) and Mixed Grassland/Prairie (Newell County) of Alberta, Canada. In all locations and for all treatments, a cow calf exclusive operation with a 700 head initial herd and a mixed cow calf-cropping operation with a 150 head initial herd were modeled.

The study used expected wealth maximization to compare systems. Net Present Value (NPV) was used as a proxy for wealth. NPV was calculated over a 20-year horizon, using values generated by Monte Carlo simulation. Both production risk (i.e., pasture productivity) and market risk (i.e., beef prices and purchased feed prices) were modeled in the simulation.

Results for the representative operations suggest that using eight paddocks is the wealth maximizing system across most of Alberta, and that the more intensive systems perform worse than the single paddock system in most cases, with higher associated risk. Even with higher than assumed benefits to more intensive grazing, the eight paddock system still often out-perform more intensive grazing systems. As there are potential environmental benefits associated with more intensive grazing, and these systems are costly and risky for producers to adopt, policy intervention will likely be necessary to incentivize the provision of these benefits, given the cost of adoption.

Acknowledgements

This research was funded by AFSC's Agricultural Greenhouse Gases Project, with additional significant scholarship support from AltaLink and the Brett Cortus Memorial Scholarship. I would like to thank my supervisor Dr. Scott Jeffrey for his superhuman mentorship, patience, and effort in helping to get this project completed. I would additionally like to thank Dr. Peter Boxall for serving as my co-supervisor and providing his time and effort to editing and supporting this endeavor, and to Dr. Cameron Carlyle for serving on my committee. Further, I would like to thank the Department of REES for a wonderful and successful education, and to my REESSA cohort and friends for being a part of that journey.

Further, thank you to Dr. Edward Bork, Dr. Tim McAllister, Dr. Kim Ominski, Dr. Marcos Cunha Cordeiro, Anatoliy Oginskyy, Brenna Grant and Sarah Pogue for their expert opinion and data.

Finally, I would like to thank my family and friends for their constant support through my educational career, and Syd, for getting me not only through university but through the plague. Thank you all.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background

Ranching has been a cornerstone of the Albertan identity and economy for longer than there has been a Province of Alberta. While cropping (in 1930) and oil (in 1960) have both surpassed ranching as the most valuable agricultural product and commodity (Canadian Encyclopedia 2020; Government of Alberta 2020a)), ranching has grown in the decades since the first cattle were brought into the province in 1877, in terms of dollars and herd size (Prociuk and Nielson 1998). The industry experienced rapid growth, from 15,000 head in 1881 through to the current 4.3M[1] head (Prociuk and Nielson 1998; Statistics Canada 2019). From the original few ranches in the southern part of the province, awarded in 100,000 acre parcels, increasing settlement occurred and the large tracts of rangeland were fenced off and broken for cropping, leading to an intensification of ranching on the smaller operations that remained, with fewer cattle per operation and a higher amount of labour per animal (Prociuk and Nielson 1998).

While the land used in ranching has declined from the peak of some half of the province, 9.5M acres are still used for the ranching of some 4.3 M head, a massive area upon which both economic and environmental outcomes depend. Coupled together with 25.2M acres in crops, this makes agriculture in Alberta a significant economic sector (Statistics Canada, 2016, 2006).

Even though raising cattle is as simple a premise as getting cattle to eat and reproduce, the industry has not been idle as the world has changed around it. The cattle have to eat, and grass is the base of that diet in the summer. The delivery of that grass, however, has changed over time. Gone are the days of cattle roaming the range: rangeland is now fenced in and ownership clearly demarcated. There is no more winter grazing, at least in any substantial acreage, as cattle are now fed in the winter and no longer left to fend for themselves. Hay,

[1] M is used to denote million; B to denote billion.

silage, and other forages are grown on cropland and rationed through the cold months to ensure adequate winter feed (Prociuk and Nielson 1998).

However, just turning cattle loose into a pasture for the summer and bringing them in to feed winter rations is still an oversimplification of ranching. Around the globe, the merits of different styles of grazing have been debated, with proponents of various styles and intensities citing literature to defend their positions for what the best rangeland management looks like. How many cattle per acre? For how long in a given space? The conversation on management has also begun to shift from being purely in economic terms to being more about the environment and social stewardship: how much degradation is best for society, to provide both beef and environmental services? How much impact on native flora and fauna is the correct amount? How should these environmental assets be valued for comparison, and if in dollars, what are they worth?

Compounding this issue is that no two areas within the province, let alone globally, are the same: different weather, different soil, different native species, different productivity. There is also the consideration that not all rangeland is native rangeland. After the drought through the 1930's, it became apparent that large amounts of Alberta had been converted to farmland that should not have, especially without irrigation, and many acres were converted from crops back to pasture for grazing cattle using non-native grasses and forage species (Prociuk and Nielson 1998). With the lessons of the Dustbowl in mind, then through the early 1970's and the dawn of the modern environmental protection movement and into the current climate discussion, ranchers have again and again had to change and adapt not only to the shifting economic landscape but to the shifting environmental situation as well.

This long and varied history with changing business and regulatory goals has left a patchwork combination of grazing strategies in Alberta of varying intensities, optimization goals and rotational styles, and on a variety of grass types and range habitat zones. With so many different management schemes in practice in the province, and as little work has been done to study the impact of different grazing management styles on ranching economics and environmental valuation in Alberta, it is important that research on these issues be undertaken so that Albertan ranchers need no longer rely on data from elsewhere. Albertan work that does not need to be translated to the Alberta context and is data driven, as opposed to anecdotal evidence for making production decisions that affect livelihoods and large acres of Alberta's lands, is of importance.

1.2 Economic Problem

As with all resources that are harnessed for industry, range health is subject to some level of degradation when it is grazed by cattle for economic purposes. Just as mining requires the destruction of mountains and forestry the removal of forest, grazing cattle requires the removal of grasses and some degradation of range. Over time and with more study, the link between grazing strategy and environmental degradation has become apparent, and with the choice of grazing strategy the short and long term economic impacts have come into sharper focus. There is consistent evidence that rotational grazing is better for rangeland health, and in certain circumstances, such as larger operations with higher numbers of cattle, better for economic outcomes (Teague et al. 2008).

While there is a wide body of literature examining the choice of grazing strategy or stocking rate, the vast bulk of the literature contains no reference to Alberta, let alone the variety of different ecoregions that span the province. Further, while there is a large amount of research on the environmental impacts of grazing, there has been limited work done on the impact of grazing strategy and stocking rate on range health[2] in Alberta (Pyle et al. 2018). This understanding is vital, as the literature suggests there is location dependence - the system that works best in one area is not always the system that works best in others (Teague et al. 2008).

[2] Range health is the degree to which range is able to perform important functions (Adams et al. 2016), and is discussed and defined in more detail in Chapter 2.

This can be due to rainfall and other environmental factors but is also a function of the economic costs of increased fencing, watering apparatuses and labour needed to manage increased rotations. While the literature generally suggests that some measure of rotation yields better environmental and economic outcomes (Wang et al. 2018), the inflection point where increasing pasture yields and herd gains is outweighed by the costs to achieve these gains differs across study areas. The intersection of range health and economic health is complex and varied, and literature on both topics often takes the other for granted. Projects that encompass the long term economic planning of range management and the managing of rangeland for improving range health are limited in the broad field of literature, let alone in the Alberta context.

1.2.1 Objectives of Project and Study

The knowledge that the choice of grazing strategy has implications for range management as well as environmental and economic health, but that these implications vary by location, leads to issues when it comes to grazing strategy selection and producer support programs in Alberta. First among these issues is that the degree of these impacts has not yet been quantified, making it difficult for producers and policy makers to know what is going to happen when a management change is undertaken or incentivized with policy.

The wider project that this thesis is a component of has set out to quantify these impacts, with the project's mission statement being to determine the impact of a switch to more intensive grazing systems. The main project is primarily focused on the environmental components of grazing management decisions, looking at topics as diverse as water infiltration, plant biodiversity and native bird populations.

This thesis is one of two in the social sciences to come out of the project, the other being in sociology and focused on producer attitudes. The main objective of the analysis presented here is to determine the cost and benefits of a change in grazing management strategies on the economic health of ranching operations, assuming an objective of wealth maximization. Then, having determined the financially optimal strategy for producers and the relative impacts on producer wealth by deviating from this strategy, the thesis discusses the implications for policy and for the environment due to differences between what the environmental results suggest is the best strategy and what this thesis suggests is the best for producers. The thesis concludes with a discussion of the costs and benefits to both the ranchers and to the environment and society of changes to grazing management systems, and possible policy avenues to arrive at a system that works for all stakeholders.

1.3 Organization of Study

There are six subsequent chapters in the thesis. Chapter Two provides a more in-depth analysis of the cattle industry, as well as a broader discussion of the issues facing ranchers, policy makers, and wider society, and the current state of range management and ranching economic literature.

Chapter Three provides details on agriculture in the province, as well as the representative study areas. Details as to the study area selection criterion are also discussed.

Chapter Four discusses the theoretical framework of the economic analysis. Monte Carlo Simulation, Capital Budgeting, and optimization approaches are introduced and reviewed, and the rationale for the selection of these tools being laid out.

Chapter Five provides a description of the representative operations, and a more detailed presentation of the empirical model. The design of the modeled operations and the stochastic and non-stochastic model elements are explained, as well as the economic relationships.

Chapter Six contains the model outputs and results, and some preliminary discussion.

Chapter Seven builds on the results of Chapter Six and uses them in a discussion of the conclusions drawn from the project. The impacts on ranchers, policy makers, and other relevant parties are addressed. The chapter also touches on the limitations, the directions for further study that have become apparent or were not touched on, and provides final conclusions.

Chapter Two: Ranching, Range Management, and Environmental Outcomes

This chapter provides a brief overview of the $7.1B, 4.3M head Albertan ranching industry and its place in the Albertan economy. In addition, it examines the role of ranching in Alberta's land use and land use framework (Government of Alberta 2020). It further aims to describe rangelands, and how range, grazing, grazing management, the environment and the economy are linked.

2.1 Cattle in Alberta

2.1.1 The Beef Sector

This section examines the beef production system in Alberta, highlighting the economic contribution of each sub-segment, what each constituent section does, and how animals move through the system from birth to slaughter.

2.1.1.1 Cow Calf Operations

Cow calf operations are what most people would think of when they hear the word ranching and are the primary use of Alberta's non-crop agricultural land (Statistics Canada 2016). Cows give birth to calves in the early spring, are grazed on pasture in the summer, and then the calves are sold to backgrounding lots, into feedlots, or directly for consumption, or they are retained for herd expansion or bred and sold to expand other herds. The cows are then bred again in the late summer, to begin the cycle again after spending winter being fed some form of winter ration, often consisting of a combination of grain/forage and supplements. The base ingredients are typically hay and barley or silage, a type of cattle feed made by fermentation (both aerobic and anaerobic) of barley (CCA 2013). Such cow calf operations, of different sizes and locations, are what is being modeled in this study, under different management schemes, discussed later in this thesis.

While the largest part of the beef production system in Alberta in terms of land use, the cow-calf sub-sector is the smallest economically. In 2012 this sub-sector contributed $461M in sales and $196M toward GDP[3] (Canfax 2012). As of January 2020, there were some 2.517M cattle on ranches in Alberta, accounting for 40% of the total Canadian herd (StatsCan 2020), comprising some 9.5M acres (Statistics Canada 2016).

2.1.1.2 Backgrounding

Backgrounding operations are those intermediary operations that take cattle from cow-calf operations and feed them a high forage diet in order to slowly increase or manage weight and to ensure cattle are available for transfer to feedlots all year, ensuring a steady supply (CCA 2013). In 2020, there were 954,000 cattle in backgrounding operations in Alberta, comprising 60% of Canadian cattle being backgrounded (StatsCan 2020). In 2012, backgrounding operations generated $4.02B in sales and contributed $1.3B to GDP (Canfax 2012).

2.1.1.3 Feedlots

Feedlots are the final step before animals are slaughtered. Animals are fed a ration of forage and grain to ensure efficient growth to final weight and to improve meat quality. Animals spend between 60 and 200 days in a feedlot, depending on initial size, ration and market conditions, and are procured either from backgrounders or from ranchers (CCA 2013). In 2020,

[3] 2012 was the most current year available for sales and GDP data broken down by livestock sub-sector. They are included only to give a sense of the financial breakdown within the sector, and not to provide a current picture of the sector's financial performance.

there were 855,000 cattle in feedlots in Alberta, accounting for 61% of the Canadian herd (StatsCan 2020), generating $3.9B in sales and $1.7B towards provincial GDP (Canfax 2012).

2.1.2 Cow Calf Production

This section provides a more in-depth discussion of the cow-calf sector and how production on a ranch works, giving readers an understanding of the work undertaken, the timing of said work, and an overview of relevant terms that will appear throughout the thesis.

The production cycle begins most often in May or June, but can begin as early as mid-March or as late as August, when cows are bred, either with bulls or with artificial insemination (AI) (Waldner et al. 2019). A May-June breeding corresponds to calving in February-March, but depending on the operation, calving may be desirable at other times. After breeding, animals continue to graze, raising their young outdoors on pasture (see Section 2.2.1 for a discussion of pasture). Calves are typically weaned, or stop consuming milk and start eating solid foods, at around six or seven months of age (Lardy and Dalhen 2017). After weaning, calves are sold into a backgrounding lot or into a feedlot, depending on market conditions and a producer's relationship with buyers, although they may be grazed longer depending on forage availability and the market. Some heifers (i.e., female calves) are retained to replace older cows or to replace cows that fail to carry a calf to term, either because of miscarriage or infertility. These older or unproductive cows are removed from the herd in a process called culling. Culling decisions vary from rancher to rancher, but around 50% of animals are culled by 9 years of age (Funnel 2013), and 8 years is a common horizon over which to price animals from an accounting perspective (BCRC 2018).

At the end of the grazing season, cows and retained heifers are taken off pasture and put into what is often called a dry lot or winter lot. They are then fed a ration consisting of ingredients from crops grown on cropland. This often consists of hay or straw, and some sort of silage, a fermented feed made most commonly in Alberta out of barley or corn, as well as additional supplements or other plants, depending on the nutrient content of the feed and the time of year. It should be noted that the length of the grazing season will vary, depending in part on weather and in part on how heavily a pasture is grazed.

For many operations in Alberta, the next production cycle event is calving, which most often occurs February to March. Animals are born, usually single births with occasional twins, and nursed by their mothers until weaning.

Animals go out to pasture for the first time between late April and early June for the majority of Albertan operations (Bork et al. 2021), with the specific timing being dependent on a number of factors. Operations with a high stocking rate (many animals per unit of area) and a large number of paddocks (many small areas subdivided from the farms land base) generally begin grazing earlier and end grazing later (Bork et al. 2021), although this is not always the case. Operations with a large number of paddock and higher stocking rates are called rotational grazers, as animals rotate amongst the paddocks. Higher intensity rotational grazing is referred to as Adaptive Multi-Paddock grazing (AMP), although there is no universally agreed upon threshold for stocking rate and/or paddock number corresponding to the switch from rotational grazing to AMP. This is in contrast to continuous grazing, where animals remain in a single larger paddock all season. While a continuous and a rotational operation may have the same herd size, and the same land base, they will have different stocking rates, as the animals per acre grazed will differ.

The number of animals a farm can raise is determined by the land's carrying capacity, which is measured in Animal Unit Months, or AUM's. One AUM is defined as the amount of forage needed to feed one 1000 lb cow, with or without calf, for one month, and corresponds to 780 lb of forage (BCRC 2020). Carrying capacity is determined by two factors: the productivity of the pasture, which is the amount of forage produced by a pasture, and the utilization rate, which is the percentage of the produced forage that is consumed. Stocking rate and the number of paddocks influence the utilization rate. As the stocking rate and number of paddocks increase, animals are not able to be as selective in their consumption of forage. Animals are forced to eat lower-quality forage, thereby increasing the utilization rate, or the amount of forage produced that is consumed. While increasing stocking rate increases utilization rates and the number of animals that can be carried by a particular land base, the increased stocking rate does result in decreased rate of gain (RoG), or amount of weight animals put on per day, as they are forced to eat lower nutrient foodstuffs.

2.2 Rangelands in Alberta

2.2.1 What is rangeland and pasture?

Rangelands are defined as areas of native grassland or shrubland used primarily for grazing animals. They differ from pasture in that pastures are primarily comprised of non-native species and have undergone some form of seeding or fertilization (Encyclopedia Britannica 2020). In Alberta, if a differentiation is made rangeland is referred to as native pasture, and pasture as tame pasture. As Alberta is the study area, native pasture and tame pasture are terms that will be used and will be referred to as grazing lands or simply as pasture when referencing both. While there is some forested land in Alberta used as grazing land, only non-forested pasture is analyzed in this thesis, so numbers presented reflect only prairie grazing lands. In the 2016 Census of Agriculture, there were 5.4M acres of land in Alberta being used as tame pasture (Statistics Canada 2016). A further 4.8M acres of native pasture were being grazed in Alberta (Statistics Canada 2006)[4].

[4] Statistics Canada did not inventory native pasture in the 2016 Census of Agriculture, resulting in the differing citations for the land inventory for native and tame pastures.

2.2.2 Range Health in Alberta

Grazing land health is scored using range health (RH) score, which is based on maintenance of soil and site stability, net primary production, capture and beneficial release of water, nutrient and energy cycling, and functional diversity of plant species (Government of Alberta 2016)[5]. All elements are quantifiable, and a RH score is generated by evaluating the various elements. Each category has its own scoring system, and RH criteria differ based on whether the grazing land is native, tame, or forest, but regardless of range type, interpretation of scores in terms of the range being healthy (greater than 75% RH score), healthy with problems (50-75% score) or unhealthy (score less than 50%) is consistent (Government of Alberta 2016; Prairie Conservation Action Plan 2008). This RH builds upon an older classification system, measuring range condition (RC), which looked at similar metrics, but was less comprehensive and, thus, updated to reflect more recent scientific results and a more holistic approach, although RC does remain in use (Government of Alberta 2016; Prairie Conservation Action Plan 2008). The Government of Alberta officially refers to RC, but has updated the official guides to follow RH metrics- as this is the case, RH is the term that will be used throughout.

The Governments of Alberta and Canada do not keep track of range health, as the vast majority of range in Alberta is privately held. Pyle et al. (2018) estimate that 3.9% of all range in the Aspen Parkland of Alberta is unhealthy, with 65.7% of pasture being healthy and the remaining 30.4% being healthy with problems. While overall this is encouraging, it does show there is further potential for improved management of Alberta's range resources. Pyle et al. (2018) find that pastures continuously grazed with constant stocking rates have lower scores, but do not link health of the range to the intensity of the rotational system used. They suggest

[5] The functions considered in assessing range health are consistent with the presence of ecosystem processes and provision of ecosystem goods and services by rangeland, as is discussed below in Section 2.2.3.

rotational grazing is beneficial to range health in Alberta’s Aspen Parkland, but leave the question of degree of system intensity and the impact in other regions unanswered.

2.2.3 Ecosystem Goods and Services and Ecosystem Processes

Before continuing the discussion of range in Alberta, a brief digression on Ecosystem Goods and Services and Ecosystem Processes is in order. Ecosystem Goods and Services (EGS) are those things provided by the environment that directly benefit people (Fu et al. 2013). Grouped into three categories, these include provisioning goods (e.g., timber and foods) regulating services (i.e., the management of biological processes such as the carbon cycle, water cycle, and nutrient cycles) and cultural (i.e., the recreation and spiritual benefits of nature) (Statistics Canada 2015).

Ecosystem Processes (EP) are those processes that enable the creation and use of EGS and include such factors as pollination and water regulation. While not directly benefiting people, EP indirectly improve the lives of people. In the case of the examples noted above, pollination allows for the creation of certain foodstuffs from the environment, and water regulation helps prevent floods and provides habitat for recreationally caught fish, amongst other benefits, with are EGS as they directly benefit people through food, natural disaster mitigation, and leisure (Fu et al. 2013).

Aside from being important to sustain the functioning of society and the global system as we have built it (Statistics Canada 2015), there is a notable and unfortunate undersupply of these EGS and EP. Lant et al. (2008) find that, due to market failings and the tragedy of the commons, EGS are often undersupplied, while Robert and Stenger (2013) note a similar undersupply of EP. This leads to loss for society, as EGS and EP benefits are decreased in order to increase private benefits. The wider project has found evidence of this in Alberta, with many ranchers operating in ways that provide fewer EGS and EP than other Albertan ranchers (Dobbert et al. 2021; Shresta et al. 2020; Sobrinho 2021).

In Canadian agriculture, the undersupply of these EGS and EP has been historically dealt with through adoption of Beneficial Management Practices, or BMPs. BMPs are actions undertaken by producers that improve EGS and EP outcomes on private lands, and the requirements of meeting a BMP are outlined by the government or an environmental NGO (Government of Alberta 2010). There are many BMPs that have been identified by the Alberta Government, with manuals outlining practices for all types of operations and rural land uses; cow-calf ranching alone has dozens of recommended best practices (Government of Alberta 2004; Government of Alberta 2010). Unfortunately, despite having the practices laid out, the gap found by Lant et al. (2008) and Robert and Stenger (2013) does still exist. In large part this is because the provision of EGS and EP through adoption of BMPs tends to be an expensive undertaking for producers (e.g., empirical results presented in Koeckhoven 2008; Trautman 2012; Cortus 2005; Bruce 2017). As well, in many cases there are no legislative or regulatory requirements (Government of Alberta 2010), and external funding for BMP implementation is at times insufficient or programs suffer from poor design and a lack of extension (Brethour et al. 2007).

2.2.3.1 Ecosystem Goods and Services and Ecosystem Processes from Rangelands

Healthy grazing lands provide a wide variety of EGSs and EPs, including but not limited to renewable animal feed, noxious weed control, soil erosion prevention, wildlife habitat, carbon sequestration and water purification (Government of Alberta 2016). Further, native rangeland is considered an endangered biome, making it important to preserve not only for its EGS contributions but also because it is so rare (Government of Alberta 2016). Management and condition, however, are of increasing concern due to the presence of degraded rangeland, which offers fewer or even negative environmental services. Pyle et al. (2018) found that the majority of range being used for grazing in central Alberta was in healthy condition, but that poor range management by owners was to blame for the sites that were degraded. This is echoed by almost the entire field of literature; specifically, poor management is the cause of most range degradation.

One reason for concern over range health (RH) is that healthy range is more resistant to the encroachment of exotic species. Lyseng et al. (2018) found that moderate grazing helps to resist the expansion of foreign plants into the ecosystem and fends off the expansion of shrubs into grazing land, especially in more arid regions. Grazing also helped to increase plant richness, but did not alter any diversity indexes, meaning the moderate grazing pressure was helping to keep ecosystems stable.

RH also has more direct effects. DeBruijn and Bork (2006) found that increasing grazing pressure increased RH, and in doing so led to greater forage production, increasing the carrying capacity, while also keeping down weeds, in this case thistle. This issue is not settled, however, as Bork et al. (2020) found that increased pressure decreased RH but resulted in more carbon being sequestered. Medina-Roland et al. (2007) found that RH had an impact on soil water content, increasing an ecosystem's drought tolerance and holding more water in the system. Chaubey et al. (2010) found that deteriorating pasture condition and overgrazing led to decreased water quality. Alemu et al. (2019) found that pasture of better condition had a greater level of carbon sequestration than poorer condition pasture. With such a diversity of benefits coming from rangelands and from keeping them healthy, it is important to find ways to enhance and protect the quality of rangelands

2.3 Range Management Practices

2.3.1 Best Management Practices and Public Policy

Canada and Alberta provide some producer incentives for adopting BMPs as a part of the Canadian Agricultural Partnership (CAP), a federal-provincial joint program that oversees the country and province's agricultural support programs. CAP can provide between 30 and

50% of the cost of adopting an approved BMP proposal, up to a maximum of $100,000 (with potential for up to $100,000 for Innovative Solutions) across BMPs in five categories: Riparian Management, Manure and Livestock Facilities Management, Agricultural Input and Waste Management, Innovative Solutions, and Commercial Manure Applicators (Canadian Agricultural Partnership 2019). CAP is a relatively new program (starting in 2018) and as yet there has been no analysis regarding the success of its BMP adoption framework. Boxall (2017) did determine that the previous program, Growing Forward 2, was somewhat successful, especially when compared to the Growing Forward 1 program, although it is made clear there are massive data deficiencies in evaluating these programs. Given the number of Albertan ranches estimated by Pyle et al. (2018) to not be following grazing BMP's, however, there appears to be either significant funding or outreach deficiencies for BMP adoption in rotational grazing despite the reported success of the prior program. Funding requirements will be discussed later in this thesis; outreach and public opinion will require further work.

2.3.2 Literature on Range Management and Rotational Grazing

While not yet designated as a BMP, AMP grazing has environmental benefits that are comparable to those of many existing BMPs, and this thesis and wider project examines the impact of its adoption in the same way that previous studies examine BMPs. AMP grazing is defined as a grazing management system that uses high stocking rates and short grazing periods with frequent rotation of pasture (Bork et al. 2021). There is no set requirement for what constitutes AMP grazing and there is often considerable overlap in practices between self-declared AMP ranchers and non-AMP ranchers, due to the reputation of AMP grazing (Bork et al. 2021). Descriptions of the modeled rotational systems follow in Chapter Five.

In range management, there are two broad schools of management. One alternative is continuous grazing, in which animals remain in the same area for the course of the grazing season. The second alternative is rotational grazing, in which animals spend short periods of time in multiple smaller paddocks. While the historical debate over continuous versus rotational grazing was long and contentious, it has mostly been settled in favour of rotational grazing (Wang et al. 2018). While it is undoubtedly true that science done with solid methods led to papers suggesting no difference between continuous and rotational grazing, and even some advantages to continuous (Latinga 1985, Walton et al. 1981, Pitts and Bryant 1987), all focused on short time horizons and almost exclusively on economic or animal production criterion. More recent work, incorporating longer time scales that factor in the impact of land degradation on long term profit and risk, overwhelmingly support the hypothesis that ranching is most economically and environmentally optimal when rotational grazing is implemented, especially when environmental outcomes are considered (Pyle et al. 2018; Hillenbrand et al. 2019; Teague and Barnes 2017; Teague and Dowhower 2003). Of the recent literature published in the field, the closest thing to a positive assessment of continuous grazing is Wang et al. (2018), who find that in short term projections, continuous grazing can offer higher weight gain and profit, but it is outperformed when longer time horizons are factored in.

Within rotational grazing, however, the frequency with which cattle are moved is still a subject of debate. Recommendations range from “traditional” rotational grazing with few, large paddocks at lower stocking rates (Derner et al. 2008) through to the intensive Holistic Management of Allan Savory (2013) comprising previously unheard of high stocking rates and incredibly quick rotations. Between these two lies a continuum of AMP grazing practices, with a wide spectrum of paddock sizes, numbers, stocking rates and rest period recommendations present in the literature (Pyle et al. 2018; Hillenbrand et al. 2019; Teague and Barnes 2017; Teague and Dowhower 2003). While rotational grazing is often the main topic of discussion, it is intertwined with stocking rate. While the two generally run in opposite directions, it is important to remember that they are not fixed in relation to each other: McMeekan and Walshe (1963) found good evidence that stocking rate has twice as great an impact on animal outcomes than does the choice of grazing method, and Derner et al. (2013) found a large impact for both stocking rate and rotation speed, separately and in combination.

It can also be exceedingly difficult to compare studies in the ranching literature, due to the importance of local environmental factors and the confounding nature of some parameters, notably around stocking rates and densities (Briske et al. 2008). Work done in local environments and careful comparisons across study designs is necessary to draw meaningful conclusions for a given region from the literature.

As there remains such a heated debate over the intensity of rotational grazing that should be undertaken, and that many studies note a highly influential region-specific component to their analysis, a study of what degree of rotational management works best in the Alberta context is important. Pyle et al. (2018) report that some form of rotational grazing is practiced by 83% of producers in Western Canada. However, there are still a large number of ranchers using continuous grazing and a very diverse set of rotational grazing systems practiced. As almost every ranch in the prairies has its own rotational system (Bork et al. 2021), finding an optimal system for adoption is important understudied work.

2.3.3 Legal Requirements in Range Management

There are very few legal requirements with respect to the management of privately held rangelands in Alberta. Ranchers are obligated to ranch in a way that maintains the quality of water and wetlands on and downstream of their operations, per the *Water Act* (2000) and the *Agricultural Operation Practices Act* (2000), and with respect to air quality and other common law requirements, although actions that may lead to nuisance claims that are within the bounds of accepted agricultural practices are exempt under the *Agricultural Operation Practices Act* (2000), which gives fairly free reign to management practices (Powell 2019). Provided the degradation of land does not lead to water quality issues per these Acts, and the degradation can be argued to within the subjective bounds of conventional practices, ranchers are free to manage their grazing system as they see fit. If a rancher's land is designated as critical habitat under the *Species at Risk Act* (2002), there become requirements for conservation and stewardship to ensure the health of the endangered species. The *Alberta Land Stewardship Act* (2009) does lay some requirements for ranching for conservation easements, but these are voluntary easements and done through negotiations with a third party; the Act is the enforcement tool to follow the easement.

All in all, ranchers are given almost complete control over the management of their lands, with the exemption of Critical Habitat or Conservation Easements. This lack of range management mandates in law is what makes the adoption of BMPs so important in the agricultural industry in Alberta.

2.4 Chapter Summary

The raising of cattle in Alberta is split amongst three sub-sectors: cow-calf, which is where cattle are born and raised; feedlots, where animals are fattened for slaughter; and backgrounding, an intermediary between the two, ensuring a year-round supply of animals. This thesis focuses primarily on cow-calf production, as it has the largest land use footprint of the beef sector.

As the largest land user of the cattle industry, cow-calf operator’s production decisions have a significant impact on the EGS provided by Alberta’s land base, affecting water quality, native species, weed stands, and the scenery, amongst other things, as well as providing the stewardship of the endangered native prairie biome. While most of the province’s rangeland is healthy, or healthy with problems, there is still room for improvement, and while there are many BMPs that ranchers can follow to help in this improvement, there are none that describe rotational grazing as a pasture management BMP. With a wide literature describing the way rotational grazing can be used like a BMP to improve range health and increase the amount of

EGS provided, the literature notes a strong local effect. In order to determine how to maximize these gains for Alberta, and how to do them economically, a look at Alberta’s environmental and economic circumstances must be done to determine the value of these EGS, and at what point the cost of acquiring them exceeds their value.

Chapter 3: The Study Area

For the purposes of economic modeling, locations for representative cow-calf operations had to be selected. While it would be relatively simple to define one Alberta representative ranch, differences in soil, moisture, and temperature affecting forage and winter feed growth, as well as pricing differences and different sized cattle coming from different regions, resulted in it being necessary to model cow-calf production in more than one region in order to generate results capable of being extrapolated to the full province. Given the majority of the Alberta cattle herd is located in the Boreal, Aspen Parkland, and Mixed Grass Prairie zones with a comparatively small fraction located in other zones (Statistics Canada 2016; Alberta Parks 2014), representative farms were placed in these three areas. While more involved, defining and modeling ranches for each zone and their associated unique physical and financial environments facilitates being able to generate more useful results (Alberta Parks 2014; Komirenko 2019; McAllister 2019).

The Mixed Grass Prairie/Grassland comprises 14.4% of land in Alberta and occupies the south-east corner of the province. It is the warmest and driest region in the province and has the longest growing season, although moisture can be limiting. There is little surface water available (Alberta Parks 2014). The Aspen Parkland is smaller, comprising 9% of the province and is the most densely populated and agriculturally intensive zone, spanning the middle of the province from west to east. The zone is generally transitional, with a more prairie aspect to the south and a denser aspen forest in the north. While it has far fewer of the wetlands common in the other zones, there is much more surface water in the form of rivers and lakes than in the drier south, and much more precipitation. The Boreal is the northernmost region, spanning some 58% of the province. It is mostly forested, primarily pine trees, and is the coldest zone in the province, with cropping only possible in the warmer sub sections. The Dry Mixedwood Subregion, also referred to as the Boreal Transition, is the most conducive to agriculture and is the specific location of the third representative ranch. Like the Aspen Parkland, it is primarily aspen covered in the treed areas, but contains more wetlands and standing water, and has the lowest elevation of the three zones (Alberta Parks 2014). Figures 3.1 and 3.2 detail the biogeographical and moisture features of the province; a more detailed biological region map can be found under Appendix A12.

Choices of representative locations within zones were made at the county level, as this is the most disaggregated level of data that could be acquired for agricultural production in Alberta. Counties for potential sites were excluded if they were not fully contained within a zone and if they contained one of Alberta's five largest population centers, so as to avoid transitional zones and the potential impact of hobby farmers coming out from larger cities. These criteria narrowed potential selections to Lacombe, Ponoka, Wetaskiwin, Leduc, Camrose, Beaver, Stettler, Flagstaff, Provost, Wainwright, Vermillion River, Minburn and Parkland Counties in the Parkland; Sturgeon, Lac Ste. Anne, Barrhead, Westlock, Smokey River, Greenview, Birch Hills, Spirit River, Saddle Hills, Clear Hills, Peace, Big Lakes and Northern Sunrise Counties in the Boreal; and Newell, Cypress, Forty Mile, Warner, Cardston, Taber, Vulcan, Wheatland, Willow Creek and Pincher Creek Counties and the Southern Special Areas in the Prairie.

Deciding which county in which to place the operations for each zone was then based on the degree of importance of beef production. This was done through an assessment of cattle numbers. Numbers of cow and calf pairs, total number of calves, and number of heifers for replacement were used as primary criteria, and number of steers and heifers over one year of age as secondary criteria. On these metrics, it was decided to locate the Boreal Site in Lac Ste. Anne County, the Aspen Parkland Site in Ponoka County, and the Prairie Site in Newell County. The location of the representative counties is highlighted in Figure 3.3.

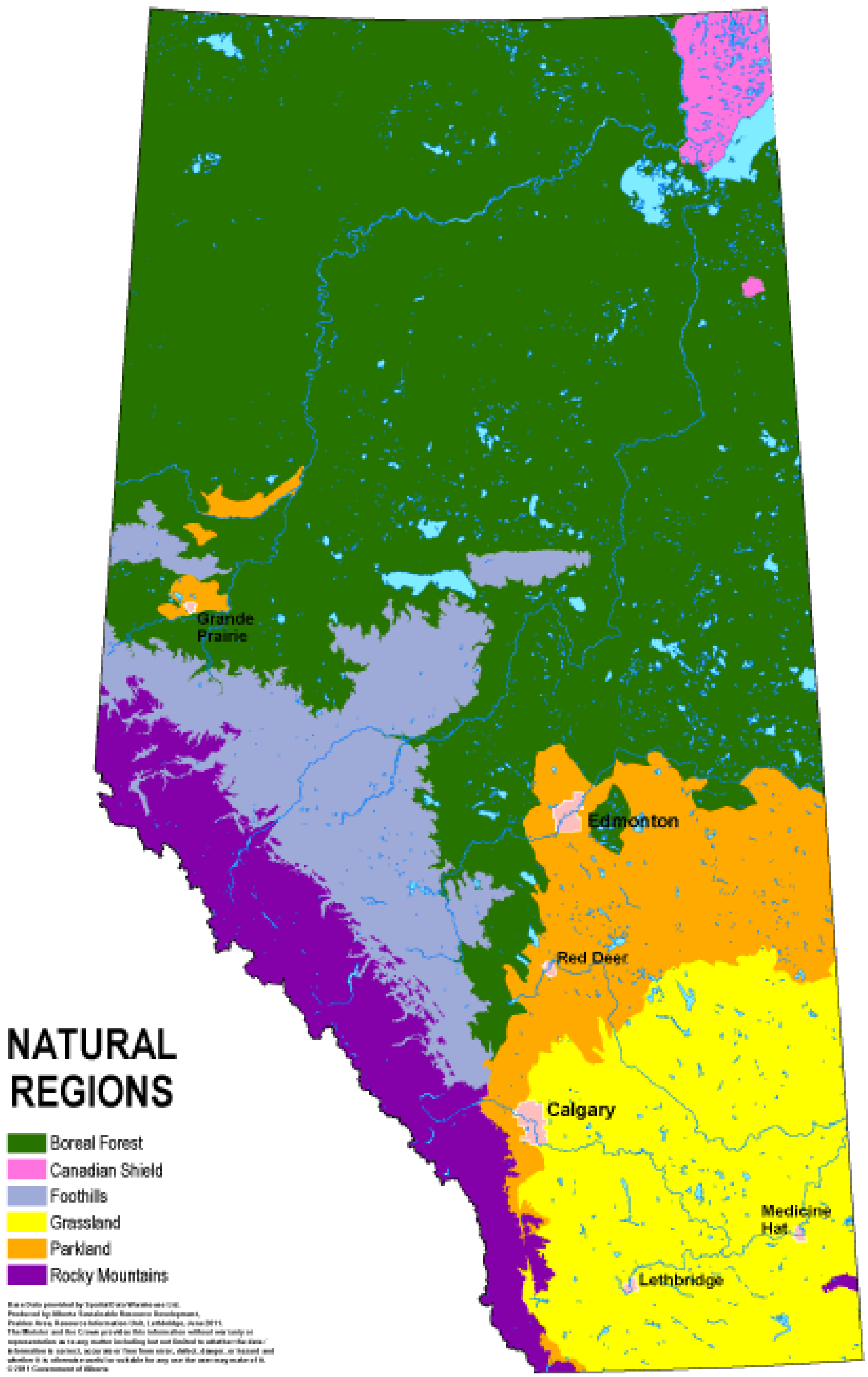


Figure 3.1: Natural Regions of Alberta
(Alberta Prairie Conservation Forum 2011)

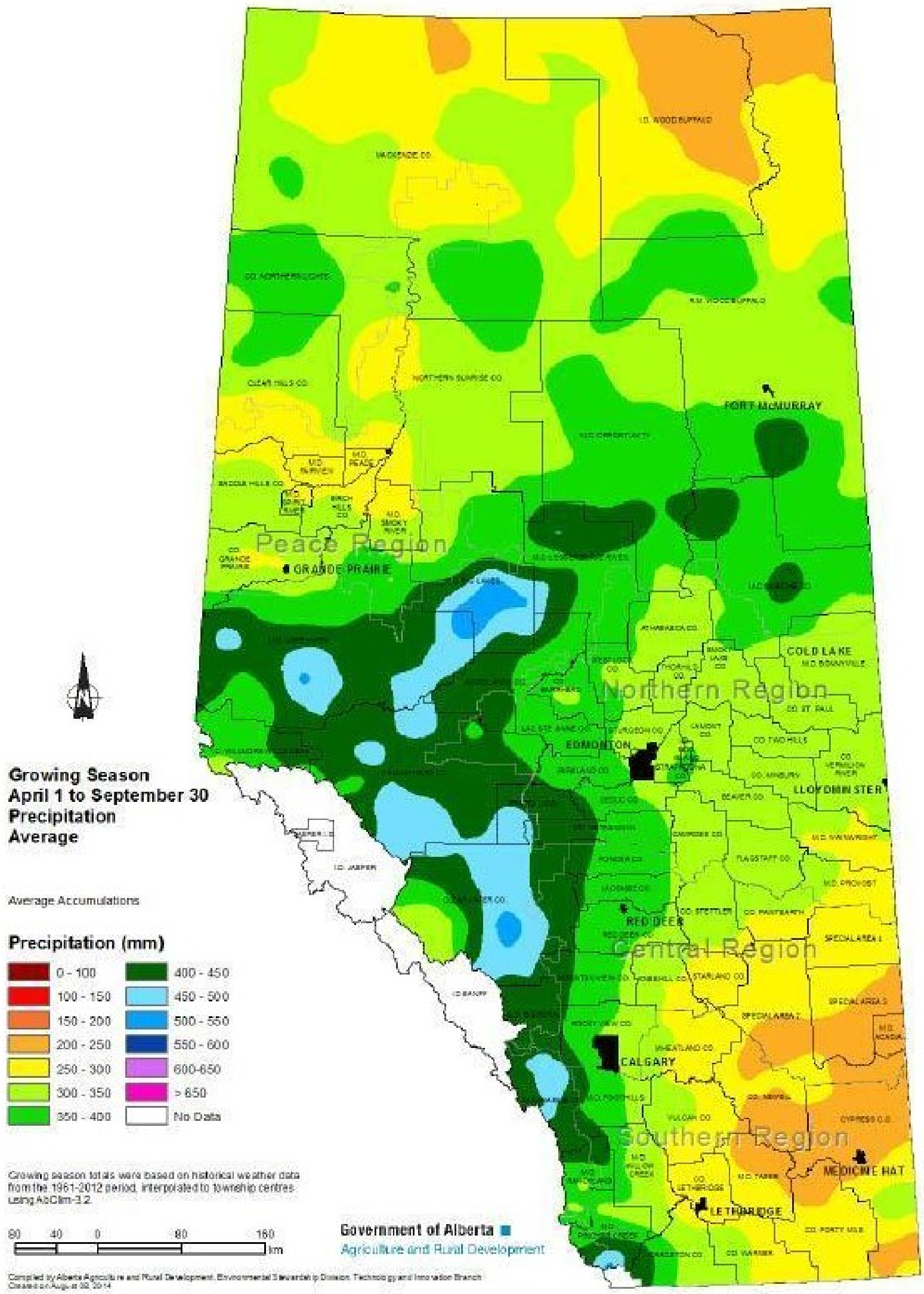


Figure 3.2: Growing Season Precipitation in Alberta
(AAF 2019)

Figure 3.3: Municipal Map of Alberta
AARD (Unknown)

3.1 Agriculture in the Study Areas

For the descriptive statistics, the three smallest Statistics Canada farm sizes and farm incomes (farms less than 130 acres and gross receipts of less than $50,000) have been removed for calculation of averages in the descriptive statistics, as these are assumed to be hobby, or non-commercial operations. All data are from Statistics Canada 2016 Census of Agriculture unless otherwise noted.

3.1.1 Lac Ste. Anne

As of 2016, there were 493,384 acres of farmland in the county. Of this area, 65% was operator owned, 26% was rented from other operators, and 15% was leased from the government. There were 660 farms in the county, with an average size of 721 acres (assuming that the 14 farms classified as larger than 3250 acres have a size of 4000 acres). Of these operations, 623 reported having crops on 216,678 acres. There were 3,696 acres allocated to summer fallow. Grains and oilseeds made up the majority of crops in all counties, with wheat and barley the most popular grains and canola the most popular oilseed. While 2016 data were not available, in 2011 four operators irrigated 16 acres and agricultural operations had average gross receipts of $280,105.

Lac Ste. Anne county typically receives 1200-1400 growing degree days in a growing season (May to August, inclusive) and 350-450mm of precipitation in the growing season (AAF 2019). The county is located almost entirely within the Dark Grey Chernozemic soil zone, with a small section within the Grey Luvisols (AFRD 2015).

There were 297 operators who indicated they ran some form of beef cow-calf or feeding operation in the county. There were 412 operations who reported owning 96,617 acres of tame pasture, and 507 operations reported having 120,247 acres of native pasture. At the time of the census 27,357 beef cows were reported, along with 28,323 calves under one year of age. There were 2,865 steers over a year of age, along with 9,073 heifers of which 2,646 were listed as being for slaughter and 6,342 for herd replacement. There were 1,610 bulls over a year of age. Of 408 farms reporting grazing animals, which does include non-bovine grazing, 356 (87%) reported using some type of rotational grazing management on their land.

3.1.2 Ponoka

In 2016, there were 737,616 acres of land used for farming in the county: 66% was owned by the operator, 8% in government leases and 28% was in private rentals. There were 848 farms in the county, with an average size of 784 acres (assuming that the 26 farms classified as larger than 3250 acres have a size of 4000 acres). There were 833 farms with a total of 366,731 acres of land in crops. There were 4,948 acres in summerfallow. In 2011, as 2106 data were not available, irrigation was used by six operators on 40 acres and agricultural operations had average gross receipts of $480,040.

The county receives an average of 1100-1400 growing degree days of heat and 350-450mm of rain per growing season (AAF 2019). Most of the county is in the Black Chernozem soil zone, although there is a significant portion located within the Dark Grey Chernozemic zone and a small section of Grey Luvisol (AFRD 2015).

There were 459 operators who indicated they operated some form of beef cow-calf or backgrounding operation in the county. There were 533 operations that had 127,358 acres of tame pasture and 642 operations with a total of 186,109 acres of native pasture. There were 43,975 cows reported for the census, and 45,096 calves. There were 8,623 steers over a year of age, 10,258 heifers for slaughter, 8,151 heifers for herd replacement, and 2,741 bulls over a year of age reported. Of 628 farms reporting grazing animals, 469 (75%) reported as using some type of rotational grazing management on their land.

3.1.3 Newell

As of 2016, there were 1,458,747 acres of farmland in the county, of which 43% was owned by the operator, 44% was leased from the government, and 14% was leased from other operators. There were 552 farms in the county, with an average size of 1265 acres (assuming that the 77 farms classified as larger than 3250 acres have a size of 4000 acres). Of this total, 542 operators reported a total of 395,170 acres of land in crops, and 13,367 acres were allocated to summerfallow. In 2011, due to a lack of 2016 data, irrigation was used by 532 operators on 244,484 acres, and agricultural operations had average gross receipts of $537,549.

The county receives an average of 1300-1500 growing degree days of heat and an average of 200-300mm of rain per growing season (AAF 2019). The county is located almost entirely in the Brown Chernozem soil zone (AFRD 2015).

There were 299 operators who indicated they operated some type of beef cow-calf or backgrounding operation in the county. There were 107,170 acres of tame pasture reported by 288 operators, and a further 912,112 acres of native pasture reported by 297 operators. There were 45,843 beef cows reported, along with 45,692 calves. There were 80,647 steers over a year of age, 12,152 heifers for slaughter, 7,447 heifers intended for herd replacement, and 3,155 bulls over a year of age. Of 338 farms reporting grazing animals, 220 (65%) reported as using some type of grazing management on their land.

3.2 Range and Environmental Health in Study Areas

It is challenging to assess the state of range health on private lands in Alberta. There is no provincial inventory on the status of Alberta's rangelands, and there are limited published papers examining this issue. Pyle et al. (2018) surveyed producers in central Alberta in the Aspen Parkland and found 79% of pastures were in healthy condition. Literature for the range health of other zones of interest could not be located. Based on the results of the 2018 Environmentally Sustainable Agriculture Survey (AAF 2018), which found 70% compliance in Grazing Management Practices Adoption, and the Pyle et al. (2018) results for the Parkland region, the state of rangelands in the Boreal and Prairie zones can be considered to be relatively strong and it seems likely 70-80% of the range stock is healthy, but without deliberate inventory work this cannot be confirmed.

Broader environmental outcomes related to agriculture and cattle rearing suffer from the same lack of data, with no central database or survey conducting authority of the environmental health of privately held lands in the study areas. While work like that of Pyle et al. (2018) and work from this wider project (Döbert et al. 2021; Shresta et al. 2020; Sobrino et al. 2021) are not uncommon, most of these studies involve comparing regimes and the change in quality between systems; there is little work focused on environmental quality inventory or indexing. What literature does exist is detailed below.

One exception to this is the aforementioned Environmentally Sustainable Agriculture Tracking Survey, undertaken by AAF (2018). While not exactly a study of the health of the environment, it does track the adoption of Environmentally Sustainable Agriculture (ESA)[6] practices, and provides the only available government data related to environmental health on private land in the province. The average adoption score given for the ESAs tracked by the survey is just 53%, although some practices score in and above the 80th percentile for adoption. While it is possible that land in agricultural production is managed well and is healthy despite owners not reporting participation in all or some ESA's, this is not an overly encouraging statistic. Grazing management, the primary focus of this thesis, does see a reasonable level of adoption, with the above-mentioned average score of 70%. While this is a relatively good score, it is apparent that there is a lot of room for improvement when it comes to the health of the

[6] While the ESA does have a biased sample in favour of BMP adoption, no better data source could be found.

Albertan environment and its rangelands from an ESA standpoint. This is particularly the case for participation in practices related to climate (15%) and soil health (28%). Also discouraging is that the frequency of High and Medium ESA practice adopters has declined into 2018 (2020 data not yet available), a disheartening trend in the province's agriculture related environmental health. However, adoption does trend positively with farm income, so analysis such as that undertaken in the current study, focusing on increasing and understanding farm income and cost barriers, provides encouragement to the improvement of the environment. The ESA Survey found that livestock operations score poorly on soil conservation and climate outcomes when compared to other types of operations, and have lower uptake levels of relevant BMPs. Future outreach and specific programing will need to take this into account, especially with the results reported from Döbert et al. (2021), Shresta et al. (2020) and Sobrinho et al. (2021).

In the specific representative counties, Blais et al. (2009) studied the health of Lac Ste. Anne County's namesake lake. While the lake would be naturally eutrophic, they find that the health could be improved by reduced human actions; specifically, agricultural and urban development. Mitchell (1999) reports similar results, making clear that improving lake quality requires a reduction of nutrient flows from human application into the lake. Donahue et al. (2006) also find decreasing quality in Lac Ste. Anne, although this decline is attributed to Alberta's coal-fired power capacity, and not the result of agriculture and range management. In Newell County, Hornung and Rice (2003) found a negative impact from cattle grazing near wetlands on dragonfly species health and recommended that grazing strategies and paddock design take this into account. Additional studies (either peer-reviewed or government published) relating to ranching in Newell, or for any environmental issues in Ponoka, could not be found.

At the broader provincial level, Cheung and Mayer (2009) examined the groundwater health of Alberta, with wells in the study areas. They found an overall healthy environment but also identified some concerns with ground water quality, and highly recommended an expanded monitoring program. Paterson and Lindwall (1992) found that water quality in Alberta was experiencing degradation from agriculture. Fertilizer and pesticide applied to hay and forage land for cattle in levels that are not uncommon was determined to lead to ground and river pollution, meaning systems that minimize the amount of winter feed needed have major benefits. Nitrogen from fertilizer and manure from the pens of intensive cattle operations (including overwintering of cows) were noted as potential pollution sources of greatest concern. They also found that the spreading of manure at rates even slightly above the recommended rate, and well within the common practice, could have significant environmental impacts. If coupled with irrigation, as is common in the more arid South, this practice increased the impacts. Hao and Chang (2003) determined that manure application has a cumulative effect on soil salts in croplands, especially under dryland conditions. The impact on grazing land salting was left unexplained. Agriculture was found, in more encouraging news, to be much less of an air pollutant than a water pollutant, with Chetner and Sasaki (2001) reporting agriculture to be a relatively insignificant source of air pollution. The exception was ammonia, where agriculture is a major source of pollution. Agriculture can and sometimes does lead to environmental pollution in Alberta, and in many cases, there remains substantial room for improving the sector's environmental footprint.

3.3 Chapter Summary

Alberta is a large province, with different agricultural regions spread across its area. The province is also an ecologically diverse area. To account for this, representative operations were placed in the three ecological zones that collectively represent the majority of the provincial beef herd, the Boreal, the Aspen Parkland, and the Grassland. The specific counties chosen to represent beef production in these three zones are Lac Ste. Anne, Ponoka and Newell Counties, respectively. All three counties contain unique environmental traits and circumstances, showing how vital it is to model multiple locations in order to generate results that can be used to understand the province and how its cow-calf industry might respond to changes to its grazing management regime.

Chapter 4: Theory and Analytical Approach

The choice of grazing method has a significant impact on the environmental status of a ranch, and has been proposed to have a significant role in the long term profitability of a cattle operation. In order to test the impact of a change in grazing strategy to the economic outcomes of a ranch, however, a method of accounting for the costs and benefits of such a change needs to be implemented. To be theoretically sound, this method of capital budgeting, the planning framework for analyzing of investments (or in this case, production method changes) must be consistent with wealth maximization, which underpins economic planning theory. This thesis uses Net Present Value (NPV) for the calculation of the wealth effects of a change in the production method and generates NPVs for the alternative grazing strategies through the use of Monte Carlo Simulation. The justification for this choice, and a more in-depth description of these methods and their assumptions follows.

4.1 Net Present Value as a Measurement of Wealth

NPV is the value, in the present, of future cash flows, both positive and negative, from a project or strategic decision (Ross et al. 2003). This valuation is done by discounting, converting future dollar values into current dollar values using the opportunity cost of capital or some other appropriate market rate, also known as the discount rate. Mathematically, from Copeland and Weston (1988) NPV may be calculated as follows:

$$NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+r)^t} - I_0 \quad (4.1)$$

where CF_t is defined as the cash flow for period t, I_0 is the initial cash investment in the project, N the project time horizon and r is the chosen discount rate. Per Copeland and Weston (1988), the discount rate chosen should reflect the opportunity cost of capital to accurately portray wealth maximization, and should also incorporate or account for the level of risk for the project (i.e., risk premium).

A commonly used approach in calculating the discount rate is the Capital Market Line Theory (CMLT). CMLT relates the opportunity cost of an investment and the risk free rate to determine what level of return results in the risky investment being preferred over the risk free investment. Cortus (2005), Koeckhoeven (2008), Trautman (2012) and Bruce (2017) provide extensive discussions regarding the use of CMLT in the context of establishing an appropriate discount rate for use in a resource economics analysis. However, while Cortus (2005) did use CMLT to estimate a discount rate, in the other studies listed here it was ultimately decided not to use the CMLT. Instead the return on a stock index was combined with an updated Canadian Bond Rate was used to arrive at a discount rate which, in all cases, turned out to be 10%. The CMLT-based discount rate calculated by Cortus (2005) was 13.91%, and Cortus determined this to be higher than was appropriate given median level of risk faced by producers. Ultimately, Cortus used a 10% discount rate as well. This 10% rate was also used in an Alberta Land Institute study of Alberta agriculture (Davies et al. 2017). As a result of this review of previous studies, a 10% discount rate was used in the current analysis.

4.1.1 Justification of Net Present Value as a Wealth Measure

NPV is not the only method of determining the impact of an investment common in the literature and in business. For example, the internal rate of return (IRR) is a common alternative, as are the payback period (PP) and the accounting rate of return (ARR) (Copeland and Weston 1988). While all come with advantages and disadvantages, NPV has been selected for this present research as it is the only method consistent with all the requirements laid out by Copeland and Weston (1988) for wealth maximization, which is the underlying theory for long term planning in economic models. These requirements are:

1. All cash flows be considered

2. The cash flows are discounted at the opportunity cost of capital
3. The capital budgeting system used should maximize wealth by selecting from mutually exclusive (choosing one option means the others cannot be selected) options
4. Project values should not be dependent upon other projects; they should be able to be considered on their own

As NPV is the only theoretically sound method for wealth maximization, and wealth maximization is the most straightforward way to discuss the results generated by this thesis, it was selected for determining the best grazing management strategy on the representative farms.

4.2 Modelling Agricultural Systems

While NPV was chosen as the framework to be used to calculate farm wealth in order to compare performance of alternative grazing management strategies, a method of modeling the data to use in the NPV formula was also required (i.e., the cash flows). There are two main forms of generating this data in economics: mathematical programming and simulation analysis. Mathematical programming is “concerned with the development of algorithms for the efficient numerical solution of discrete and continuous maximization problems” (Scarf 1989, p.2). A mathematical programming algorithm will, given the inputs and constraints employed, result in a maximum or minimum value being generated as a solution to an economic problem. With its prescribed inputs and constraints, mathematical programming has a high degree of accuracy - much higher than simulation in systems where the constraints are well defined and there is a reasonable degree of certainty in parameter values (Lund et al. 2017). This approach suffers, however, because it is challenging to build in uncertainty due to the non-stochastic nature of mathematical programming systems. It further suffers from a significant loss of accuracy with increased uncertainty in parameter values. Also, the structure of mathematical programming models tends to be somewhat rigid, making it a challenge to accurately model complex relationships, particularly as the number of them increase and potentially interact with each other. This can result in an oversimplified model (Lund et al. 2017; Lee Undated).

Simulation Analysis, like mathematical programming, also involves building an algorithm to help approximate real world relationships. However, simulation tends to be less rigid than mathematical programming, in terms of model structure. As opposed to seeking maximum or minimum solutions like mathematical programming, a simulation model attempts to recreate systems and solve to a new equilibrium when changes to inputs are made (Novales 2000). Free from the optimization constraints, simulation is also more flexible as instead of requiring parameter values to be specified with certainty, simulation programs may use distributions of potential parameter values, selecting from these distributions for every iteration (Novales 2000). The model is then run many hundreds or thousands of times, and the results averaged to narrow in on the true value. Simulation thus has obvious advantages over mathematical programming in systems where data is scarce, highly variable, or stochastic in nature, as well as requiring fewer assumptions about the parameters as they can be described with equations or relationships and are not represented by single numerical values (Lund et al. 2017; Lee Undated). This does come with the disadvantage of having to rely on averages for the results, and the ability to include stochastic elements over time introduces the challenge of doing so accurately and managing to deal with risk in the face of uncertain and random events (Lund et al. 2017; Lee Undated).

Both methodological approaches have their advantages and disadvantages and neither is inherently better than the other, but instead each has its own domain where it excels over the alternative. For the work required for this study, with many stochastic variables and a desire to compare systems, Simulation Analysis is the obvious choice.

4.2.1 Simulation Analysis

Due to the restrictions of mathematical programming outlined above, simulation analysis was selected as the modelling structure of choice for this thesis. Simulation analysis, at its most basic, is “the process of building a mathematical or logical model of a system or decision problem, and experimenting with the problem to gain insight into the system’s behavior or to assist in solving the decision problem” (Evans and Olson 2002 p.2).

Simulation modeling has been frequently used in agriculture, with Dent and Blackie (1979) and Csaki (1985) writing general textbooks on how to design optimal simulation models in the field. Both note the value of the flexibility generated by the models, and the ability to change inputs easily to generate comparative results across management decisions, disease pressures, and cost and price shocks.

For a stochastic simulation of an agricultural operation, the fixed costs for the operation (maintaining its machinery complement, costs per head for electricity or water, repairing its physical infrastructure) are calculated and put into the farm's costs. The variables over which the producer has decision-making control (input levels, herd retention) are then specified. Finally, the uncontrollable variable inputs (e.g., weather, prices) are drawn from pre-specified statistical distributions, completing the model inputs. These then interact to determine the net return on production in a year, with the controlled inputs and uncontrolled variable inputs interacting to determine the amount of commodity produced and the price at which it is sold, and the fixed per head costs and controlled variables interacting to determine the overhead. Simulating the system several times (i.e., multiple iterations) generates a distribution of income, and changing the controlled variables or distributions of uncontrollable variables allows for a comparison of production decisions or examining impacts of changes to risk levels.

4.2.2 Monte Carlo Simulation

Monte Carlo simulation, defined by Palisade (2020) as the class of simulation analysis that specifies stochastic parameters as distributions, is the specific type of simulation chosen for this study. By drawing from the stochastic distributions with every iteration, Monte Carlo simulation can create a distribution of relevant outcomes. For the current analysis, the outcomes are NPVs associated with the choice of grazing management strategy, accounting for the inherent uncertainty that comes with participating in an industry reliant on the weather and international prices. The simulation generates not only mean values, but also the standard deviations and other risk parameters. This allows not only a comparison of the payoffs of different strategies but the riskiness of these strategies as well. Monte Carlo Analysis also provides for flexible parameter specification, allowing for breakeven tests and sensitivity analysis to be performed. While subject to potential sampling error, as noted by Evans and Olson (2002), as with all sampling errors using a large number of iterations decreases errors in accordance with the law of large numbers.

4.3 Farm Models

This study focuses on the wealth impacts of changes to the grazing management system. By making changes to certain assumptions and management practices and then re-simulating through multiple iterations, the simulation model allows for an assessment of changes to the grazing system on farm wealth by comparing the post-simulation averages from the pre- and post-assumption change iterations.

The operation's representative, non-stochastic elements were built in first: ration components of cattle, the timing of sales and the size of the operation, amongst others. Then, because agriculture production is inherently risky, stochastic elements were incorporated to account for both price and production risks. Production risk was incorporated through the use of stochastic rainfall, which led to variable pasture productivity when connected to a pasture productivity equation. Price risk was incorporated through the use of stochastic market prices, for both cattle sold and for inputs with the highest variability that were used in large quantities (i.e., hay and barley). Risk was also incorporated into the model by means of the discount rate, discussed above. To mitigate some of this risk, the operation participates in publicly available risk reduction programs, detailed in Chapter 5.

Having generated the stochastic yields and prices for a year and having the fixed costs on a per head basis, the operation can then make animal sale and purchase decisions. Sale and purchase decision rules are explained in Chapter 5. Profit or loss, is recorded for the year, and the model then solves for profit for the next year, using new rainfall and price draws and carrying over the prior year's herd size. Profits or losses over a 20 year time horizon are discounted to provide the NPV.

Grazing management system changes were incorporated into the model by changing certain assumptions about the representative operation's infrastructure, and how that infrastructure impacted the biological productivity of the operation. Baseline assumptions about the operation structure, as well as the adjustments associated with changing the grazing management strategy, are detailed in Chapter 5. With these changes to the underlying model made, the simulation was run again and the new NPV compared with the baseline assumption - a greater NPV suggesting that more money could be made by switching systems, and a lower NPV indicating that the switch was a net loss to the producer.

4.4 Chapter Summary

This chapter aimed to describe the reasoning behind the use of certain theoretical tools and made an argument for the use of simulation modeling in the wealth maximization economic analysis, and using NPV as a proxy for wealth in that analysis. In order to factor in risk to this NPV analysis, further reasoning was laid out for the use of Monte Carlo simulation to incorporate both stochastic and non-stochastic elements. These stochastic elements include prices, both beef and crop, as well as precipitation, to allow for stochastic pasture production. Additionally, a general discussion of the modelling of agricultural operations and how the model operates on a high level was undertaken, to provide context to the construction of this model and the wider field of work, which is detailed more in Chapter 5.

Chapter 5: Empirical Simulation Model

This chapter provides details regarding the simulation model used to measure the effect of grazing management decisions on ranch and mixed farm wealth, as well as the model's data inputs. The model was built using the @Risk package for Monte Carlo modelling (Palisade Group 2020) in Excel, following the framework and reasoning laid out in Chapter 4. This modeling system allowed for a large model, with inclusion of stochastic factors such as rainfall, and the resulting pasture productivity, and cattle, barley and hay prices. Details of the business and biological aspects of the representative ranching operations are discussed to give a picture of the workings of the model and the assumptions needed to model representative cow calf and cow calf-cropping systems.

5.1 Representative Operations

The representative operations were built to reflect typical operations in the study areas of purely cattle focused operations and mixed crop-cattle operations. The representative operations included a ranch with a 700 head initial herd and a mixed crop-cattle operation with a 150 head initial herd. Both types of operations were modeled in the Boreal Transition in Lac Ste. Anne County, the Aspen Parkland in Ponoka County, and the Mixed Prairie in the County of Newell. A detailed description of the locations for the representative operations was provided in Chapter 3.

5.1.1 Cow Dynamics

5.1.1.1 Herd and Animal Size

When deciding on the size of the representative operations, two alternative approaches were considered. The first was to choose a fixed initial herd size for each operation type, with the land base being adjusted in each location to ensure that sufficient pasture productivity was provided. The second was to choose the land base, with the initial herd sizes then varying based on regional productivity. It was decided to use the same herd size across areas, as cattle operations are discussed in terms of herd size more commonly than they are discussed in terms of land base. Based on expert opinion, it was decided to set the initial herd sizes at 700 head for the ranch operations, and 150 head for the mixed operations (Brenna Grant 2020).

Also assumed about the operations was the size of cattle that would be produced and sold. Based on expert opinion (Brenna Grant, 2020; Tim McAllister, 2020), a distinction was made between animals (both cow weights and target weights for calves) for ranches located in sites in the North (Lac Ste. Anne and Ponoka) versus ranches at the more arid South site (Newell). Cows on the Lac Ste. Anne and Ponoka ranches were assumed to weigh 1500 lb with a forage requirement of 1.5 Animal Unit Months (AUM), and calf target weights of 630 lb. Cows on the South ranches (in Newell County were assumed to be 1300 lb with a 1.3 AUM forage requirement, and calves with 550 lb calf targets. Once weaned, calves were assumed to be grazed to higher target weights to make use of the available forage in years when pasture is highly productive or understocked. Specifically, calves could weigh up to 700 lb for the Lac Ste. Anne and Ponoka ranches and up to 605 lb for the Newell ranches, respectively, at the time of sale. Conversely, in dry or overstocked years, animals were sold when available forage ran out, at whatever weight was achieved.

5.1.1.2 Production Cycle

The production cycle for the beef herds was assumed to begin in June, when cows and replacement heifers would be bred. The number of calves born was slightly lower than the number of cows in the herd, due to a combination of conception rates being less than 100% and due some pregnant cows not carrying a calf to term. The likelihood of an animal giving birth to a calf, due to both imperfect conception and calving rates, was assumed to be 95% for cows and

85% for heifers[7]. The conception rate is the rate at which cows get pregnant after breeding and the calving rate is the percentage of cows that, having become pregnant, carry to term. Calving was assumed to occur in February, and calves were kept until November, when they were sold. Due to the biological nature of cattle ranching, there was a chance that some of the calves would not survive, and the likelihood of calf death was set at 1.4%[8]. There was also a chance of cow death, set at 1% (Koeckhoven 2008).

When a cow fails to become pregnant, fails to carry to term, or gets old and starts experiencing health problems, it is not a productive economic asset. In the simulation modeling, animals that failed to give birth were fattened over winter and culled in March per BCRC (2018)'s recommended best practices. Animals that reached old age were assumed to be culled in November, based on BCRC's (2018) extension recommendations. Both types of culled animals were assumed to be sold as D1[9] animals. It was assumed in the model that in addition to animals culled for infertility or removed from the herd as death loss, 10% of the herd would be culled for old age every year to keep the herd in an optimal condition. Selecting the old age cull rate and final herd turnover rate was not clear cut, as most empirical research in this area had a focus on dairy cows. The 10% rate was based on a) Funnell (2013) who determined that 48% of animals were culled by the age of nine, b) BCRC (2018) replacement plans pricing out animal purchases on 8-year horizons, and c) Koeckhoven (2008)'s beef model rate of a 16% cull across the herd. A 10% old age cull rate, coupled with infertility and death loss removals from the herd, resulted in a total herd cull of 15%. This fell within the bounds of previous work and extension planning recommendations for ranchers. Heifers were held back every year to replace

[7] These values were estimated based on Alberta beef cost of production and production parameter data made available for this project courtesy of the Economics Section of AAF.
[8] These values were estimated based on Alberta beef cost of production and production parameter data made available for this project courtesy of the Economics Section of AAF.
[9] D1 is the highest of four grades for cull animals, defined as having excellent (as opposed to medium to excellent in D2) muscling, with less than 15mm of firm, amber or white coloured back fat (differentiated from D2 by replacing amber with yellow) (OMAFRA 2015).

culled cows and dead animals, keeping the herd at a constant size, and an allowance was made to retain additional heifers to expand the herd if needed (see Section 5.1.1.4).

5.1.1.3 Bulls

The optimal bull to cow ratio is to have one bull for every 20-30 cows (Day 1999), with an average productive life span of 5 years in the herd (USDA 2019). Given the initial herd sizes, this resulted in there being 28 bulls for the ranch herd and 6 for each mixed herd. To maintain herd genetic diversity, bulls were assumed to be purchased by the operation for breeding and then culled at the end of their useful life. In order to avoid bull purchases biasing results, bulls were treated as a constant asset with fixed upkeep. Specifically, bulls were depreciated using the straight line method over their five year useful life, with purchasing and salvage costs from BCRC (2021). Bulls were sold at the expected salvage value from BCRC (2021) of $2375 per animal. However, given that the BCRC calculator was intended to represent the cost of maintaining bulls from the herd rather than purchasing them on the market, bulls were assumed to be purchased at a 20% premium, or $6396 per animal. Historic non-cull bull prices for Alberta (or Canada) could not be found. However, Meteer (2015) recommended paying between $4400 and $4800 USD for bulls, which equated to between $6061 and $6612 at Q1 2019 CDN$[10], putting the estimated price squarely in the middle of the range. This resulted in a yearly value for the bull complement of $44,809.52 for the ranch and $9,602.04 for the mixed operation, with each bull having a constant book value of $1600.34.

5.1.1.4 Herd Expansion

Producers may sometimes decide to change the size of the herd. For example, it may be decided to expand the herd size because of increased land base, successive good years

[10] All dollar values provided are in Canadian Dollars, at Quarter One of 2019 purchasing power, unless otherwise stated.

resulting in plentiful forage, restocking with a return to normal weather conditions after a sell off due to successive poor forage years, or a change in pasture management that results in increased available forage. Herd reductions can also occur, should there be a drought or change in pasture management or grazing management strategy that reduces available forage[11]. While the land base was assumed to be fixed in the current analysis, herd size changes resulting from other factors was considered to be relevant for the representative operations. Specifically, expansion of the herd was allowed in cases where it was warranted by increased or decreased availability of forage, and after a change to grazing management system. Herd expansion was done primarily through retaining additional heifers, keeping them to expand the herd instead of selling them. The expansion or contraction rule on a year-to-year basis for the simulation was that animals would be retained (or sold) such that the herd size AUM requirement for the following year was between the level of forage production from the current year (upper bound) and one AUM below current year forage production (lower bound)[12]. This was done in order to keep the pasture from being overgrazed in successive years.

Changing grazing management systems resulted, in some cases, in large changes to available forage due to changes to the utilization rate. As a result, it was assumed that up to 30% of available heifers were retained. A 30% cap was implemented to ensure the operation a) was not holding back more heifers than were born in a year and b) was not holding back heifers of questionable health, genetics, and breeding potential.

When changing grazing management systems, there were years where there was sufficient forage available to expand to a greater degree than possible through retention of

[11] There may also be economic reasons for increasing/decreasing herd size; that is, producers may respond to changes in beef prices. However, this was not modeled in the current study (see Section 5.2.2 for a more detailed justification).
[12] In reality, this is likely to vary significantly across producers and across zones, with individual producers having their own preference. As well, it is likely that a more conservative rule would be implemented in the more arid south. The assumption made in the current study provided for a consistent and systematic rule.

heifers. When this was the case, it was assumed that bred heifers may be purchased to the point where the herd was increased by 50%. This cap was imposed based on the assumption that beyond this point there would arise issues with availability of bred heifers and/or logistical constraints surrounding how many heifers could be processed and acquired in a year. Bred heifers were purchased at $1750, the BCRC (2018) recommended price.

As noted above, the herd expansion decision rule within the simulation analysis was based on increased forage availability. An additional decision rule was used to determine herd size expansion with a shift in grazing management strategy. The herd expansion per year was limited to an increase that could be supported based on 75% of the new anticipated available forage from a switch to a different grazing management regime, until the herd size had stabilized, at which point the model reverted to its original expansion/contraction rule. This was done to eliminate the potential for the analysis to result in repeated increases and decreases in herd size within a particular simulation iteration.[13] While not optimal to force an additional and somewhat arbitrary constraint on the model, given that most operations keep their pasture in good health (Pyle et al. 2018) and that most producers are risk averse (Sulewski and Kłoczko-Gajewska 2014) it seemed unlikely that producers would be making the “mistake” of retaining too many cattle in the expansion years and overgrazing their pastures, so a stabilizing constraint seemed appropriate.

More animals in the herd resulted in a greater demand for bulls to ensure an adequate conception rate. New bulls were bought whenever the bull:cow ratio was above 1:30, and were purchased until the ratio fell below 1:30, with a target ratio of 1:25 and a minimum of 1:20. Further details for each grazing management scenario are provided in Section 5.1.1.3.

[13] Not limiting herd expansion during the transition period resulted in problems that made it difficult for the model “settling” on an equilibrium to equilibrate at a constant herd size. In some cases, it took longer than the 20 year horizon to stop oscillating between heavy overgrazing and heavy undergrazing of pasture.

5.1.1.5 Winter Feeding

Animals were assumed to be fed a ration of barley and hay through the winter. This ensured adequate winter food supply and also assisted in avoiding pasture damage. The specific ration used in the simulation analysis was adapted from the work of Pogue et al. (2020). Details are provided in Table 5.1.

The ranching operation was assumed to buy all components of the ration (hay and feed barley) at simulated market prices, detailed in Section 5.2.2. This resulted in an average ration cost of $0.92/head/day for the ranch before adding the cost of supplements and minerals (See Section 5.3.2).

The mixed operation was assumed to "buy" the ration components from the cropping side of the operation at cost, with the cost of production data coming from AAF (2019a; 2019b). This resulted in an average daily ration cost of $0.69/head before considering the cost of minerals and supplements (Section 5.3.2). See Section 5.3.5 for a discussion of the mixed ranch cropping assumptions.

The time over which each ration is fed to cows differed for each of the grazing management treatments. This was due to differences in the length of the grazing season, as more intensive grazing rotation systems were often associated with a longer grazing season. Further details are provided in Section 5.4.1.2.

Table 5.1: Winter Rations for Cows and Heifers (kg/head/day).

		Lac Ste. Anne and Ponoka Counties		Newell County	
		Hay	Barley	Hay	Barley
	End Grazing- January	13.47	0.584	11.012	0.478
Cows	January-March	13.496	2.486	11.042	2.034
	April-Start Grazing	15.137	1.989	12.385	1.627
Heifers	End Grazing-Start Grazing	8.84	1.367	7.277	1.119

5.1.2 Land Base

An important decision in constructing the model was to determine the amount of pasture land required to support the cow herd for each representative operation. Determining the physical size of such operations proved difficult with available data. Appropriate size is a function of a number of factors, including geography, the target weight of animals, length of grazing period, average pasture productivity, producer risk tolerance for variability in pasture productivity, local real estate prices and long term operational legacy impacts, amongst others. It was decided to use the recommended herd size, the grazing period length data collected from participating producers for the wider project (Bork et al. 2021), and the expected AUM of cattle given the target weights for the three locations (BCRC 2020) to determine the land area needed to sustain the herd at their initial sizes. Additional assumptions were made that all the representative ranches had a combination of mixed and native pasture land consistent with proportions present in the host county (Statistics Canada 2016) and that pasture productivity was, on average, consistent with the BCRC (2020) estimates for the operation's region.

While recognizing that the resulting land bases were likely slightly higher than generally seen, it was decided that this systematic approach was appropriate given available information. The resulting sizes of the operations are summarized in Table 5.2. These values include an additional land base for operations in Newell County (i.e., dry Mixed Prairie region) that are assumed to use irrigation on some pasture (15% of tame pasture land base).

The area of cropland for the mixed operations also had to be considered. While the ranch was assumed to buy all winter ration components (hay and barley) at market prices (i.e., no cropping enterprises), by definition the mixed operation included a significant cropping operation. The decision was made to base the size and structure of the cropping enterprises on work by Trautman (2012). The land base for the mixed operations is also summarized in Table 5.2. Again, based on Trautman's work, the Lac Ste. Anne and Ponoka mixed operations used a crop rotation consisting of Alfalfa-Alfalfa-Alfalfa-Spring Wheat-Canola-Barley-Canola-Spring Wheat. The Newell operations (dryland and irrigated) used a crop rotation consisting of Alfalfa-Alfalfa-Alfalfa-Spring Wheat-Canola-Barley-Dry Beans-Spring Wheat. The area allocated to each crop during the rotation varied between the operations; 243.46 ha of each crop for Lac Ste. Anne and Ponoka operations and 203.06 ha per crop for the Newell operations. Further discussion about the mixed operations is provided in Section 5.3.5.

Table 5.2: Land Base and Pasture Composition of Representative Operations (ha).

	Ranch Pasture	Mixed Pasture	Percentage of Pasture, Tame	Mixed Cropland	Mixed Total Land Base
Lac Ste. Anne	3650	780	44.5	973.84	1753.84
Ponoka	4170	895	40.6	973.84	1868.84
Newell (Dryland)	11455	2450	10.5	1015.28	3465.28
Newell (Irrigated)	8622	1850	10.5	1015.28	2865.28

Statistics Canada (2016) and Trautman (2012)

5.1.3 Machinery Complement

Machinery is an important component of any agricultural operation, and this is certainly true for the representative operations modeled in this analysis. The machinery complement assumed to be used in these simulated operations had an impact on cash flows, particularly cash outflows. There were annual costs for fuel and repairs, as well as more irregular (but larger) cash outflows associated with machinery replacement. In the case of the representative operations in the current study, due to differences in the size and business focus of the two types of operations, commercial ranch versus mixed operation, they were assumed to need different machinery complements.

There are two common ways of building machinery complements for this sort of work: machinery requirement algorithms and ad-hoc selection. Algorithms for agriculture equipment selection have been developed based on operation focus, land base, location, and other factors. However, these algorithms tend to primarily focus on cropping operations with much less emphasis on beef operation equipment requirements. Cortus (2005), Koeckhoven (2008), and Trautman (2012) were all unable to find appropriate algorithms and data for use in similar simulation analyses focused on representative agricultural operations in Alberta or Saskatchewan. That difficulty continued in the current study.

Due to the lack of available machinery algorithms for cattle focused operations, the ad-hoc method was used to build the machinery complement. The ad-hoc selection method involves first determining tasks required to fulfil the tasks of an operation, and then selecting machinery that can fulfill these tasks in an economically efficient manner while also bearing in mind the tendency of farmers to have a larger machinery complement than would be assumed as necessary (Rotz 1983). For the mixed operation, as the crop side of the simulated farm operation was based on Trautman's (2012) model, the machinery complement was also based on her work. Her crop-focused operation contained the following machinery listed in Table 5.3 and 5.4.

Table 5.3: Cropping Machinery Complement of the Newell County Mixed Farming Operation.

Powered Equipment		Drawn Equipment		Other	
Item	Size	Item	Size	Item	Size
4WD Tractor	325 hp	Air Hoe Drill	40 ft	Bean Windrower	6R 30"
S.P. Swather	24 ft	Harrow	50 ft	Combine Header, Pickup	14ft
Combine	Class 7	Bean Rod Cutter	6R 30"	Combine Header, Straight Cut	30ft
Grain Truck One	350 hp			Combine Header, Bean Pickup	22ft
Grain Truck Two	350 hp			Grain Auger	10ft
Farm Truck	3/4 ton			Valmar	55 Series

Table 5.4: Cropping Machinery Complement of the Lac Ste. Anne and Ponoka County Mixed Farming Operations.

Powered Equipment		Drawn Equipment		Other	
Item	Size	Item	Size	Item	Size
4WD Tractor	325 hp	Air Seeder	50 ft	Combine Header, Pickup	16ft
S.P. Swather	24 ft	Harrow	80 ft	Combine Header, Straight Cut	30ft
Combine	Class 7	Cultivator	50 ft	Grain Auger	10ft
Grain Truck One	350 hp			Valmar	55 Series
Grain Truck Two	350 hp				
Farm Truck	3/4 ton				

Koeckhoven (2008) built an Alberta complement for a mixed crop-beef operation, and identified equipment needed for the beef enterprise, equipment required for the cropping enterprises, and equipment that would be shared. Powered equipment in the Trautman (2012) complement was sufficient to operate all ranching equipment specified in the Koeckhoven and Bruce models, so no further powered equipment was added to the machinery complement. However, some cattle specific tools were noted by Koeckhoven and were added to the mixed complement. These included a baler, a mower, a rake, a bale wagon, a grinder, and a feed wagon. With the exception of the feed wagon (assumed to have a 500 cubic feet capacity), there were not enough examples of any one item for sale in Alberta when prices were calculated to get a mean cost measure for a specific size of equipment, so sizes were not specific and all were assumed to be the average size of each available in Alberta. One final difference from the original Trautman (2012) complement was that equipment for seeding forage was included in the current study. This was assumed to be a Valmar seeder and heavy harrow system. The mixed complement already included a harrow, so a Valmar seeder was added to the farm machinery complement.

The commercial ranch operation complement was built based on the complement for the mixed operation developed by Koeckhoven (2008). Machinery that was purely for cropping, or that was larger than needed to run the ranching equipment, was not carried over into this complement. Discretion had to be used in some cases. The final ranching machinery complement is shown in Table 5.5.

Table 5.5: Ranch Operation Machinery Complement.

Equipment	Size
Bale Wagon	
Grinder	
Feed Wagon	1000 ft3
Harrow/Valmar	80ft/55 series
Light Tractor	150-250hp
Medium Tractor	200-250hp
Sprayer	90ft
Semi	595hp
Cattle Trailer	43ft

The cost of this equipment was determined by searching on the IronSearch (2020) website, consistent with Koeckhoven's (2008) work, with Alberta specified as the search zone. Machinery was assumed to be 5 years old, consistent with the assumption made in previous studies by Koeckhoeven (2008) and Trautman (2012). Equipment was excluded from the price averaging if it was greater than 10 years old. For a given equipment type, the values of the first results were averaged, with a minimum of 10 prices and a maximum of 15. If 10 samples of an item were not for sale at search, the value reported by Koeckhoven was used after being price adjusted using the Statistics Canada machinery price index (2020).

5.1.3.1 Machinery Complement Replacement

Because of the timeframe of the study (20 years), machinery replacement was a relevant issue. Machinery replacement strategies vary greatly between agricultural producers. Given that the expenditures associated with machinery replacement are large, arbitrarily picking a strategy could bias the empirical results. To ensure this did not occur, it was decided to proxy cash outflows for machinery replacement with a constant dollar amount. This approach is consistent with previous studies (e.g., Koeckhoven 2008; Trautman 2012). The average age of equipment was determined to be 5 years, in line with Koeckhoven (2008) and Trautman (2012), and machinery values were depreciated to the average age, assuming a depreciation rate of 8%. This resulted in annual machinery complement maintenance expenditures of $44,747 for the ranching operation and $12,261 for the mixed operation. Note that the costs of maintenance for the mixed operation were lower than the ranch operation despite having a larger complement as all machinery costs used by the crop side were attributed to the crop simulation; only ranching specific equipment was included in this calculation. Note also that this estimate represented the cost of maintaining ownership, not the costs associated with servicing and repairing the equipment. Repair costs are discussed in Section 5.3.2.

5.2 Stochastic Elements

All agricultural operations face some measure of risk. To produce anything dependent on the weather and to then sell and buy in markets where the prices are determined in large part by local and international demand, as well as supply and geopolitical events, involves large forces outside of producer control. To account for the stochastic nature of parts of the beef operations, Monte Carlo simulation, as discussed in Chapter 4, was used. The three stochastic simulation components of focus were a) weather, which influenced pasture productivity and by implication end weights of animals and length of grazing season, b) beef prices, affecting revenues, and c) prices of hay and barley, affecting input prices. Without these changing factors, the model would not have provided a complete picture concerning the nature of the impact of a change in grazing system on operation NPV. A discussion of how these stochastic elements are incorporated into the modeling is provided below.

5.2.1 Stochastic Weather and Pasture Yield

While the impact of weather on pasture yield was well known, obtaining a usable model that is relevant across Alberta was somewhat more difficult. Bork et al. (2001) and Smoliak (1987) both estimated pasture yield models that depended on weather variables; Bork et al. for the Boreal and Smoliak in the mixed grass prairie. However, both models were relevant for very specific conditions and context. Batbaatar et al. (2021) further supports the highly localized nature of the weather-pasture yield relationship. This limited the ability to which the Bork et al. (2001) and Smoliak (1987) results could be used for research that required generalizing beyond the region-specific nature of the results.

As a result, another method was required. BCRC (2020) had developed a calculator to determine pasture yield from rainfall, based on Alberta's rainfall zone and on the health of the pasture. Using productivity from the rainfall zone as a proxy for pasture productivity in each county was not as accurate as models developed for each area, but using one system to generate all of the yield results did provide consistency across locations within the study. Given that BCRC calculators are used by producers in making grazing management decisions and are designed for use province wide, it was decided to proceed using the calculator. Results were checked with a range expert (Carlyle 2020) and found to be within expected levels for the areas.

Pasture yield functions were estimated from the BCRC calculator for rainfall zone by generating a series of rainfall and yield data from the calculator and then using this data to run STATA's Non-Linear function. Quadratic models were found to have the highest R^2 values and these were used to estimate rainfall-yield relationships. Pasture for the representative ranches was assumed to be excellent in all cases for modeling; thus the excellent pasture equation was reported.

$$Yield_{kg/ha} = 1771.18 - 913.61 * Precipitation + (196.18 * Precipitation_{mm})^2 \quad (5.1)$$

Since precipitation level was the independent variable for pasture productivity for a given range score, precipitation levels were required to be stochastic to run the model. Precipitation data were obtained from AAF (2019) at the township level for each county. Within each county, data for six townships[14] were averaged over the period from April 1980 - April 2020 (AAF 2019). Using @RISK's distribution fitting tool, distribution parameters for growing season (May to August) and off season (September-April) precipitation levels were estimated. Values were drawn from these distributions when simulating the model. As the model was not built to deal with excessive or prolonged droughts or floods, precipitation values were truncated at plus/minus three standard deviations from the mean. Precipitation was not correlated from year to year to avoid large-scale herd sell-offs or build-ups. Further work looking at the impact of long periods of drought or long wet periods is an important area of further research. Distributions of weather, and associated important descriptive parameters are given in Table 5.6.

Table 5.6: Fitted Statistical Distributions of Moisture Levels By Location and Season used to Simulate Beef Cattle Operations in Alberta.

Location of Operation	Growing Season	Dormant Season
Lac Ste. Anne	Normal Distribution	Rayleigh Distribution
	Mean - 299.065 SD - 70.341	Mean - 85.345 Shape - 77.807
Ponoka	Rayleigh Distribution	Uniform Distribution
	Mean - 104.13 Shape - 158.25	Upper - 81.428 Lower - 274.6
Newell	Rayleigh Distribution	Rayleigh Distribution
	Mean - 106.47 Shape - 52.237	Mean - 72.349 Shape - 49.855

[14] The township in the geographic centre of the county was selected first. Then, the townships on the four cardinal direction borders were included. AAF (2019) allowed data to be accessed six townships at a time, so the most North-West township relative to the geographical centre township was also incorporated into the average.

Final pasture yields were then determined by substituting the stochastic precipitation values from the distribution draws into the yield equations built from the model. While equations for all grades of pasture were estimated, only the “Excellent” pasture quality equation was used in the simulation models.

5.2.2 Stochastic Pricing Model

As noted above, beef prices and prices for some ration ingredients were also modeled as stochastic parameters in the simulations. Historical beef price data were acquired from Canfax (Komirenko 2019). The data were monthly, for the period January 1976 through July 2019, for multiple animal types and weight classes in multiple regions. Specifically, prices were collected for steers in seven weight classes, six heifer weight classes, and three categories of cull cows, in South, Central and Northern price zones. As data for the Central zone were available for a much shorter time period, only North and South data were used for analysis. Heifers were assumed to be sold in the 500-600 cwt weight class, while steers were sold in the 500-600 cwt (South) or 600-700 cwt (North) classes. Culled cows were sold as D1 Cattle, at November prices for aged out animals and March prices for early cull cows.

Prices for ration crops (barley and hay) were also estimated in the price model. Barley prices from 1976 to 2009 were obtained from AARD (2010), while 2010-2017 prices were obtained from AAF (2017). In both cases, the prices were at a provincial level of aggregation. Earlier data did exist, but it was decided to keep the time frame the same as was used for the beef price data.

Some hay price data were available from AFSC (2019), but only for the period 2012-2018. Due to the lack of historical data, and because of the local nature of hay markets, hay prices were modeled using a separate fitted distribution based on the available data. This was done so that the small sample size would not influence the wider pricing model when correlated together while still having some element of stochastic hay prices.

Hay prices were determined to be normally distributed. The resulting distribution parameters are presented in Table 5.7. Annual values were drawn from this distribution and used in the simulation analysis. Hay prices were truncated at plus/minus three standard deviations from the mean. Hay was priced as the average price of first and second cut hay in the appropriate production zone, in the October-December pricing period. Prices for both animals and crops were converted to January 2019 dollars using the Statistics Canada Consumer Price Index.

Table 5.7: Parameters used in Normal Distributions for Estimating Prices of Hay Across Regions in Alberta, Years 2012-2018 ($/lb).

	Lac Ste. Anne	Ponoka	Newell
Mean	0.123	0.16	0.184
Standard Deviation	0.05	0.055	0.042

In previous similar studies of Alberta cow-calf production (e.g., Koeckhoven 2008, Bruce 2017) stochastic prices were modeled as functions of lagged historical prices; that is, using time series modeling. However, this approach was chosen based on an assumption of stationarity in prices. In the current analysis, Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests were used to test the stationarity of beef and barley prices. The null of the ADF test is that the prices are non-stationary while the KPSS null assumes stationary prices. The test results are summarized in Tables 5.8 and 5.9.

Table 5.8: Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test Results for Lac Ste. Anne and Ponoka Pricing Models.

	ADF		KPSS	
	Test Statistic		Test Statistic	Lag
Steers	-2.805***		0.208**	1
Heifers	-3.120**		0.159**	1
Cows, Spring	-2.351		0.218*	1
Cows, Fall	-2.179		0.231*	1
Barley	-3.029**		0.238*	3
	Beef Critical Value for ADF Test	Crop Critical Value for ADF Test	Critical Value for KPSS Test	
1%*	-3.634	-3.641	0.216	
5%**	-2.952	-2.955	0.146	
10%***	-2.61	-2.611	0.119	

The ADF test determined that cow prices were non-stationary, while all other prices were stationary. The KPSS test results suggested that prices were not stationary, at varying levels of significance; steer and heifer prices were stationary at less than 5%, the others at 1%. Based on the overall results for these tests (i.e. ADF reporting stationarity and KPSS suggesting not) it was concluded that no correction was needed for a unit root, understanding that cow prices were likely non-stationary but that this would have a limited effect on the performance of the model.

Table 5.9: Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test Results for Newell Pricing Model.

	ADF		KPSS	
	Test Statistic		Test Statistic	Lag
Steers	-2.907***		0.202**	1
Heifers	-3.305**		0.142***	1
Cows, Spring	-2.351		0.218*	1
Cows, Fall	-2.179		0.231*	1
Barley	-3.029**		0.238*	3
	Beef Critical Value for ADF Test	Crop Critical Value for ADF Test	Critical Value for KPSS Test	
1%*	-3.634	-3.641	0.216	
5%**	-2.952	-2.955	0.146	
10%***	-2.61	-2.611	0.119	

Given the ADF/KPSS test results, the five price categories were each assumed to be a function of their lagged prices. To account for possible correlation between prices, SUR estimation procedures were used to estimate the time series equations. . The price equations took the form:

$$P_t^j = \beta_0^j + \sum_{i=1}^{n} \beta_i^j P_{t-i}^j + \varepsilon_t^j \quad (5.2)$$

where P_t^j was the current price of the j[th] commodity, P_{t-i}^j was the i times lagged price of the j[th] commodity, ε_t^j was the error term and β were the estimated parameters. Price equation error correlations and random error draws were used to complete the pricing model.

Optimal lag lengths were determined using the minimum of the Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC) test statistics. The test statistics are provided below in Tables 5.10 and 5.11. All tests were conducted over 10 periods. Optimal lags for cattle prices were all one period; the optimal lag for barley price was three periods. SUR modeling was then carried out. The resulting price model parameters are provided in Tables 5.12 to 5.14.

Table 5.10: Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC) Lag Length for Lac Ste. Anne and Ponoka (*= Minimum of Criterion; **=Minimum of Both Criterion).

		Number of Lags										
		0	1	2	3	4	5	6	7	8	9	10
Steers	AIC	2.54	2.02	2.06	2.06	1.94*	2	2.06	2.11	2.17	2.22	2.24
	SIC	2.58	2.12**	2.2	2.24	2.16	2.27	2.37	2.48	2.57	2.67	2.74
Heifers	AIC	2.4	1.98	2.02	2.04	1.95*	2.01	2.07	2.13	2.18	2.24	2.26
	SIC	2.45	2.07**	2.16	2.22	2.17	2.28	2.39	2.49	2.59	2.69	2.75
Cows, Spring	AIC	1.65	0.73**	0.78	0.84	0.9	0.93	0.97	1.03	1.09	1.12	1.18
	SIC	1.69	0.82**	0.92	1.02	1.12	1.2	1.29	1.4	1.49	1.58	1.68
Cows, Fall	AIC	1.66	0.77**	0.82	0.86	0.87	0.93	0.95	0.98	0.97	0.99	1.03
	SIC	1.71	0.87**	0.95	1.04	1.09	1.2	1.27	1.35	1.38	1.45	1.52
Barley	AIC	-3.4	-3.6	-3.6	-3.7**	-3.6	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5
	SIC	-3.4	-3.6	-3.6	-3.6**	-3.4	-3.4	-3.3	-3.2	-3.1	-3	-3

Table 5.11: Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC) Lag Length for Newell (*= Minimum of Criterion; **=Minimum of Both Criterion).

		Number of Lags										
		0	1	2	3	4	5	6	7	8	9	10
Steers	AIC	2.71	2.26	2.3	2.31	2.23*	2.29	2.35	2.41	2.46	2.52	2.55
	SIC	2.76	2.35**	2.44	2.49	2.45	2.55	2.66	2.77	2.87	2.96	3.05
Heifers	AIC	2.55	2.18	2.22	2.24	2.12*	2.18	2.24	2.29	2.35	2.4	2.43
	SIC	2.6	2.27**	2.36	2.42	2.34	2.45	2.56	2.65	2.76	2.86	2.93
Cows, Spring	AIC	1.64	0.73**	0.78	0.84	0.9	0.93	0.97	1.03	1.09	1.12	1.18
	SIC	1.69	0.82**	0.92	1.02	1.12	1.2	1.29	1.4	1.5	1.58	1.68
Cows, Fall	AIC	1.66	0.78**	0.82	0.86	0.87	0.93	0.95	0.98	0.98	1	1.03
	SIC	1.71	0.87**	0.95	1.04	1.1	1.2	1.27	1.34	1.38	1.45	1.52
Barley	AIC	-3.4	-3.6	-3.6	-3.7**	-3.6	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5
	SIC	-3.4	-3.6	-3.6	-3.6**	-3.4	-3.4	-3.3	-3.2	-3.1	-3	-3

Table 5.12: Price Correlation Coefficients.

Lac Ste. Anne and Ponoka Counties	Steer	Barley	Heifer	Cow, Spring	Cow, Fall
Steer	1.000				
Barley	-0.045	1.000			
Heifer	0.992	-0.062	1.000		
Cow, Spring	0.497	0.295	0.520	1.000	
Cow, Fall	0.835	-0.023	0.823	0.403	1.000
Newell County	**Steer**	**Barley**	**Heifer**	**Cow, Spring**	**Cow, Fall**
Steer	1.000				
Barley	-0.073	1.000			
Heifer	0.989	-0.055	1.000		
Cow, Spring	0.506	0.295	0.497	1.000	
Cow, Fall	0.815	-0.023	0.811	0.403	1.000

Table 5.13: SUR Price Model Coefficients for Lac Ste. Anne and Ponoka; All Significant at 1%.

	Steer	Heifer	Cow, Fall	Cow, Spring	Barley
P_{t-1}	0.646	0.628	0.712	0.739	0.903
S.D	0.065	0.070	0.058	0.087	0.126
P_{t-2}					-0.529
S.D					0.161
P_{t-3}					0.339
S.D					0.116
Constant	1.345	1.298	0.467	0.512	0.056
S.E	0.269	0.265	0.114	0.190	0.021
R^2	0.522	0.452	0.713	0.588	0.656

Table 5.14: SUR Price Model Coefficients for Newell; All Significant at 1% Except Barley at 5%

	Steer	Heifer	Cow, Fall	Cow, Spring	Barley
P_{t-1}	0.629	0.628	0.727	0.765	0.905
S.D	0.061	0.068	0.056	0.087	0.127
P_{t-2}					-0.489
S.D					0.163
P_{t-3}					0.357
S.D					0.117
Constant	1.495	1.356	0.442	0.459	0.043
S.E	0.276	0.274	0.112	0.191	0.021
R2	0.501	0.416	0.715	0.588	0.657

It should be noted that, while the cattle market is noted to go through cyclical price phases that are approximately 10 years in duration (Canfax 2018), the pricing model in the current study did not incorporate cyclical pricing. This was for two primary reasons: 1) the length of a cattle cycle, and of its four component phases, is highly variable from cycle to cycle, and 2) the variance in price over the cycle and from cycle to cycle is high (Canfax 2018). While it would have been feasible to model such a cycle, the amount of additional data required to accurately capture the effect of the cattle cycle made it beyond the scope of the project.

5.3 Economic Relationships

As outlined in Chapter 4.3, NPV was chosen as the financial measure used to compare treatments. To determine the NPV, a Modified Net Cash Flow (MNCF) was calculated and used to proxy the operation’s income in each year of the simulation, and thus to determine the operation’s performance. MNCF includes elements of gross margin (revenue minus variable costs) and net cash flow (cash inflows minus cash outflows) (Koeckhoven 2008). MNCF incorporates revenues and expenses from the raising and selling of beef animals and, in the case of the mixed operations, cropping activities. Also included are the participation costs and payouts associated with government risk management programs and the outflows associated with the upkeep of the machinery and equipment needed to keep the operation running, per Chapter Four. This section describes the components of the revenues and expenses of the operation as well as how participation in public risk management programs, specifically AgriStability is modeled.

5.3.1 Cash Inflows

The commercial ranch operations have two cash inflows: revenues from the sale of livestock and payments from AgriStability. The mixed operations have a third inflow, from the cropping side of the operation, that is functionally independent of the cow-calf operation and its AgriStability support claims. A discussion of the mechanics of AgriStability, its payments, and a discussion of non-participation in other potential support services follows in Section 5.3.3.

Revenues from the sale of animals was largely derived from the sale of steers, heifers, and cull cows.[15] The value paid for each animal was calculated as the product of animal weight and the stochastic price drawn for the relevant weight class, price zone, and sale period. This was North or South price zones, 500-600 cwt or 600-700cwt for the steers and heifers, D1 price for cull cows, November prices for steers, heifers, and aged out cows and March prices for animals culled due to infertility. Culls were sold in different periods, depending on the reason for removing animals from the herd. Older animals had lower weight gain over the winter and were more likely to die or have health problems. Thus, selling them in the fall was a less risky strategy. Healthy animals culled for infertility were assumed to be less likely to get sick or die over the winter and thus have a better rate of gain. They were sold in March to capitalize on the (often) higher March price and to hedge against the potential of the March price going down.

[15] The operation also generates some revenue from bulls. See Section 5.1.1.3 for details.

Heifers and steers were sold at the weight achieved when they come off pasture, with the amount of weight gain being subject to either forage availability in drier years when weight gain is constrained, or time of year in average or better than average years where gain was limited because of the sale time prescribed by the model to conform to the assumed price period. To prevent simulated rates of gain from becoming unrealistically high, as they were determined exogenously in the model for a given target weight and period of grazing, there was a maximum weight of 700 lb for North animals and 605 lb for South animals imposed in the model.

The mixed operations had additional revenue from cropping enterprises. Section 5.3.5 provides further discussion of these revenues.

5.3.2 Production Costs

Production costs were those expenses associated with inputs into the beef or crop production process. Beef enterprise production costs included such costs as veterinary and medicine, fuel, repairs and maintenance, and trucking and marketing. These were obtained from two sources. Most of the costs came from the Government of Manitoba's (2020) beef production cost calculators. The cost of winter bedding and custom work were adapted from Koeckhoven (2008) and were adjusted to Q1 2019 dollars using Statistics Canada's (2020) Farm Input Price Index.

Alberta beef cost data were considered for use in the modelling[16]. However, it was decided to not to use these data, but instead use Manitoba information. This was because the Alberta data provided a far less detailed breakdown, with many cost categories being amalgamated. As the Manitoba costs were similar to those reported by AAF (2020) and the inflation-adjusted numbers used in Koeckhoven (2008), it was elected to use the Manitoba

[16] Alberta beef cost of production data were obtained from the Economics Section of AAF

numbers for all but the winter bedding costs and custom work from Koeckhoeven (2008) that could not be found elsewhere. Numbers for the cost category Taxes, Licenses, Water Rate, etc., was taken from AAF (2020) as these were deemed to be significantly different from those in Manitoba. Costs on a $/head basis are detailed in Table 5.15.

Table 5.15: Production Costs ($/Head).

Cost Component	Costs
Pasture Costs	33.10
Minerals	37.55
Veterinary and Medicine	23.60
Bedding	7.79
Trucking/Marketing	35.00
Fuel, Repairs & Maintenance	36.72
Utilities	11.00
Custom Work	2.06
Labour	192.00
Taxes, Water Rates, Licenses, etc.	10.97

5.3.3 Agricultural Support

Canada has a wide array of agricultural support programs and services. The two most relevant for beef operations in Alberta are AgriStability and the Western Livestock Price Insurance Program (WLPIP). The WLPIP is a price insurance program offering coverage from price, currency, and basis volatility. This is important, as beef markets can be volatile and beef prices in Canada are heavily influenced by the USD and American futures markets. Support is offered in five classes: calf, feeder, fed, cattle price reporting and for hogs. However, the decision was made to not have the representative operations participate in this program, as there actually is very low participation by Alberta beef producers in WLPIP (Boyd 2020). In addition, to properly model the WLPIP program would necessitate building currency exchange volatility and futures market volatility into the simulation model and this was not deemed sufficiently valuable to the overall project objectives to warrant the additional model complexity required.

Participation in AgriStability by the representative operations, however, was included in the models. AgriStability is a joint federal-provincial agriculture support program designed to decrease farm income volatility and is open to both cropping and livestock operations.
The program works by first determining the Applied Reference Margin (ARM), which is used to determine the point at which AgriStability payouts are "triggered". The ARM value is equal to the lesser of two alternative calculations; the Olympic Average Reference Margin (OARM) and the Reference Margin Limit (RML). The OARM is the average margin calculated using a list of permitted revenues and expenses made by the farm in three of the last five years, with the highest and lowest margin years being dropped. The RML is the average of the allowable adjusted expenses[17] in the same three years used in the OARM Calculation. However, if the RML is less than 70% of the OARM, the ARM is set to 70% of the OARM.

If the producer's actual margin, or production margin (i.e., permitted revenues minus allowable adjusted expenses), falls below the ARM, producers receive a payment equal to 70% of the difference between the ARM and the production margin. The minimum AgriStability payment is $250, and payment is capped at $3,000,000.

Producers are charged nominal fees to participate in AgriStability. Fees are equal to 0.45% of the OARM calculated two years prior to the program year, multiplied by 70%, plus a $55 administrative fee. There is a minimum payment of $45 required (AFSC 2019).

---

[17] AFSC maintains a list of what expenses are considered allowable for inclusion in creating the RML, with the chief aim of preventing farms from triggering a payout by making substantial capital purchases, reducing their net income. See AFSC (2019) for the full list.

In the case of the mixed operation, the cropping component, adapted from Trautman (2012), had its own initial assumptions about support. It participated in CAIS[18], the precursor to the current AgriStability program. CAIS operated in much the same way as AgriStability, at an 85% coverage level. Further, it was assumed in the models that the producer participated in crop insurance, at an 80% coverage level.

5.3.4 Other Cash Outflows

Besides the production costs associated with beef production (and crop production in the case of mixed operations), there were also other cash outflows considered in the MNCF calculation. These included expenditures associated with purchasing bred replacement heifers, if needed. While the primary source of replacement animals was retained heifers (see Section 5.1.1.4) the operations were able to buy more animals on the market to expand if this source proved insufficient. These heifers were bought at the simulated November market price. Described in Section 5.1.3, there were also expenditures modeled associated with the upkeep of the machinery complement, through machinery replacement. The proxied annual expenditure required to maintain the initial book value of machinery was $44,747 for the commercial ranches and $12,261 for the mixed operations.

Lastly, there were expenditures associated with the purchase of bulls. Discussed in Section 5.1.1.4, replacement bulls for breeding purposes were assumed to be purchased. The annual expenditure for this purpose was calculated to be $44,089.52 and $9,602.04 per year for the baseline commercial ranches and mixed operations, respectively.

[18] CAIS is the Canadian Agricultural Income Stabilization program, which operated from 2003-2006

5.3.5 Mixed Operation Cropping

Mixed operations are, as the name would suggest, a mix of both cow-calf and cropping in one operation. This is a common structure of operation in Alberta and comprises the majority of herds in the province not operated by hobby farmers (Statistics Canada 2016). Because of this, modeling a smaller herd with the same structure as the ranch operation would not be an accurate or overly useful representation of cow-calf operations of this size, as most operations with smaller herds also include significant cropping enterprises.

There has been previous economic analysis in Alberta focused on mixed operations: studies by Koeckhoven (2008) and Bruce (2017) focused on the impacts of adopting BMPs by mixed operations. Due to the nature of their research questions, both the beef and cropping sides of their simulated operations were modelled explicitly. This current project, however, is slightly different. Specifically, the grazing management practices researched here affect only the cow-calf side of the operation, other than the impact on cropping in terms of the small amounts of crop used for winter feed. Given the number of locations and the treatments, focusing on the cropping side was not considered beneficial and more focus was devoted to the direct answering of the research question focused on grazing management. As a result, it was decided to not model the cropping side explicitly. Instead the cropping models from Trautman (2012) were used. These models, developed and originally used in a cropping BMP study, are for representative operations located in the same regions of Alberta employed in the present study.

The Trautman (2012) models are of a similar nature and design to the models built for this grazing study. There are multiple locations, in multiple environmental regions of differing climate and growth conditions, with different treatments to the cropping operations modelled at each location. The Trautman (2012) study looked at three sites in the Mixed Prairie region: Taber, Starland and Forty-Mile Counties. In approximating the Newell site in the current study, data from the Taber simulation were used, as Taber and Newell counties are adjacent, while Starland and Forty-Mile are further away. The Trautman (2012) cropping operation from Camrose County in the Aspen Parkland as used to represent the mixed operation in Ponoka County, as this was the only Aspen Parkland site modeled by Trautman. Deciding which Trautman (2012) operation to use for the Lac Ste. Anne mixed operation was more challenging, as there were no Boreal Transition sites modeled by Trautman. There was a representative cropping operation located in the Boreal region, in the M.D. of Smoky River, but substantial differences exist between the Boreal and Boreal Transition in weather and soil types. In the end, it was elected to use the Camrose site to represent cropping for the Lac Ste. Anne mixed operation. While in a different zone (Aspen Parkland versus Boreal Transition), the Camrose site was some 200 km closer to Lac Ste. Anne than was Smoky River, and also shared a similar soil type and latitude.

Both Trautman (2012) operations differed slightly in a few key metrics. The differences in the machinery complements have already been mentioned in Section 5.1.3. This difference arose from the major difference in the operations' size. The Taber cropping operation used to represent the cropping portion of the Newell mixed operation was 1015.28 ha, while the Camrose cropping operation used to represent cropping for the two Northern sites was 973.84 ha in size. The two sites also had slightly different crop rotations. The Newell mixed operation was originally assumed to have a rotation of Alfalfa-Alfalfa-Alfalfa-Spring Wheat-Canola-Durum Wheat-Dry Beans-Spring Wheat, but Durum Wheat was replaced with Barley when simulated for the current analysis to provide barley for winter rations. The two North Site ranches were assumed to have a rotation of Alfalfa-Alfalfa-Alfalfa-Spring Wheat-Canola-Barley-Canola-Spring Wheat. Both locations had equal areas for all crops: 243.46 ha of each crop for the Lac Ste. Anne and Ponoka operations, and 203.06 ha per crop for the Newell operations. Given the large area covered by each crop and the assumption of no devastating drought or flood years, there was no risk of failing to meet the winter feed requirements with this given land base, so no emergency purchasing of winter feed rules were needed.

The Trautman (2012) models were both consistent with this model in their design of representative operations, using crop yield and pricing models designed for Monte Carlo work and estimating production costs in the same manner. Further, machinery complements were designed and depreciated in the same manner, while the discount rate was also identical.

To use the Trautman (2012) models, they were first simulated 1000 times, to match the simulation number used for this model. Distributions of the Net Cash[19] per hectare (inclusive of program payments) were then estimated and adjusted to Q1 2019 dollars using the Statistics Canada (2020) inflation estimates. Based on these distributions of 1000 simulated values, the distribution fitting tool in @Risk was used to estimate distribution parameters to include in the mixed operation models. For both models (i.e., Camrose and Taber) the best fitting distribution was Log Logistic. The resulting estimated parameters are provided in Table 5.16. These distributions were then included in the respective mixed operations as a random draw for every year, adding to the operation's yearly return. Total MNCF for the mixed operation in a particular year was calculated as the sum of the stochastic Net Cash per hectare, multiplied by the number of cropping hectares for the particular mixed operation, and the MNCF associated with the cow-calf enterprise for the operation.

As discussed in Section 5.1.1.5, the beef operation used barley and hay in the winter rations, and it was assumed that this barley and hay came from crops produced by the mixed operation. The simulated values for hay and barley prices (Section 5.2.2) were used to value these commodities as they were transferred from the cropping enterprise to cow-calf enterprise for the operation. The estimated dollar value of the commodities was then reduced by the cost of production of these commodities, estimated from AgriProfit$ (AAF 2019a and 2019b) for the

[19] "Net Cash" is the same as the modified net cash flow (MNCF) measure generated by the model developed for the current analysis.

operations located at the North and South sites, respectively. This net profit for the hay and barley was then subtracted from the cropping side profit, to reflect the reduced cash sales of those commodities by the operation.

The main benefit of the approach taken here for the cropping portion of the mixed operations was parsimony in modeling. However, there were limitations associated with the approach as well. The most obvious was the lack of connection between the draws for the whole model and the cropping side; that is, the weather draws for the pasture productivity and the weather draws for the crop yields, as well as the price draws, were not correlated. There were also issues with the calculation of Business Risk Managament (BRM) program support. BRM are government run programs, discussed more in Section 5.3.3. AgriStability, as well as the precursor (CAIS) used in the Trautman (2012) models are/were whole farm programs. However, in the current modeling the calculations were done separately. The mixed operations thus had an inaccurate AgriStability calculation, as the support for the cropping enterprises was captured through the Net Cash draws while the support for the cow-calf enterprise was explicitly calculated. AgriStability payments were thus likely to be lower for operations than was modeled in the current analysis, as the crop side would potentially have buffered income declines on the cow-calf side, and vice versa. While of some concern, neither was considered a significant problem, as the production related issues were minimized by the 20-year time horizon being considered sufficient for good and bad weather years to average out production on the crop and beef sides, and crop side production being sufficient to provide ration crops in all cases.

Table 5.16: Distribution Parameters of the Log-Logistic Mixed Operation Crop Yield Estimation (kg/ha).

Region	Gamma	Beta	Alpha
North	-485.4	783.9	14.35
South	-1024.39	1400.88	17.07

5.4 Modelling of Rotational Grazing Decisions

Since the focus of this project was on the economic impact of alternative grazing management decisions, different grazing systems were identified and defined for modeling purposes. This was done using data for participating producers from the wider project (Bork et al. 2021).

5.4.1 Determining the Representative Grazing Management Systems

As discussed in Chapter 2, grazing management exists along a continuum of practices, with those reporting AMP and those reporting non-AMP existing at almost all points along this spectrum. Data for producers participating in the larger project were analyzed to identify appropriate management systems to examine in the current study, by identifying representative groupings. Specifically, Cluster Analysis was employed to develop groupings, which then formed the basis for defining the different strategies. Average Linkage Cluster Analysis was used, as the purpose of the clustering is to determine group averages afterward. Data from the wider project (Bork et al. 2021) were clustered based on the number of paddocks, and the stocking rate for each ranch. These criteria were used because AMP is defined in terms of an increase in the number of paddocks and the associated stocking density within those paddocks (Bork et al. 2021).

The Calinksi-Harabasz stopping rule, which uses a pseudo-F statistic to determine similar clusters, was utilized to identify the "optimal" number of clusters, with a max of n=15[20] where n is the number of clusters. This rule involves looking at the sum of squared distances within a partition and comparing that to the data outside the partition, considering the number of clusters and the size of the data (Halpin 2016). The resulting test statistics for the alternative

[20] This is the standard value for n in the STATA software package for this analysis, where n=15 is the maximum number of clusters.

numbers of clusters are provided in Table 5.17. This reveals that there is a natural peak in statistic value for four, eight, and ten clusters (i.e., n=4, n=8, and n=10).

Table 5.17: Cluster Analysis Stopping Results, Clustering on Paddock Number and Stocking Rate, Full Dataset of Participating Producers.

Clusters	Calinski/Harabasz pseudo-F
2	1534.84
3	2103.78
4	5486.75
5	4931.02
6	6736.97
7	7193.07
8	8092.14
9	7995.18
10	16645.21
11	16006.56
12	16824.03
13	19460.83
14	19395.84
15	22354.84

Even at clusters for n>15, ranchers using continuous grazing (i.e., only one paddock) were still included in groups with ranchers practicing "light" rotational grazing. To avoid combining characteristics of both continuous and rotational grazing practices in defining specific grazing management strategies, ranchers who have only one paddock (11 observations in total) were removed from the clusters, and placed into a separate "Continuous" group, as Continuous Grazing is a standard baseline for purposes of comparison in the grazing literature. Also, a massive outlier observation, which has over 1500 paddocks, more than 10x the next amount and significantly greater than the data average, was also removed. The clusters were then run only on those practicing rotational grazing in some form. The results are presented in Figure 5.1 and Table 5.18.

In Figure 5.1, the height of the vertical bar indicates the degree of dissimilarity between operations. Individual operations are represented by the terminal ends of the bars, at the base of the dendrogram, and clusters of operations and clusters of clusters of operations are represented by horizontal bars containing all operations and clusters branching from them.

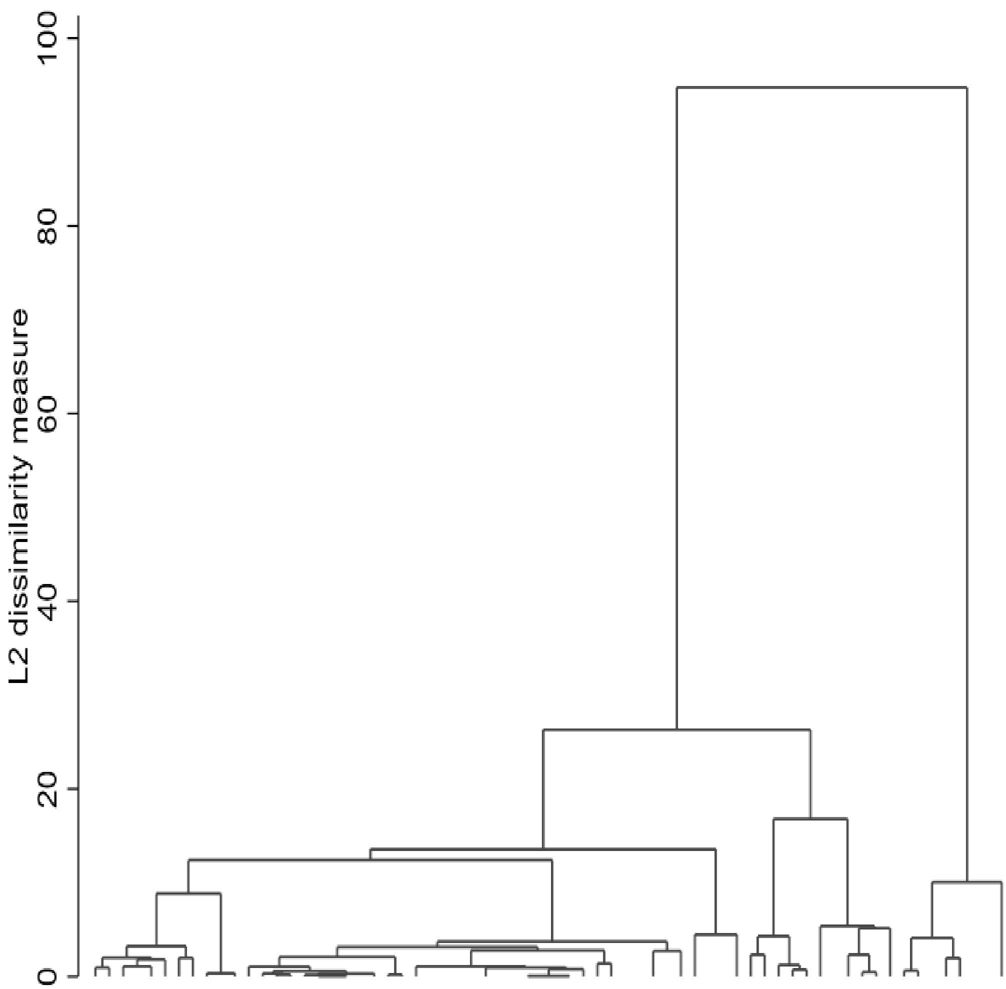


Figure 5.1: Dendrogram of Participating Producers, Clustered on Paddock Number and Stocking Rate, No Outlier and No Continuous Operations

Table 5.18: Cluster Analysis Stopping Results, Clustering on Paddock Number and Stocking Rate, No Continuous Operations or Outlier.

Clusters	Calinski/Harabasz pseudo-F
2	93.21
3	226.11
4	186.23
5	261.77
6	282.54
7	332.15
8	335
9	631.04
10	608.59
11	658.91
12	644.5
13	718.67
14	988.78
15	995.22

The results in Figure 5.1 and Table 5.18 indicate that three, nine and eleven clusters are now natural groupings of ranching practices. For ease of analysis and explanation, it was decided to use three clusters. Specifically, rotational grazing was split into three distinct grazing management strategies: low, medium, and high rotational grazing, referred to as Traditional, Slow AMP and Fast AMP, respectively. It should be noted that not all participating producers who were included in the AMP categories self-identified as such. These three grazing management strategies corresponded to 8, 50 and 115 paddocks, respectively. The dendrogram detailing their clustering is given in Figure 5.2. Continuous grazing was defined as a fourth strategy, represented in the participating producer sample by the 11 observations where there was a single paddock. The continuous grazing strategy was used as the baseline in the simulation analysis.

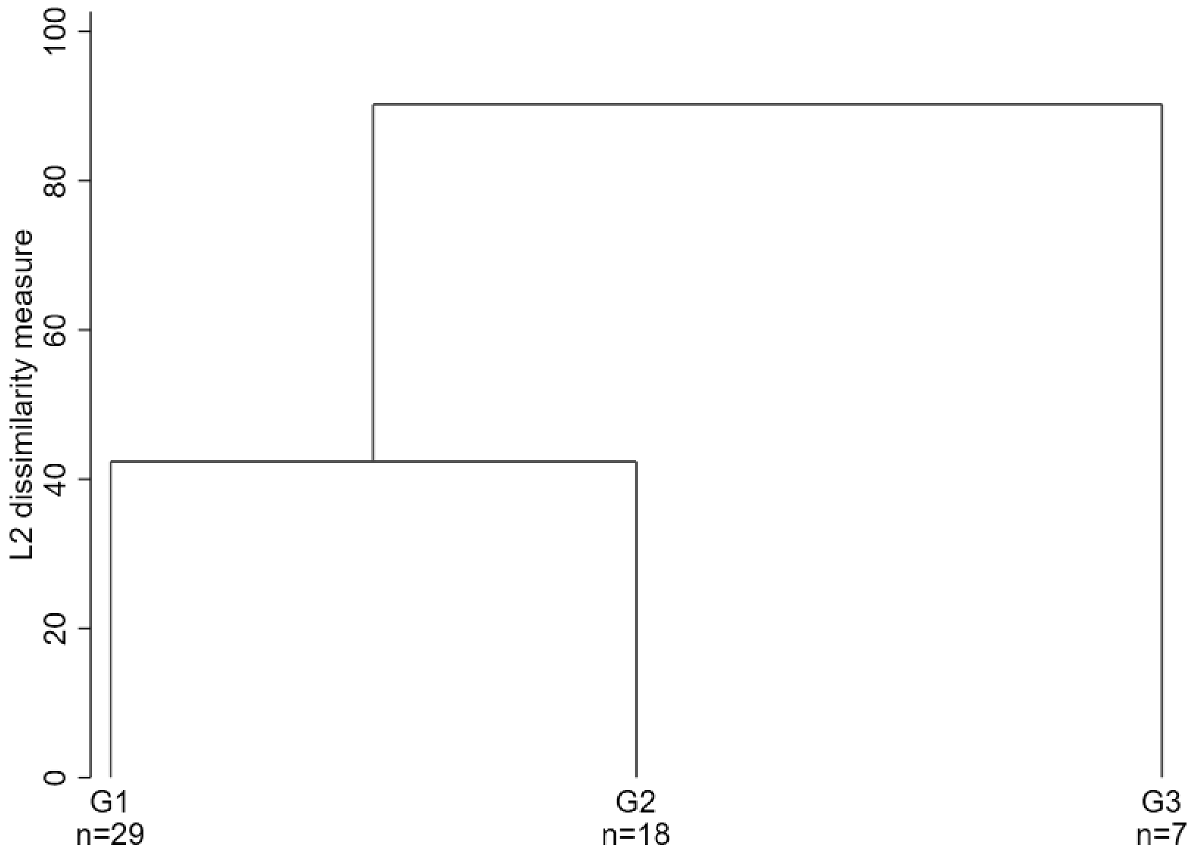


Figure 5.2: Dendrogram of Participating Producers, Clustered on Paddock Number and Stocking Rate, Truncated at Selected Cluster Amount, Without Continuous or Outlier
Note: G1 Denotes Traditional (8) Paddock Grazing, G2 Denotes Slow AMP (50) Paddock Grazing, and G3 Denotes Fast AMP (115) Paddock Grazing. The n is the Number of Operations per Cluster.

5.4.1.1 Cluster Characteristics

While clustered on paddock numbers and stocking rate, the two most common AMP characteristics, the data contained other relevant information that could be used to develop simulation model parameters associated with the different strategies. As the model focused on the impact of a switch from continuous grazing to some form of rotational grazing, with no additional purchased land, paddock size became smaller as a result of the switch. The clusters provided the start dates for the grazing season for each grazing system, as well as the length of the grazing system. Using the same target weight for each operation, the grazing season length was directly related to the implied rate of gain for each system in the model. This rate of gain was compared to values from Holechuk et al. (1999) and Heitschmidt et al. (1990), and determined to be acceptable given the known impacts of grazing system on calf rate of gain and expected animal gains. However, it was included as a factor to be examined in the sensitivity analysis[21]. Grazing period and rate of gain information, by grazing management strategy, is summarized in Table 5.19. The cluster to which a particular rancher was assigned had no significant statistical impact on seeding of pasture, fertilizer use, the density of animal units, the pasture size, or whether the pasture had been cultivated. As a result, common values for these characteristics were assumed for all four strategies.

Table 5.19: Number of Grazing Days and Rate of Weight Gain (kg/day) by Cattle in Four Grazing Systems in Sites in Northern and Southern Alberta.

	Continuous	Traditional	Slow AMP	Fast AMP
Number of Grazing Days	142	157	202	236
Rate of Weight Gain, North	1.05	0.979	0.897	0.812
Rate of Weight Gain, South	0.918	0.855	0.783	0.708

5.4.2 Utilization Rate Determination

Utilization of pasture was not a fixed parameter in the simulation models. Instead, the percentage of available forage that consumed by the cattle was dependent on the length of the grazing period and the spatial distribution of grazing. Shorter grazing periods increased utilization due to decreased trampling and fouling from manure; smaller pastures increased utilization by decreasing the amount of preferred forage available at a time and forcing the consumption of less preferred forage (Gerrish 2003).

Having determined the grazing scenarios, the utilization rate associated with each scenario was determined based on information from relevant literature. Utilization rate[22] for the

[21] This is discussed in Sections 6.1.2 and 6.1.3 for the commercial ranches, and Sections 6.2.2 and 6.2.3 for the mixed operations.
[22] The amount of forage available to cattle over the grazing period, defining period as time during a grazing period spent in a given paddock, that is consumed.

base Continuous System was 0.4, increasing to 0.6, 0.725 and 0.775 for Traditional, Slow AMP and Fast AMP, respectively (Kyle 2013). The original Kyle (2013) recommendation for estimated utilization rate for more than 24 paddock systems was 0.75 which, if used, would mean both AMP systems would have had the same utilization rate. To create some spread between systems the estimates were changed to the aforementioned values, but sensitivity analysis was also used to test whether this distinction was significant in terms of having an impact on the results. It should be noted that Gerrish (2003) found that if the number of days spent in each paddock were used as the determining factor for clustering different systems, and not paddock numbers, utilization rates for the equivalent of the Fast and Slow AMP systems would likely be different from each other for beef operations in the US. This result, although not specific to Alberta, could be used to support the decision to use the 0.725 and 0.775 utilization rates.

5.4.3 Costs Associated with the Management Systems

There are two major costs associated with the switch to rotational grazing systems: the cost of fencing and the cost of infrastructure for providing water to paddocks. The processes for developing costs used in the simulation model for both of these are detailed in this section. In both cases, the initial investment costs were incorporated into the NPV analysis as cash outflows. To avoid having to make an arbitrary assumption about the capital structure for the ranches or the combination of equity and debt capital used in financing the initial investment requirements, the full costs associated with switching systems were treated as cash outflows in the year of adoption.

5.4.3.1 Cost of Fencing

Fencing was the largest of the two costs associated with implementation of rotational grazing. This involved separating the overall area of pasture into multiple paddocks. The amount of fencing required varied by grazing management system due to differences in number of paddocks. Based on feedback from participating producers who had adopted AMP, it was decided to model the use of single string electric fencing with permanent posts as the fencing option for both rotational and AMP grazing systems.

Reliable information for the price of installing single wire electric fencing was not readily available for Alberta. Information from Saskatchewan was used instead (Government of Saskatchewan 2020), resulting in costs of $9132.91/km. Maintenance costs per year were set at 8% of this, to match depreciation of other capital goods in the model.

Determining the total length of fencing needed for changing to more intensive grazing systems in a systematic way proved to be another challenge. In practice, paddocks are constructed with the natural environment and geography in mind, and as a result there would be no consistent pattern from producer to producer in terms of the shape or area for each paddock. As there was no ready source of data for the average amount of fencing per paddock for a given intensity of rotational grazing, an assumption was made that the overall area of pasture for each representative operation consisted of one continuous square of land; that is, the pasture was square in shape. This area was then divided into equal sized paddocks. The resulting cost estimates for fencing are provided in Table 5.20.

Table 5.20: Costs of Installing Electric Fencing for Converting Grazing Systems from Continuous to Rotational Grazing in Alberta ($).

		Lac Ste. Anne	Ponoka	Newell, Dryland	Newell, Irrigated
Ranch	Traditional	96,780	103,445	171,450	128,931
	Slow AMP	338,731	362,057	600,076	451,257
	Fast AMP	508,097	543,085	900,114	676,886
Mixed	Traditional	44,739	47,924	79,291	59,865
	Slow AMP	156,587	167,734	277,518	209,526
	Fast AMP	234,881	251,601	416,278	314,290

5.4.3.2 Cost of Providing Water

There are a wide range of watering systems employed by ranchers in Alberta to provide water to cattle. While more expensive than letting animals drink from naturally occurring water sources, off stream watering comes with benefits that include an increased rate of gain in calves, prevention of bank erosion or overgrazing of riparian areas, and the increased utilization of pasture away from naturally occurring water sources (BCRC 2020). For these reasons, in addition to the fact that it is unlikely that a naturally occurring water feature would be able to satisfy the demand in all of the paddocks needed in the AMP rotations, it was decided that all operations would utilize some form of off-stream watering system. This included the continuous and traditional rotational grazing scenarios as well as the AMP scenarios. While it was conceivable that natural water features would be able to satisfy animal water demand in case of Continuous or Traditional rotational systems, it was determined they would use off-stream water in order to have a more comparable rate of weight gain across systems. As well, there is evidence that this investment is economically viable due to experienced increased rates of gain (BCRC 2018). Because of impacts to riparian areas the use of these watering systems is also a recommended Best Management Practice (Cows and Fish 2020).

There are many off-stream watering systems with varying requirements for labour and infrastructure. Ultimately it was decided that the Continuous and Traditional rotation systems would use solar pumping systems, as described by BCRC (2018). For the Northern sites, pipes were assumed to be used to move water from a natural water source to the troughs; while at the Southern site the pumps were assumed to be attached to a well, given the lower amount of surface water in Southern Alberta. While not the least expensive watering option, BCRC (2018) and CanFax (2018) use this system as one of the options explored in a cost calculator for ranchers, so less uncertainty exists in accurately pricing this system relative to other alternatives. This system was also recommended by the Government of Alberta (2007) as a useful system and was a middle of the road option for price and maintenance per their recommendations. It was assumed that the Continuous operations have two such systems. In order to minimize costs, for the Traditional rotational grazing system it was assumed that paddocks were structured and located such that four pens shared a water system placed in the adjacent corners. With eight pens, there was a need for two watering systems, so the Traditional system had no increased watering costs relative to continuous grazing and had maintenance costs that were equal to those for the Continuous system. A simplifying assumption was made that the watering system infrastructure would be built at the start of the simulation for the Continuous grazing operation. As a result, the North sites had annual maintenance costs of $0.37 per head, while the South site had an annual maintenance cost of $0.43 per head (BCRC 2018).

For the AMP systems, it was deemed unlikely that producers could economically build watering systems in the corners of all of their pens. This would require 13 watering systems for the Slow AMP method and 29 for the Fast AMP method, with an investment requirement of almost $13,000 per system (BCRC 2018). While the solar pumps used for continuous and traditional rotational grazing were movable, repositioning and repriming a pump every day or three (as would have been needed for AMP grazing) also did not seem likely to receive wide adoption by producers.

The Government of Alberta (2007) recommends using water tanks and portable water troughs on a trailer when attempting to provide water in hard to reach areas. This system requires more labour than a system of dugouts, which seems the next best system in terms of cost and labour for many paddock systems, but it does have a much lower initial cost and initial labour requirement. As a result, for the purpose of the analysis in this thesis, it was assumed that the adoption of AMP systems involved using a trailer with water tanks and portable troughs for watering. Using the New Brunswick Department of Agriculture (2020) recommendation of 15 gallons water per head per day, the Mixed operations used three 1250-gallon (4 x $780) tanks and one 200-head trough ($1040). For the commercial ranching operations, three 5000-gallon tanks (3 x $4500) and four 200 head troughs (4x$1040) were used. Both types of operations were assumed to use a flatbed semi-trailer ($10,000), for a total system cost of $14790 for the mixed operations and $27660 for the commercial ranching operations (UFA 2020; IronSearch 2020). Given an assumption of an average of 10km of hauling for the water, at $2.72/kilometer over a 115 day grazing season, the annual truck and trailer cost for fuel, maintenance and use value was calculated to be $3125.73 (Ray Barton and Associates 2006). Due to lack of information on the lifespan and depreciation of water tanks and cattle troughs, both were assumed to have maintenance and depreciation at 8% of initial cost over the simulation timespan, resulting in annual costs of $332.8 for the Mixed and $1412.8 for the Commercial operation.

5.4.3.3 A Note on Labour Costs

The impact of range management system transition on operation financial performance is an understudied topic. As a result, reliable estimates on how the switch to a more intensive grazing management system impacted labour expenses were not available. Producers from the wider project were contacted, but an insufficient number replied to yield a meaningful result. Anecdotal evidence suggested that there was minimal change associated with adopting AMP grazing, although some did report “massive” changes to the amount of work needed to run the operation. As such, it was decided to leave the average cost of labour per head for a cow-calf operation unchanged across pasture management systems.

5.5 Time Horizon and Simulation Iterations

The model used a 20-year time horizon, as this was the lifespan of the most expensive infrastructure (Government of Saskatchewan 2018). Longer timeframes (25, 40, and 50 years) were tested, but did not change the ranking of the systems with respect to NPV of wealth. The representative operations were iterated 1000 times per simulation. Simulation runs with 5000 iterations were also modeled, but changing the number of iterations did not qualitatively change the results with respect to wealth ranking. As a result, 1000 iterations were used.

5.6 Economic Assessment of Grazing Strategies

As previously discussed in Chapter Four, NPV was the primary method used to assess the economic performance of the different grazing strategies. The grazing strategy with the highest expected NPV was considered to be the best, provided variation of NPV values over the period remained reasonably stable. While other methods were considered, comparing economic performance across systems was most easily understood in terms of wealth maximization, defined as identifying the strategy generating the greatest net cash flows and thus NPV. In terms of reporting results, the NPV of the ranch is reported, but for the mixed operation the NPV of the whole operation as well as the NPV associated with the cow-calf enterprise was calculated. NPV was not estimated in perpetuity, due to there being large and periodic capital expenditures required to replace rotational grazing infrastructure in the future. These periods were approximately 20-year intervals, but could be longer or shorter due to their being dictated by the lifespan of fencing, making in-perpetuity values misleading due to their not including these periodic costs.

5.7 Verification and Validation

In any model building exercise, verification in terms of building the model correctly, and building the correct model, are obviously important steps. Verification is relatively straightforward and done throughout the model building process. The models here in this present study were built in stages, with each stage examined independently before being attached to the other components of the model. At each stage, the model was run to ensure results were as expected, and if they were not, the model was adjusted so that results were consistent with expectations, or an explanation was identified for the unexpected results.

Validating these sorts of models is a more difficult and less clear-cut task. Ideally, the simulation model would be built with specific, real world data; for example, financial and production records for one particular farm along with data concerning historic weather experienced by the farm operation. In this situation the simulation output can be checked against the historic data. Unfortunately, this was not possible with the type of modeling used in the current study, as the model was built based on averages over many firms along with expert opinion, making it difficult to determine if all components in the model were valid. It should also be noted that obtaining the necessary data to model an actual operation would have represented a significant challenge, as no such data currently exists; surveying individual producers would be time consuming, costly, complicated, and there is a risk of producers being reluctant to share cost information to the level of detail required for such a project should such a survey be undertaken.

An alternative approach is to take real world data that corresponds to a relevant model output and undertake a comparison. For example, in previous studies (e.g., Trautman 2012), land values were compared with simulated per hectare wealth measures. However, land value was not an appropriate measure to use in the case of ranches and rangeland, which faced cropping conversion pressure in addition to urban and peri-urban development pressures.

These two potential price factors made meaningful comparisons unlikely given the required assumptions.

For the current study, simulation results were compared with available average cow-calf financial performance data from the Government of Alberta (2018) and the Government of Manitoba (2020). They reported average per cow net returns of $140.09 and $155, respectively. An issue in using these values was that they were net returns which factored in owner unpaid labour and the costs of supporting owners and, in the case of the Alberta value, also included capital costs. The simulation model used in the current analysis made no assumptions about ownership structure and did not incorporate any payment to equity or debt capital. As well, only minimal assumptions were made about labour requirements and labour system structure of the operations. Removing these costs from the Alberta and Manitoba performance estimates resulted in per cow returns of $236.92 and $397.58, respectively. The equivalent per cow returns from the simulation models discussed in this present study yielded the following results, for the baseline scenario of continuous grazing: $360.21, $328.05, and $264.08 for the Lac Ste. Anne, Ponoka, and Newell Dryland mixed operations, respectively. In the case of the commercial ranches (again assuming continuous grazing), the simulated average per cow returns were $363.12, $362.06 and $325.07 for the Lac Ste. Anne, Ponoka, and Newell Dryland ranches, respectively. With the simulated average returns sitting squarely within the ranges provided by the Alberta and Manitoba data for expected cow-calf returns, and with the larger operations having larger per head returns than the smaller operations, as expected, it was concluded that the simulation models were valid for use in the current analysis.

Finally, the model was built in consultation with various experts in their fields, and their input was valuable in ensuring that the input and output values were within expected ranges. Further, results of a prototype version of the model, and an explanation of its structure were presented to a group of beef producers. Their feedback was valuable and led to a model that they thought more accurately reflected the costs and returns they faced, especially with respect to the costs of fencing. This added confidence in the validity of the simulation models.

5.8 Chapter Summary

This chapter describes the model constructed to simulate the impact of a change in grazing management system on both large ranches and mixed cow-calf-cropping operations in representative locations across Alberta. Three representative locations, each with two operations sizes, were modeled. The simulation was built with stochastic pricing and weather, to incorporate price and production risk, and was simulated over a 20 year time horizon, modeling four grazing system treatments. NPV and wealth maximization were then used to compare treatments. Further sensitivity scenarios are undertaken, to ensure the model describes the Albertan situation with as much accuracy as is possible.

Chapter 6: Results and Preliminary Discussion

This chapter details the results of the simulation modeling and associated sensitivity analyses. For each Mixed or Ranch operation, the basis for comparison is the Continuous grazing management strategy, unless otherwise stated. In particular, the expected NPV resulting from the baseline Continuous system is compared with the equivalent measure resulting from a change in grazing management strategy. Beyond this basic comparison, herd size, average margin, net cash per head in the first and final five year periods, expected NPV/head and Average Annuity per Head are also reported. In the case of the Mixed Operations, expected NPV for the cattle operation is reported in place of Average Annuity per Head. Results are first presented for the commercial ranch operations, with the 700 head initial herd. This is followed by an equivalent discussion of results for the mixed beef-cropping operations

6.1 Ranch Results

6.1.1 Ranch Base Results

The results for the Continuous, one paddock operation are presented and discussed here, to provide a baseline against which a switch to more intensive grazing management schemes can be compared. Table 6.1 provides a summary of these results. Beginning a trend that will hold for the rest of the chapter, the Lac Ste. Anne site had the highest level of expected wealth as measured by expected NPV, of $2.355M over the 20 year period[23]. Ponoka had a similar, but lower, amount of wealth, with an expected NPV of $2.335M, a baseline 0.9% lower than the Lac Ste. Anne site. The Newell sites, both dryland and irrigated, did not perform as

[23] Unless indicated otherwise, the NPVs refer to mean or expected values calculated over the 20 year simulation time horizon.

well as the Northern sites, with expected NPVs of $2.072M and $1.129M; 12% and 52% below Lac Ste. Anne, respectively.

Table 6.1: Measures of Wealth (Mean NPV Over 20 Years) for Continuous Grazing for Representative Ranches in Three Regions of Alberta ($); (SD)

	Lac Ste. Anne	Ponoka	Newell (Dryland)	Newell (Irrigated)
Expected Net Present Value	2,355,077.97 (627,709.61)	2,334,638.12 (612,550.64)	2,071,854.88 (457,347.93)	1,129,278.38 (454,231.62)

These results were mostly consistent with the expectations of the model building. The Lac Ste. Anne site, having the most productive pasture, had the highest expected NPV; Newell, which is much drier and has smaller animals, had the lowest expected NPVs. The initial irrigated result came as a bit of a surprise, and was double checked, as it was expected that ranch performance under irrigation would be much better than indicated by the simulation results. However, having double checked the prices and mechanics of the model, everything seemed to be in order. The poor performance of the irrigated site appears to have resulted from the massive cost of irrigation equipment; the gains to pasture productivity are not cost effective in most cases. If the model had incorporated drought with the risk to financial stability there may have been a different result, but under non-extreme weather conditions it appears that irrigating pasture does not represent a viable investment.

6.1.2 Initial Grazing Management Change Results

This subsection presents the results of a switch from Continuous Grazing to Traditional, Slow AMP and Fast AMP grazing management systems for the representative ranches. The assumptions made to model each system, as well as the costs and environmental and financial benefits of each system, are discussed in Chapter 4. Results are broken down into more easily understandable sub-sections. Please see Appendix A1 for a figure containing the full results of the grazing management system change simulations.

6.1.2.1 Comparison of NPV's Across Systems

For ease of understanding, results are shown first as a comparison of the NPVs across all systems. These results are presented in Table 6.2. More detailed results by location follow in later sections.

Across all locations, Traditional 8-Paddock grazing consistently provided the highest level of expected wealth of the systems modeled, and the Fast AMP 115-Paddock system provided the lowest expected wealth. In Lac Ste. Anne, the Slow AMP 50-Paddock system had the second highest level of expected wealth, but this was the only location where this result occurs. For both Ponoka and Newell sites, Continuous grazing provided the second highest level of expected wealth. The slightly greater productivity advantage in the Boreal Transition region (i.e., Lac Ste. Anne ranch), due to the higher precipitation levels, was just enough to make the AMP system more viable than Continuous grazing. Conversely, the move to AMP at the more arid sites did not result in a sufficient increase in utilizable forage to make the switch to AMP grazing better than staying the course. Newell County, with smaller animals than at the Northern sites, saw even greater comparative losses than Ponoka from a switch to AMP, as lower productivity and smaller animals resulted in greater economic sacrifices.

Traditional grazing increased Lac Ste. Anne expected wealth by 9% compared to Continuous grazing ($2,566,717 versus $2,355,078), and by 7.4% compared to Slow AMP. Slow AMP provided a 1.5% increase in expected wealth relative to Continuous grazing ($2,389,518 versus $2,355,078). Conversely, adoption of Fast AMP resulted in a 7.6% reduction in expected wealth relative to Continuous grazing ($2,175,528 versus $2,355,078).

For the Ponoka ranch, Traditional grazing provided an increase in expected wealth of 8.1% and 8.8% relative to Continuous and Slow AMP, respectively ($2,523,151 versus $2,334,638 and $2,319,528). Adoption of Slow AMP saw an expected wealth decrease of 0.6%

relative to Continuous grazing ($2,334,638 to $2,355,078), while the corresponding decrease for Fast AMP was 10.4% ($2,334,638 to $2,319,528).

The Dryland Newell ranch experienced an expected wealth increase of 3.4% by switching to Traditional ($2,071,855 to $2,141,938), and Traditional outperformed Slow AMP by 31.2% ($2,141,938 versus $1,632,177). Relative to Continuous grazing, adoption of AMP for this ranch resulted in significant declines in expected wealth; 21.2% and 42.2% for Slow and Fast AMP ($2,071,855 to $1,632,177 and $1,197,947), respectively. The irrigated Newell ranch saw the least expected benefits and greatest expected wealth penalties associated with changes away from Continuous grazing. Switching to Traditional rotational grazing generated only a 3.2% gain in expected wealth ($1,129,278 versus $1,165,118). The decreases associated with switching to AMP were significant; 41% and 77.4% for Slow and Fast AMP systems, respectively, relative to Continuous grazing ($1,129,278 to $665,759 and $255,223). Traditional rotational grazing outperformed Slow AMP by 75% ($1,165,118 versus $665,759).

Table 6.2: Measures of Wealth (Mean NPV Over 20 Years) for Alternative Grazing Systems for Representative Ranches in Three Regions of Alberta ($); (SD)

	Lac Ste. Anne	Ponoka	Newell (Dryland)	Newell (Irrigated)
Continuous	2,355,077.97 (627,709.61)	2,334,638.12 (612,550.64)	2,071,854.88 (457,347.93)	1,129,278.38 (454,231.62)
Traditional	2,566,716.86 (704,216.99)	2,523,151.01 (689,981.75)	2,141,938.14 (568,618.45)	1,165,118.08 (567,862.71)
Slow AMP	2,389,517.65 (681,296.23)	2,319,528.22 (669,157.40)	1,632,176.64 (537,904.82)	665,758.93 (535,430.82)
Fast AMP	2,175,528.14 (647,242.55)	2,091,577.89 (633,317.49)	1,197,947.27 (505,119.65)	255,223.12 (508,032.63)

6.1.2.2 Lac Ste. Anne Ranch Results

Table 6.3 provides more detailed simulation results for the Lac Ste. Anne ranch. As noted earlier, the results for this representative ranch were slightly different than for the other two sites, as Slow AMP grazing provided the second highest level of expected wealth.

Traditional rotational grazing provided the greatest expected wealth, followed by Slow AMP, Continuous grazing, and Fast AMP. This pattern was driven in large part by the slightly larger margins seen in Lac Ste. Anne, compared to the other sites that were in turn a result of higher pasture productivity. This led to animals being less likely to be sold early and underweight than for the other sites. Another effect of the higher productivity was that it allowed for a slightly larger herd than for the other ranches. This led to enough income to pay for the Slow AMP costs, relative to Continuous, that the other sites did not see.

The standard deviations for the NPV results followed the expected pattern, with Continuous having the lowest, Traditional the highest, and the two AMP sites between them, with the smallest herd (and lowest number of animals to sell) having the smallest variance in NPV. Variability increased with increasing herd size and the number of animals for sale. Relative variability, as measured by the coefficient of variation[24], increased slightly moving from Continuous (0.267) to Traditional (0.274) to Slow AMP (0.285) to Fast AMP (0.300). This suggested that risk exposure of the producer was marginally impacted by changes in grazing management, and that the risk faced by the producer increased as capital expenditure on conversion increased.

Directly related to the NPV results was herd size. As shown in Table 6.3, under the base scenario of Continuous grazing, ending herd size was, on average, below the initial level of 700 cows. While the land base for the representative ranch was determined to be the number of hectares needed to maintain the 700 cow herd in average conditions, not every year is average, nor is every five year interval average. As a result of the rules governing herd expansion and contraction (discussed in Section 5.1.1.4) the average ending herd size for Continuous grazing tended to be slightly lower than the initial size. It was more beneficial to have a slightly smaller

---

[24] The coefficient of variation measures variability relative to the expected level of performance and is calculated as the standard deviation divided by the mean.

herd, between three and nine head (0.4 and 1.3%) lower, than to run a larger herd selling slightly lighter animals.

In contrast, all rotational grazing scenarios (Traditional, Slow and Fast AMP) resulted in significantly increased average ending herd sizes. Traditional rotational grazing had the largest ending average herd size (approximately 1148 cows), followed by Slow AMP (approximately 1100 cows) and Fast AMP (1036 cows). In the simulation of alternative grazing management scenarios, utilization rate increased with intensity, suggesting that this ordering should be reversed. However, data from Bork et al. (2021) showed that the length of the grazing period also increased with intensity and this longer grazing season effect dominated the effect increasing utilization had on available forage per animal. This resulted in smaller herds (relatively speaking), and correspondingly smaller per head over winter costs.

Average margin had a significant effect on the NPV results. Margin was calculated as revenue minus variable costs and so reflected annual profitability, excluding fixed costs. As shown in Table 6.3, the pattern of average margin values did not correspond to the ranking of expected NPV values. Specifically, Continuous grazing had the lowest average margin, suggesting that it was less profitable on a year-to-year basis than any of the other scenarios, including both versions of AMP. However, what this also indicated is that while adoption of AMP by the Lac Ste. Anne ranch resulted in increased annual margin, the degree of increase did not always offset the initial investment in fencing and watering equipment (i.e., the case of Fast AMP) once time preferences (i.e., discounting) was factored into the analysis.

Two adjusted NPV measures are reported in Table 6.3. NPV per head is calculated as the expected NPV divided by the average number of head[25] over the simulated time horizon. This measures wealth generated per animal. As shown in Table 6.3, Continuous grazing provided the greatest wealth per cow. However, the net marginal benefits (over the costs of

[25] Average head was calculated the sum of the herd size every year, divided by the 20 year time horizon to get an annual average.

adoption) achieved by adopting Traditional rotational grazing or Slow AMP were reflected in the ability to increase herd size and generate greater overall wealth.

Average annuity per head (Table 6.3) is calculated as the NPV per head converted to an annuity using the present value of an annuity formula[26]. These annuity values can be loosely interpreted as the annualized margin per cow generated by each grazing management scenario. The pattern of annuity values was herd size dependent, to a certain extent. While AMP costs played a role in the ordering, the annuity increased as herd size decreased.
It should be noted that Average Margin differs slightly from Net Cash per Head, in that Net Cash is the profit divided by number of head, whereas Average Margin is the Production Margin, the margin used to calculate BRM payments, and thus omits program payments and costs.

One result requiring further explanation was that Net Cash per Head in the last five years of the simulation was lower than Net Cash in the first five years. This occurred because, while all prices were in Q1 2019 dollars, the real price of beef has declined over the last decades and with no expectation of any change in this pattern into the future. This resulted in a lower net cash per head in the final years, as the average real return declined with a decline in real prices. While there were years that spiked above the downward trend line, the trend was downward, resulting in the average five year Net Profit/Net Cash declining in each subsequent five year period. The ordering of the Net Cash results was primarily a function of herd size, with the average value decreasing with increased herd size. However, other factors also impacted this result, such as the yearly cost of AMP infrastructure maintenance associated with system intensity (Net Cash decreased as intensity increased) and the decreasing winter feed costs with increased system intensity. The net impact of this interplay between effects was that Net Cash decreased as herd size decreased, but these other effects should not be ignored.

[26] This formula is $\mathrm{PV}=\mathrm{A}((1-(1+r)\verb|^|-N)/r)$ where PV is present value (expected NPV here), r is the discount rate, N is the time horizon, and A is the annuity to be calculated.

Table 6.3: Lac Ste. Anne Ranch Results ($/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV	2,355,077.97 (627,709.61)	2,566,716.86 (704,216.99)	2,389,517.65 (681,296.23)	2,175,528.14 (647,242.55)
Average Annuity per Head	2,971.67 (730.28)	2,706.50 (658.57)	2,828.95 (650.98)	2,845.14 (636.27)
Average Margin	255,596.27 (60,608.22)	325,600.03 (79,857.10)	319,351.94 (77,281.59)	301,530.72 (73,297.48)
NPV per Head	3,527.13 (898.03)	2,589.74 (692.96)	2,488.96 (687.34)	2,366.40 (676.69)
Average Net Cash per Head, Years 1-5	386.92 (125.38)	340.76 (112.99)	355.72 (111.67)	359.6 (108.62)
Average Net Cash per Head, Years 15-20	335.01 (144.63)	305.05 (125.88)	320.76 (124.36)	323 (122.42)
End Herd Size	697.4 (36.72)	1,148.34 (93.04)	1,100.09 (92.75)	1,035.91 (90.01)

6.1.2.3 Ponoka Ranch Results

Table 6.4 presents simulation results for the Ponoka representative ranch under the alternative grazing management scenarios. As noted earlier, Traditional rotational grazing was the system that generated the greatest level of expected wealth, while Continuous grazing was the second best scenario in that respect. Fast AMP provided the lowest expected NPV.

In Ponoka, the difference between the systems, in percentage terms, was smaller than for the Lac Ste. Anne ranch. The difference between the second and third best options (Continuous and Slow AMP) was only 0.6% ($2,334,638 versus $2,319,528), compared to 1.5% in the case of the Lac Ste. Anne ranch ($2,355,078 versus $2,389,518). This suggested that the results for the Ponoka ranch were more sensitive to small changes in the costs and benefits assumed with a transition. This will be an important note of discussion later, in Section 6.1.3.

Consistent with the expected NPV results, average margin was greatest for the Traditional scenario. However, average margin was lowest for the baseline Continuous grazing scenario. This result indicated that while the AMP scenarios resulted in greater year-to-year expected margin, the improvement did not outweigh the initial expenditures required to implement those grazing management strategies.

The pattern for standard deviations associated with the Ponoka NPV results (Table 6.4) was similar to what was observed for the Lac Ste. Anne ranch; as was expected, variability increased with increased expected performance. There was also a similar pattern in relative variability, with the coefficient of variation increasing from a value of 0.262 for the baseline Continuous scenario, to a maximum of 0.303 for the Fast AMP scenario.

Trends across all other metrics followed similar patterns as for the Lac Ste. Anne ranch, only with smaller values and a smaller spread between Continuous, Traditional, and Slow AMP. Fast AMP uniformly resulted in lower values as a percentage of the other systems. This was most apparent in that the difference between margins was sufficiently small that the expected NPV ranking shifted, with Continuous having a small enough margin deficit that it was more than offset by the lack need for any investment cost requirements that were associated with adoption of Slow AMP. Compared to Lac Ste. Anne, the different rotational systems performed more poorly as a percentage of Continuous income, although trends remained the same. This was primarily due to the Ponoka site needing to be larger in size due to less forage being produced per hectare, which led to higher fencing costs for the rotational systems. There was also the added effect that the rotational herds in Ponoka increased by fewer head than in the case of the Lac Ste. Anne ranch, because the increase from 40% pasture utilization to 60, 72.5 and 77.5% resulted in a lower increase in forage available per hectare, again due to the lower productivity.

Table 6.4: Ponoka Ranch Results ($/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV	2,334,638.12 (612,550.64)	2,523,151.01 (689,981.75)	2,319,528.22 (669,157.40)	2,091,577.89 (633,317.49)
Average Annuity per Head	2,945.92 (719.76)	2,680.29 (649.99)	2,789.53 (643.03)	2,798.38 (631.67)
Average Margin	254,004.87 (59,104.80)	322,530.18 (78,078.65)	314,432.81 (75,966.21)	295,510.13 (72,260.13)
NPV per Head	3,505.97 (886.67)	2,554.09 (694.11)	2,419.20 (685.16)	2,275.02 (672)
Average Net Cash per Head, Years 1-5	383.84 (124.5)	337.62 (113.6)	351.01 (112.56)	353.56 (108.71)
Average Net Cash per Head, Years 15-20	334.26 (140.64)	304.94 (122.92)	319.05 (122.54)	320.64 (121.15)
End Herd Size	695.46 (36.13)	1,144.11 (92.58)	1,097.26 (91.36)	1,033.71 (89.49)

6.1.2.4 Dryland Newell Ranch Results

The results for the dryland Newell County ranch are presented in Table 6.6. Expected performance for all scenarios at this site was significantly lower than for the other two sites. This was due to the substantially larger land base for the ranch which resulted in greater costs in shifting to more intensive grazing systems. As well, the more arid landscape meant lower pasture productivity and smaller weaned animals. The Newell ranch also had fewer animals than at the other sites for the alternative rotational grazing management scenarios, resulting from lower absolute gains to available forage attributable to transitioning to more intensive systems. This also had a negative impact on performance.

Relative to the Lac Ste. Anne and Ponoka ranch results, the results for the Newell ranch displayed larger spreads between the various scenarios. Slow AMP, for example, provided an expected wealth level that was over 25% lower than that for the Traditional scenario and 21% lower than expected wealth for the Continuous scenario ($1,632,177 versus $2,141,938 and $2,071,855, respectively). A similar pattern existed for Fast AMP as well. These results suggest that the more intensive grazing management systems were far more unlikely to be adopted, even allowing for individual producer differences in key parameters. This is discussed further in the section on Sensitivity Analysis for Newell.

Consistent with the previous ranches, adoption of rotational grazing systems increased (for the most part) year-to-year net returns, as shown in the pattern of average margins presented in Table 6.5. The exception was Fast AMP, for which average margin was lower than for the baseline Continuous scenario. However, even for Traditional and Slow AMP, the degree of increase in average margin was smaller than for the Lac Ste. Anne and Ponoka ranches. This was due to the degree of increase in costs of conversion to rotational grazing and increases to annual maintenance costs for the intensive grazing strategies attributable to the larger land base, as noted above.

Variability in NPV of the Newell site was of some note. While following the same trend, with the standard deviation increasing with increased herd size and relative variability (i.e., coefficient of variation) increasing with the capital expenditure associated with conversion to more intensive grazing, the level of variance, especially as measured by coefficient of variation was much larger for this site than for the others. Coefficient of variation values increased from 0.221 (Continuous) to 0.265 (Traditional) to 0.330 (Slow AMP) to 0.422 (Fast AMP), an increase from Continuous to Fast AMP of 0.201, compared to corresponding increases of 0.041 for Ponoka and 0.033 for Lac Ste. Anne. Risk was substantially increased by converting to more intensive systems in Newell, in addition to much lower expected NPVs. The majority of this was attributable to weather. Both growing season and off season moisture distributions for Newell were best approximated by Raleigh Distributions. Raleigh distributions are characterized by large right tails, leading to a higher probability of dry years interspersed with much wetter years than for the other two ranches, which had only one Raleigh distribution each approximating the two seasons. It could also be explained in part by Newell being in a different price zone than the Lac Ste. Anne and Ponoka sites, with the South Alberta pricing zone having larger standard deviations in prices for Steers and Heifers, and the same level of variance in Fall Cows (See Table 6.5).

Table 6.5: Standard Deviations of North and South Pricing Models ($/cwt)

	Fall Cows	Steers	Heifers	Spring Cows
North	0.664	0.746	0.934	0.839
South	0.664	0.897	1.052	0.746

Some of the trends seen in the Northern sites were also different for the Newell ranch. Average Annuity and the two Net Cash per Head measures had a different pattern, with all three measures decreasing as system intensity increased, as opposed to the previous pattern of Continuous highest, Traditional lowest, and then Slow AMP third and Fast AMP second highest. This resulted from a combination of there being lower herd sizes than the other sites, the animals being smaller and thus selling for less, and the costs of the conversion rising immensely as the land base increased to deal with the much lower productivity.

Table 6.6: Dryland Newell Ranch Results ($/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV	2,071,854.88 (457,347.93)	2,141,938.14 (568,618.45)	1,632,176.64 (537,904.82)	1,197,947.27 (505,119.65)
Average Annuity per Head	2,646.23 (548.71)	2,406.27 (536.14)	2,354.01 (529.37)	2,246.22 (520.31)
Average Margin	250,975.90 (47,029.44)	300,875.10 (64,273.48)	264,129.58 (61,558.34)	225,616.18 (58,153.72)
NPV per Head	3,108.71 (672.42)	2,135.01 (578.22)	1,701.79 (569.28)	1,321.75 (560.42)
Average Net Cash per Head, Years 1-5	331.61 (94.53)	295.82 (98.89)	289.71 (94.17)	281.81 (90.45)
Average Net Cash per Head, Years 15-20	302.9 (107)	271.78 (99.85)	267.79 (99.3)	255.92 (98.76)
End Herd Size	691.46 (32.36)	1,139.58 (85.17)	1,084.10 (85.68)	1,014.10 (86.39)

6.1.2.5 Irrigated Newell Ranch Results

Based on the simulation results presented in Table 6.7 (and compared to the results presented in Table 6.6), irrigated pasture was significantly less economically viable than dryland production for the Newell ranches. As discussed in Chapter 5, it was assumed that the irrigated Newell ranch had infrastructure to irrigate 15% of the pasture land base. Expected NPV for the irrigated operation under the baseline Continuous grazing scenario was 45.5% lower than for the equivalent scenario on the dryland Newell ranch ($1,129,278 versus $2,071,855). In the case of the Traditional rotational grazing scenario, the decrease was 45.6% ($1,165,118 versus $2,141,938). The degree of decrease in expected wealth relative to dryland production was even greater for the AMP strategies. As discussed earlier, the pattern in relative performance was probably due at least in part to the modeling of weather (i.e., rainfall) in the analysis. It is possible that there could be some benefit seen if the modeling had incorporated the potential for drought conditions. However, this did represent a very large decrease in wealth compared to the dryland operation.

The pattern in expected NPV was consistent with the dryland Newell ranch (as well as with the Ponoka ranch). As shown in Table 6.6, Traditional rotational grazing provided the greatest level of expected wealth, followed by Continuous grazing, Slow AMP and Fast AMP. As with the dryland ranch, the difference between Traditional and Continuous was relatively insignificant. The gap between Continuous and the two AMP scenarios with respect to expected wealth was similar to the results for the dryland operation in absolute terms, but significantly larger in terms of a percentage change.

The pattern in variability of NPV for the irrigated ranch was also the same as for the dryland ranch, with a similar explanation being plausible. Given the lower level of expected NPV values, however, relative variability was significantly greater.

Aside from being markedly lower than all other modeled locations across grazing systems, the same general trends held for changes to herd size, margin and the other reported statistics when compared to the Newell Dryland site, aside from Average Annuity per Head for the Continous being lower than for the Traditional site and the Continuous Net Cash per Head in the final period making the same switch, as the significant costs of irrigation were experienced by the operation. The trends were the same, the costs were just overwhelming.

Given the nature of the results for this ranch, no further analysis of the irrigated Newell ranch was undertaken. Specifically, no sensitivity or scenario analysis was conducted, as the changes to the assumptions required to allow for AMP grazing to be economically viable were beyond the realm of possibility. Further, making irrigated production viable relative to dryland for this ranch was also non-viable.

Table 6.7: Irrigated Newell Ranch Results (in $/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV	1,129,278.38 (454,231.62)	1,165,118.08 (567,862.71)	665,758.93 (535,430.82)	255,223.12 (508,032.63)
Average Annuity per Head	1,371.87 (558.67)	1,555.82 (538.68)	1,468.02 (534.17)	1,295.73 (533.41)
Average Margin	135,670.75 (48,076.01)	186,405.13 (65,720.67)	148,725.32 (62,542.73)	109,449.35 (58,517.97)
NPV per Head	1,706.34 (667.55)	1,155.01 (565.27)	692.26 (556.34)	282.94 (561.88)
Average Net Cash per Head, Years 1-5	211.34 (90.43)	200.1 (93.2)	194.09 (90.95)	181.73 (89.27)
Average Net Cash per Head, Years 15-20	142.66 (109.02)	175.55 (101.54)	165.64 (101.43)	145.03 (101.02)
End Herd Size	693.3 (29.11)	1,124.11 (77.21)	1,064.72 (76.23)	988.50 (75.95)

6.1.3 Sensitivity Results

Simulating the performance of these ranch operations required a lot of assumptions, and the operations modeled were representative operations defined using secondary data and expert opinion. It was thus important to examine the sensitivity of the simulation results to changes in key assumptions. This provided the opportunity to gauge the impact of key parameters having values that were higher or lower than originally modeled. It also permitted investigation of the potential impact of incorrect assumptions or values; specifically, would errors in these values change the qualitative results (e.g., ranking of grazing management scenarios)? Finally, sensitivity analysis also allowed for consideration of “breakeven” analysis in terms of identifying by how much a particular parameter would need to be different or change before the relative ranking of the grazing management scenarios would be changed.

This section details the results of sensitivity analysis, where all assumptions are held constant except one, which is then changed until a particular grazing management system improves its ranking in terms of expected wealth maximization. This was done using @Risk (Palisade 2020). While the @Risk program does contain a GoalSeek function that would find the exact breakeven point, using this function was time consuming and prone to crashing. To save on time, breakeven points were estimated by iteratively changing parameters and re-simulating the particular operation/scenario. Given the inexact nature of conducting sensitivity analysis in this way, breakeven is reported with a margin of +/-$5000.

In the case of comparing Traditional to Continuous for the Newell and Ponoka ranches and Traditional versus Slow AMP for the Lac Ste. Anne ranch, the relevant parameter was changed until the Traditional scenario drops in terms of ranking. The specific scenario comparisons examined in this analysis were Traditional versus Continuous, Slow AMP versus Traditional, Slow AMP versus Continuous, Fast AMP versus Slow AMP, and Fast AMP versus Traditional. The parameters considered for change included utilization rate, pasture productivity, rate of gain, and AMP adoption costs (i.e., fencing and watering systems). These were chosen on the basis that they were deemed important in terms of contributing to the quantitative and qualitative results of the analysis, as well as representing parameters that may vary by producer and/or be subject to estimation error.

In addition to these model parameters, three new parameters were considered in the sensitivity analysis. In all three cases, these represented potential policy-related considerations. The three parameters were: 1) an initial subsidy paid to the producer to offset start-up costs, 2) a price premium paid on animals produced using more intensive grazing systems, and 3) a yearly program payment to the producer. All three were incorporated into the simulation model. The initial subsidy parameter would be similar to existing cost-sharing policy instruments used to encourage the uptake of beneficial management practices (BMPs) by agricultural producers[27]. While not as commonly used, the price premium would represent a market incentive provided to producers in return for adopting more environmentally sustainable grazing management practices. The annual program payment could be interpreted as a direct subsidy paid to producers in return for adopting appropriate grazing management practices.

For the annual program payment, the value estimated in the sensitivity analysis could be considered as either increased income or decreased income needed to change the ranking. This represented an intuitive way of looking at the result in the case where the number is negative, and the initial system was outperforming the one to which it is being compared. In cases where the system whose assumptions were being changed had higher expected wealth than the other system being compared, initial subsidy and price premiums were not reported; for example, the case of changes to Traditional rotational grazing when compared with Continuous grazing.

---

[27] Producers would need to have completed an Environmental Farm Plan (EFP) to access funding under this framework. The costs of completing an EFP are not incorporated in the simulation, and would increase the net cost of adoption if this hypothetical policy were to operate within the current BMP policy framework.

The sensitivity analysis results are provided, by ranch, in the following sub-sections. Results for pasture productivity and AMP costs are reported as percentage changes relative to their original values that would be required to change the relative ranking.

The sensitivity analysis results for pasture utilization were reported as the percentage of forage that would need to be utilized for a change in ranking. As discussed in Chapter 5, the base assumption for pasture utilization varied by pasture management scenario, with base levels of 0.4, 0.6, 0.725 and 0.775 for Continuous, Traditional, Slow AMP and Fast AMP, respectively.

Results for rate of gain were reported as kilograms per day. As discussed in the previous chapter, the rate of gain was determined endogenously within the model, based on the rate of gain required at each ranch site for animals to hit the target weight given the number of grazing days reported by Bork et al. (2021) for the project. This was checked to be within reason for the grazing intensity, target weight and grazing period (Holechuk et al. 1999; Heitschmidt et al. 1990). For the Lac Ste. Anne and Ponoka ranches, this worked out to 1.05, 0.979, 0.897 and 0.812 kg/day for Continuous, Traditional, Slow AMP and Fast AMP, respectively. For the Newell ranch, the corresponding rates of gain were 0.918, 0.855, 0.783 and 0.708 kg/day.

The values for the initial subsidy, price premium, and annual program support were reported in dollars/head in the initial herd, dollars/head sold, and dollars per year, respectively. Since these parameters were not included in the original simulation analysis, in all cases they would be compared with initial values of zero.

6.1.3.1 Lac Ste. Anne Sensitivity Results

Table 6.8 provides a summary of the sensitivity analysis results for the Lac Ste. Anne ranch. A similar structure was used for the results for ranches at the other Alberta regions as well. The comparison between the Traditional and Continuous scenarios on the Lac Ste. Anne ranch (Table 6.8) was used to illustrate the interpretation of the sensitivity results. The forage utilization rate for Traditional rotational grazing would need to decrease to 0.545 (from 0.6) for the Continuous scenario to perform as well in terms of expected NPV. Similarly, pasture productivity would need to decrease by 13% or AMP adoption costs would need to be 355% greater, or the rate of gain would need to decrease to 0.83 kg/day (from 0.979). Alternatively, the relative ranking would change only If there were increased annual costs of $22,000 per year under Traditional Rotational grazing,

The most apparent result from the Lac Ste. Anne sensitivity analysis simulations was that Fast AMP remained unlikely to be a sound business decision for operations, even under very different (more advantageous) conditions for adoption.

In order for Fast AMP to surpass the wealth of Slow AMP, productivity would need to be 114% of the initial productivity level and to become the wealth maximizing system would require a 29% increase in productivity. Alternatively, utilization would have had to increase to more than 90% for the system to be wealth maximizing. This was beyond what could likely be grazed without jeopardizing pasture health and future productivity, with rate of gain levels for animals increasing to the near the upper level of what is possible. Adoption costs would need to decrease by 38% relative to the original model estimates, an unreasonable level of decline given the confidence in the cost estimates and the improbability of the costs of fencing and water systems declining significantly in future.

With the literature being inconclusive as to whether or not there are any gains to productivity to be had from intensifying grazing management, and the large improvements in biological factors or adoption costs required, this system seemed unlikely to be widely adopted without significant financial support. This support would also have had to be significant. To make Fast AMP the wealth maximizing system required an upfront payment to the operation of $386,400, or $552/head in the initial 700 cow herd. While there are not a huge number of cow-calf operations in Alberta (12,282; Statistics Canada 2016), that would still mean an expense of $4.7B should the government subsidize the full adoption cost without cost sharing. Scaling per head costs to the 1.565M head provincial herd (Canadian Beef 2016) provided lower but still significant cost estimates, at $864M. Regardless of the measure, these were expensive propositions. Using yearly payments or legislating the use of Fast AMP to capitalize on the environmental benefits and forcing producers to fund the costs would result in $41,000 per year in payments or decreased earnings. Across all farms, knowing that this was the low end estimate, as the Lac Ste. Anne ranch had the lowest per head costs, meant total payments (or foregone revenue) of $504M per year. Finding a market for environmentally raised beef, or selling environmental credits could, however, be within the realm of possibility. For the $63/head breakeven estimate, this would have raised the price by $0.17/lb, assuming 100% cost increase pass-through from operator to consumer. It also assumed that the animal was at target weight, and had a live weight to hanging weight ratio[28] of 0.6 (Mossback Farm 2013). For ground beef, at $5.25/lb in Q1 2020 (Bedford 2021), this would have added 3% to the price.

On the opposite end of the results spectrum, very little change to any of the key parameter values was required to remove the incentives for the ranch to shift from Continuous to Slow AMP; that is, this ordering was very sensitive to parameter values. Declines in utilization rate, pasture productivity, rate of gain or increases to AMP adoption of less than 5% would have resulted in Continuous grazing generating a greater expected wealth (Table 6.7). In dollar terms, a $3300 per year decline in returns generated by the adoption of Slow AMP was sufficient to reverse the ranking.

The comparison of Traditional to Continuous was important as Continuous grazing, despite general recognition in the literature as a less economically and environmentally viable system, is still widely used in Alberta, albeit more often on smaller operations than larger ones. The sensitivity analysis results in Table 6.8 for the Lac Ste. Anne ranch indicated that Continuous ranchers in the province were forgoing significant returns by not converting to

[28] This is the difference between the weight of a live animal and the weight after butchering

Traditional rotational grazing. Annual returns (i.e., Annual Program result in Table 6.8) would need to decrease by $22,000 before Continuous grazing would be equivalent to Traditional in terms of expected wealth. There was also considerable potential “slack” for the biological factors, with productivity having to decline by 13%, relative to the original assumptions in the model, or forage utilization rate declining from 0.6 to 0.545. This represented a considerable margin of decline. Similarly, the rate of gain for Traditional rotational grazing would need to decrease from 0.979 kg/day down to 0.83 kg/day, also substantial. The cost of fencing and water would also have to increase by 355% over the current model estimate. These results provided significant confidence in the ranking of Traditional rotational grazing as being wealth maximizing for the Lac Ste. Anne ranch.

The most interesting results from a policy perspective were for the comparison of Slow AMP to the Traditional rotational grazing scenario. Fast AMP appeared to be non-viable without massive market intervention or the development of new beef or carbon markets, but Slow AMP still had many environmental benefits over Traditional grazing. In order for Slow AMP to be as economically viable as Traditional, pasture utilization required an 8.4% larger improvement over the level originally used (i.e., 0.786 versus 0.725). This was significant but not beyond the realm of possibility for some operations. Pasture productivity needed to increase by 12% over the modeled level. Again, not inconsequential but possible. Alternatively, a decrease of 25% in adoption costs or an increase in the rate of gain of 17.1% (1.05 kg/day instead of 0.897 kg/day) would have had the same impact. These all represented large changes.

In terms of policy responses, a startup contribution of $175,000 to the producer (i.e., $250/head) was required. Alternatively, a price improvement of $28/ head ($0.07/lb for consumers) or an annual payment of $18,500 to the operation would have been equivalent. All of these represented large improvements over the initially assumed values for Slow AMP. However, they also hinted at the possibility that if improvements could be made to multiple assumed parameters, such as greater improvement in utilization along with a cost-sharing policy program, slow AMP might be viable. This potential is examined in section 6.1.4.

Table 6.8: Lac Ste. Anne Ranch Sensitivity Analysis Results; N/A Denotes Scenarios Not Run

Initial Scenario	Final Scenario	Utilization (% Forage Used)	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Price Premium ($/Head)	Annual Program Support ($/Year)
Traditional	Continuous	0.545	-13%	+355%	0.83	N/A	N/A	-22000
Slow AMP	Traditional	0.786	12%	-25%	1.05	250	28	18500
Slow AMP	Continuous	0.714	-2%	+4.5%	0.862	N/A	N/A	-3300
Fast AMP	Slow AMP	0.855	+14%	-20%	1.07	300	34.5	22250
Fast AMP	Traditional	0.925	-13%	+355%	1.28	552	63	41000

6.1.3.2 Ponoka Sensitivity Results

Sensitivity analysis results for the Ponoka representative ranch are provided in Table 6.9. The Fast AMP sensitivity results were very similar to those for the Lac Ste. Anne ranch. With a yearly payment required in excess of $45,000 to become wealth maximizing, it seemed unlikely that this grazing management would be viable. Even making it equally viable as Slow AMP (i.e., third in the ranking) required $24,000 per year in support. This seemed like a high cost to society and producers for the gains accrued.

Similar to the Lac Ste. Anne ranch, for the Ponoka ranch Traditional outperformed Continuous by a wide margin. This was confirmed in the sensitivity analysis results presented in Table 6.8, as significant changes in key parameters were required for this result to be overturned. Utilization would need to decline from 60% use to 55%, productivity would need a 12% decline, rate of gain to fall from 0.897kg/day to 0.847kg/day, or the costs of fencing and water would need to increase by 300% relative to the originally estimated values. The qualitative result of Traditional grazing outperforming Continuous grazing for this ranch therefore appeared to be stable. This was also confirmed in that an annual reduction in returns of $20,000 (Table 6.9) would be required before the two scenarios performed equally well.

In terms of what would be required to make Slow AMP as viable as the baseline Continuous grazing scenario for the Ponoka ranch, the changes in parameters needed were smaller than for the Lac Ste. Anne ranch. A change of less than 3% in a biological or cost assumption resulted in adoption of Slow AMP providing greater expected wealth than maintaining Continuous grazing. In terms of the policy parameters, an initial payment of approximately $10,500 ($15/head), a $2 price premium per head, or $2,000 per year in support payments were required. While not insignificant, these would seem to be within the realm of possibility. While still not wealth maximizing (i.e., Traditional rotational grazing provided the greatest level of expected wealth), given that Continuous is still practiced by a significant number of producers and was the base case for this study, this was an encouraging result for the adoption of AMP grazing and its environmental benefits.

Not surprisingly, the required degree of parameter change for Slow AMP to at least equal the performance of Traditional rotational grazing was greater. As shown in Table 6.9, percentage improvements of 9.7% (from 0.725 to 0.795), 14%, 27.3% and 23.7% (from 0.897 kg/day to 1.11 kg/day) were required to utilization, productivity, AMP infrastructure costs and the rate of gain, respectively, to make Slow AMP the wealth maximizing grazing system. With respect to policy instruments, an initial subsidy of $201,600 ($288/head in the Slow AMP herd), a price premium of $32/animal ($0.09/lb to consumers), or an annual producer payment of $21,500 were required to result in Slow AMP being at least as viable as the Traditional scenario. It is conceivable that some producers may be able to achieve the levels of improvement in the enterprise/adoption parameters, although it would be more likely to be feasible if multiple parameters improved beyond the originally assumed values (see section 6.1.4 for more detail). However, the government expenditure required to provide the necessary policy support is unlikely to be feasible.

Table 6.9: Ponoka Ranch Sensitivity Results; N/A Denotes Scenarios Not Run

Initial Scenario	Final Scenario	Utilization (% Forage Used)	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Price Premium ($/Head)	Annual Program Support ($/Year)
Traditional	Continuous	0.55	-12%	+300%	0.847	N/A	N/A	-20000
Slow AMP	Traditional	0.795	+14%	-27.3%	1.11	288	32	21500
Slow AMP	Continuous	0.73	+1%	-3.4%	0.917	15	2	2000
Fast AMP	Slow AMP	0.857	+16%	-20%	1.07	325	36.5	24000
Fast AMP	Traditional	0.945	+33%	-40%	1.45	615	70	45500

6.1.3.3 Newell Sensitivity Results

Sensitivity analysis results for the Newell representative dryland ranch are presented in Table 6.10[29]. The first result of note was that the wealth maximizing ranking of Traditional rotational grazing was not as stable as for the other two ranches. For example, if pasture utilization were 4.2% less than the original parameter value used for the Traditional scenario (i.e., 0.575 instead of 0.6), the Continuous scenario would have performed equally well. Similarly, a productivity decline of 4.4%, or a 17% increase in adoption costs resulted in Continuous being equally good in terms of expected wealth. In dollar terms, if annual returns for the Traditional scenario were reduced by $7000, the Continuous scenario would perform just as well.

Sensitivity analysis results for the more intensive AMP grazing systems suggested a fair degree of stability in the rankings from the original analysis for the Newell ranch. Significant improvements in the various parameters examined here were required for these scenarios to "break even" with the Traditional or Continuous scenarios (Table 6.10). For example, $46,000 and $54,000 per year in support payments were needed for Slow AMP to be equally as viable

[29] As noted earlier in this chapter, initial sensitivity analysis results for the irrigated Newell ranch resulted in unrealistic "break even" parameter values, due to the poor performance of the AMP scenarios. As a result, they were not presented or discussed here.

as the Continuous and Traditional scenarios, respectively. The per head initial subsidies required for the equivalent effect on the same comparisons were $625 and $730, respectively. Similarly, for Slow AMP to perform as well as Continuous grazing required close to 100% pasture utilization (0.97 instead of 0.725), a 48 percent increase in pasture productivity, or a 36% reduction in adoption costs. None of these seemed realistic, although it was conceivable that a combination of improved parameter values might be more feasible to consider. This is explored later in this chapter.

One further indication of the unlikeliness of economic viability for the AMP scenarios was the issue with “break even” levels for rate of gain. All rate of gain numbers for comparisons involving Slow or Fast AMP were sufficiently unrealistic that it limited the model’s ability to generate meaningful results and so these were not reported in Table 6.9.

These results were not encouraging for AMP or even rotational grazing and the potential environmental benefits offered by these management strategies, given that very similar economic outcomes resulted from avoiding the significant infrastructure expenditure and maintenance. Wang et al. (2021) found that rotational grazing and more intensive rotational grazing systems performed better and recovered faster from droughts than continuous systems. Thus, the lack of consideration of drought conditions in the current analysis probably contributed to an underestimation of the net benefits from adoption of AMP. Further work quantifying the ability of producers in Southern Alberta to survive droughts, and the impact rotational grazing has on this ability, is a topic deserving of further study.

Table 6.10: Newell Ranch Sensitivity Results; N/A Denotes Scenarios Not Run; - Denotes Infeasible Scenarios

Initial Scenario	Final Scenario	Utilization (% Forage Used)	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Price Premium ($/Head)	Annual Program Support ($/Year)
Traditional	Continuous	0.575	-4%	+17%	0.8	N/A	N/A	-7000
Slow AMP	Traditional	1.022	0.58	-43%	-	730	80	54000
Slow AMP	Continuous	0.97	0.48	-46%	-	625	68	46000
Fast AMP	Slow AMP	0.993	0.4	-34%	-	625	71	46000
Fast AMP	Traditional	1.38	1.05	-56%	-	1350	154	99000

6.1.4 Multi-Factor Sensitivity Results

While it is useful to examine the sensitivity of the results to changes in individual factors, it may be the case that values for multiple model parameters are different from those modeled in the current analysis. It was therefore important to examine how changes to multiple parameter values interacted in terms of affecting both quantitative and qualitative model results. While not feasible to test all possible combinations of parameter values, it was decided to investigate this on a limited basis. The approach taken was to identify one parameter of interest and systematically vary its value. For each of the alternative values, sensitivity analysis (similar to what was presented and discussed in the previous section) was conducted to identify "break even" values for other key parameters. Specifically, the degree of change in parameter value required for the Slow and Fast AMP scenarios to be equally viable as Traditional rotational grazing was identified.

Pasture utilization rate was chosen as the parameter to be systematically varied in this multi-factor sensitivity analysis. It was increased (and decreased) in 5% increments from -15% up to +20%. Sensitivity analysis was then performed again on the same set of parameters discussed in the previous section. This provided a more complete picture of the potential for grazing management change to impact financial performance of the representative ranches.

Utilization was selected as the factor undergoing systematic change because it had the highest potential variability across producers and because it had the greatest level of uncertainty in the selection of the values used in the original analysis.

6.1.4.1 Lac Ste. Anne Multi-Factor Sensitivity Results

The multi-factor sensitivity analysis results for the Lac Ste. Anne ranch are presented in Tables 6.11 and 6.12 for Slow and Fast AMP, respectively. For both Slow and Fast AMP, the patterns exhibited by these results were as expected. If the change in pasture utilization attributable to AMP adoption was greater (lower) than originally estimated, it required a smaller (larger) improvement in other parameters in order for the specific AMP scenario to be at least as preferable as Traditional rotational grazing.

One clear outcome from the analysis results in Tables 6.11 and 6.12 was that if the improvement in pasture utilization were smaller than originally expected, the prospects for either form of AMP grazing to be economically viable were poor. This could be seen by examining the degree to which pasture productivity or AMP costs needed to improve relative to original estimations. For example, pasture productivity needed to improve between 21.1% up to 42% over the original estimated improvement for Slow AMP, or AMP adoption costs needed to be between 41.8% and 95% lower than initially estimated (Table 6.11). The degree of improvement required for these parameters was even greater for Fast AMP adoption (Table 6.12).

However, as shown in Table 6.11 if the improvement in utilization were even slightly greater than originally estimated, the potential for Slow AMP to be a viable alternative to Traditional rotational grazing was improved. For example, if Slow AMP resulted in a 5% increase in utilization rate relative to its initial estimate (i.e., 0.761 instead of 0.725), it became the expected wealth maximizing system for the Lac Ste. Anne ranch if pasture productivity also saw a 5% increase over the original estimated improvement, or if AMP adoption costs declined by 10%, or if rate of gain were improved by 8.7% over the initial estimate (Table 6.11). The magnitude of change reflected here is certainly within the realm of possibility, either due to estimation error or managerial abilities of individual producers. To subsidize initial adoption costs at this new level of utilization required $73,500 ($105/head in the Slow AMP herd), or $8,000 in annual subsidies. These still represented a sizable investment by the government and so the feasibility of this magnitude of policy response was still questionable.

As the degree of improvement in utilization for Slow AMP increased further, the additional required improvements in other key parameters became even more realistic. For example, if the improvement were at least 10% more than initially estimated, AMP adoption costs could actually have been greater than initially estimated or the increase in pasture productivity smaller than expected (i.e., negative changes for productivity and positive changes in AMP adoption costs in Table 6.11), However, the potential for pasture utilization to improve to this degree with adoption of Slow AMP (i.e., values of 0.8 or greater) would need to be considered.

As shown in Table 6.12, the prospects for economic viability of Fast AMP adoption by the Lac Ste. Anne ranch remained questionable, even with greater improvement in pasture utilization. For example, even a 10% boost to utilization over the original improvement would have required pasture productivity to be 12% greater than the original estimate, or AMP adoption cost to be at least 16% lower (Table 6.12). Similarly, the degree of subsidy required was still substantial; an initial subsidy of $175,000 ($250/head in the Slow AMP herd) or an annual producer payment of $18,000 being required to achieve an equivalent level of expected wealth as the Traditional scenario. At a 15% or 20% increase to utilization over expected, the hurdles were substantially lowered. However, the prospects for this type of improvement in pasture utilization (i.e., approximately 0.90) were not good. As a result, it can be stated with some level of confidence that Fast AMP systems are unlikely to be the wealth optimizing system for ranches in the Lac Ste. Anne region.

Table 6.11: Lac Ste. Anne Ranch: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.61625	+42%	-95%	1.75	806	60000
-10	0.6525	+31%	-65%	1.6	600	45000
-5	0.68875	+21.1%	-41.8%	1.206	420	31000
5	0.76125	+5%	-10%	0.975	105	8000
10	0.7975	-2%	+3%	0.871	-35	-2500
15	0.83375	-8%	+15%	0.758	-170	-12000
20	0.87	-13%	+24%	0.673	-290	-21000

Table 6.12: Lac Ste. Anne Ranch: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.65875	+64%	-92%	1.913	1140	84000
-10	0.6975	+51%	-73%	1.814	925	68000
-5	0.73625	+39%	-53%	1.689	740	54000
5	0.81375	+20%	-28%	1.415	400	29500
10	0.8525	+13%	-16%	1.093	250	18000
15	0.89125	+6%	-7%	0.938	119	8500
20	0.93	-1%	+1%	0.8	-10	-1000

One final scenario (not shown) was simulated, in which pasture utilization, pasture productivity, and rate of gain were all increased by 5%, while AMP costs were decreased by 5%. For Slow AMP, this resulted in a 10.7% increase in wealth compared to Traditional; that is, with these changes to adoption parameters Slow AMP provided the greatest expected wealth of the options considered in the analysis. For Fast AMP, expected wealth was still 3.1% lower than for the Traditional scenario. Improving all of these parameters by 10% did result in Fast AMP generating greater expected wealth than Traditional (5.1% greater), although Slow AMP would still provide a greater level of expected wealth in that case. While suggesting that Fast AMP remains unlikely to see adoption, 5% improvements to estimates across the board may be realistic for some producers. With some financial aid provided, or income from a potential carbon market, it may be financially prudent for producers to switch their operations to a Slow AMP system.

6.1.4.2 Ponoka Multi-Factor Sensitivity Results

The results for the Ponoka ranch are provided in Tables 6.13 and 6.14 for Slow AMP and Fast AMP, respectively. For the most part the qualitative results of this analysis mirrored those for the Lac Ste. Anne ranch. If the improvement in pasture utilization from AMP adoption were lower than initially estimated (i.e., rows with negative percentage changes in utilization in the two tables), prospects for economic viability of adoption were poor. As well, unless the increase in pasture utilization was significantly greater than was originally incorporated into the analysis the potential for Fast AMP to be economically viable was limited. Even for 10 and 15 percent improvement above the original increase, it required significant improvements in one (or more) other key parameters, or significant policy intervention (e.g., $23,000 producer payment per year even with a 10% additional improvement in utilization, as shown in Table 6.14), for this scenario to be economically viable.

For Slow AMP, the Ponoka ranch scenario results were very similar to the Lac Ste. Anne ranch results (Table 6.13). With a 5% additional increase in utilization rate, Ponoka's Slow AMP system required a 6.5% additional increase in pasture productivity, a 12% additional decrease in AMP adoption costs, or a 11.5% additional increase to the rate of gain of calves (i.e., 1 kg/day instead of 0.897 kg/day) to be equally as viable as Traditional rotational grazing. The required policy interventions in this case, however, were still substantial; either a $98,000 upfront subsidy ($140/cow in the Slow AMP herd) or an annual producer payment of $10,000 was needed. The required improvements in adoption parameters were still within the realm of possibility for individual producers.

Also similar to the Lac Ste. Anne ranch, with additional improvements in utilization at a 10% level or more, the prospects for economic viability of Slow AMP seemed promising (Table 6.13). The question is whether utilization rates of 0.85 or more are possible for commercial ranches.

Table 6.13: Ponoka Ranch: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.61625	+44%	-94%	1.75	840	62000
-10	0.6525	+33%	-66%	1.611	640	47000
-5	0.68875	+23%	-46%	1.218	460	34000
5	0.76125	+7%	-12%	1	140	10000
10	0.7975	0%	+1%	0.894	0	0
15	0.83375	-6%	+11%	0.777	-131	-10000
20	0.87	-12%	+21%	0.682	-255	-19000

Table 6.14: Ponoka Ranch: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.65875	+67%	-90%	1.928	1200	88000
-10	0.6975	+54%	-70%	1.841	990	72500
-5	0.73625	+43%	-64%	1.724	790	58500
5	0.81375	+24%	-39%	1.449	460	34000
10	0.8525	+16%	-19%	1.15	315	23000
15	0.89125	+9%	-10%	1.008	175	13000
20	0.93	+2%	-2%	0.856	50	3000

As with the Lac Ste. Anne ranch, an additional analysis was simulated for the Ponoka representative ranch with a simultaneous 5% improvement for utilization, productivity, adoption costs and rate of gain (results not presented). This resulted in Slow AMP being the best grazing management system, with expected wealth that is 3.3% greater than Traditional. A 10% improvement in all four factors was required for Fast AMP to outperform Traditional rotational grazing (i.e., expected wealth 4.1% greater). While confirming that there is potential for Slow AMP to see some natural adoption in Ponoka, and much higher levels of adoption with comparatively low levels of subsidy, the likelihood of mass adoption of Fast AMP grazing, even with significant financial support, appears limited.

6.1.4.3 Newell Multi-Factor Sensitivity Results

The analysis results for the Newell dryland ranch are presented in Tables 6.15 and 6.16. Similar to the other two ranches, prospects for economic viability of the AMP strategies were poor if pasture utilization did not increase to the extent originally projected (i.e., results in the two tables for negative percentage changes to utilization). Also similar to the Lac Ste. Anne and Ponoka ranches, the results for Newell in Tables 6.15 and 6.16 indicated that even with greater increases in pasture utilization, Fast AMP was unlikely to be economically viable due to the significant improvements still required in one of the other key parameters in order to "break even" with the Traditional scenario. One additional note concerning the results in these tables is that in all cases, break even rate of gain requirements could not be calculated as they required such unrealistic daily gains as to make the model begin to generate illogical results.

The main difference with the results for the other two ranches was in terms of Slow AMP; specifically, even with greater increases in pasture utilization, significant improvements in other parameters were required for Slow AMP to be equally viable as Traditional rotational grazing. With a 5% additional improvement to utilization, pasture productivity gains needed to be approximately 49% greater than originally estimated, or AMP adoption costs needed to decline by 35%. Even with a 20% additional increase to utilization (which would result in a utilization factor of 0.87) pasture productivity or AMP adoption costs needed to improve by 24.5% and 16%, respectively. The subsidy required (one-time up front for adoption costs or on an annual basis) to support adoption of AMP was also prohibitive, as indicated in Table 6.15. Again, with a 20% additional increase in utilization, the required start-up subsidy was $300/head or $210,000 in total. Alternatively, the annual required producer payment was $22,000. Therefore, despite the environmental and purported economic benefits, AMP grazing may be non-viable in Alberta's more arid regions, even with better than average performance in environmental factors resulting from transition and potentially huge inflows from the public purse.

Table 6.15: Newell Ranch: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization; N/A Denotes Unfeasible Scenarios

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.61625	+103%	-80%	N/A	1210	89100
-10	0.6525	+87%	-65%	N/A	1030	76000
-5	0.68875	+73%	-52%	N/A	870	64000
5	0.76125	+49%	-35%	N/A	610	45000
10	0.7975	+39%	-28%	N/A	500	37000
15	0.83375	+33%	-22%	N/A	390	29000
20	0.87	+25%	-16%	N/A	300	22000

Table 6.16: Newell Ranch: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization; N/A Denotes Unfeasible Scenarios

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.65875	+148%	-85%	N/A	1860	137000
-10	0.6975	+129%	-74%	N/A	1670	123000
-5	0.73625	+110%	-64%	N/A	1505	110500
5	0.81375	+83%	-48%	N/A	1205	88500
10	0.8525	+71%	-43%	N/A	1085	80000
15	0.89125	+60%	-38%	N/A	975	72000
20	0.93	+51%	-34%	N/A	875	64500

The additional scenario (i.e., joint improvement in utilization, pasture productivity, AMP adoption costs, and rate of gain) was also run for the Newell ranch. Even with simultaneous improvement of 15%, neither Slow nor Fast AMP was able to outperform Traditional rotational grazing. Capturing the environmental benefits of AMP grazing in the province's more arid regions will require significant legislative or financial incentives and come at tremendous cost. While an argument can be made that in the more arid climates, increased labour would be used as opposed to increased infrastructure to handle paddocks, even this seems unlikely given the cost of labour and the percentage declines in the conversion costs needed in this simulation. Further work will be required to settle this debate, but the results here suggest AMP grazing will be of limited financial viability in Alberta's more arid regions.

6.2 Mixed Operation Results

Section 6.2 examines the results for the representative mixed operations in the three locations, Lac Ste. Anne, Ponoka, and Newell. As discussed in the previous chapter, these operations combined commercial crop production with a 150 head initial beef cow herd. The same grazing management strategies were modeled and simulated as for the representative commercial ranches. The initial baseline strategy was Continuous grazing, and this was compared with three versions of rotational grazing; Traditional, Slow AMP and Fast AMP. The structure of this section is consistent with the previous section. First, the baseline scenario results are presented and briefly discussed. This is followed by more detailed discussion of results for the different scenarios modeled for each representative mixed operation, and then sensitivity and multi-factor sensitivity analyses.

6.2.1 Mixed Base Results

Similar to results for the commercial ranches discussed in Section 6.1, the NPV results for the baseline Continuous scenario are presented for all representative mixed operations, in Table 6.17. NPV results for both the whole mixed operation (i.e., beef and crop enterprises) as well as for just the beef enterprise are presented in the table. The beef enterprise NPV was calculated using the same general formula, but with only beef-related revenues and costs being included. Given the focus of this study, the beef enterprise NPV results were considered to be the more important metric for the discussion of the thesis and potential future policy. While also presented in later tables, discussion of the whole-farm NPV results is primarily done here.

NPV results for the four mixed operations, assuming Continuous grazing is used, are presented in Table 6.17. As indicated in the table, the greatest expected wealth occurred for the Newell (dryland) operation, followed by Newell (irrigated), Lac Ste. Anne and Ponoka. The higher ranking for the Newell representative operations was largely due to the larger size of the cropping part of the business (i.e., 1295 ha versus 1036 ha for the Lac Ste. Anne and Ponoka operations). The primary difference in expected wealth for Lac Ste. Anne versus Ponoka was due to the performance of the beef enterprise, also shown in Table 6.17. Expected NPV for the beef enterprise on the Lac Ste. Anne operation was greater than that for the Ponoka mixed operation ($409,987 versus $360,622).

An examination of the expected NPVs for the beef enterprises (Table 6.17) revealed that the ranking of expected wealth was the same as for the commercial ranches; Lac Ste. Anne, Ponoka, Newell Dryland, and Newell Irrigated. The reasons for the differences were also essentially the same as those discussed for the commercial ranches in section 6.1.1; that is, differences in pasture productivity, and size of animals. However, the relative differences between operations were different than for the commercial ranches. The Lac Ste. Anne and Ponoka commercial ranches were separated by less than a percentage point in terms of expected NPV. For the mixed operations, the expected wealth generated by the beef enterprise on the Ponoka operation was just 88% of the expected wealth generated by the Lac Ste. Anne operation. The difference between the Ponoka and Dryland Newell operations was much smaller than was the case for the commercial ranches: less than 2% separates Ponoka and Newell Dryland. However, consistent with the earlier discussion for the commercial ranches, the irrigated beef enterprise also performed poorly.

These results were primarily due to herd size. The smaller herd had fewer animals over which to spread the fixed costs, leading to lower wealth for the less productive sites that required larger infrastructure costs. The magnitude of this penalty for maintaining larger pastures, however, is surprising; there is substantial pressure to increase herd size for operations in more arid regions, compared to wetter climates.

Before moving to results for the different grazing management scenarios, it should be noted that the beef enterprise contributed a relatively small proportion of overall wealth for these mixed operations; for example, approximately 12% in the case of the Lac Ste. Anne operation

($409,987 of a total of $3,394,843, from Table 6.17). This was simply due to the relative size and importance of the cropping versus beef enterprises in terms of revenue generation. These mixed operations were modeled as having extensive cropping enterprises and a relatively small initial beef herd (150 cows). Because of the dominance of cropping for these mixed operations, changes to grazing management systems did not have a large impact on overall business wealth. As a result, the discussion on performance of the different grazing scenarios focused on changes to the expected wealth (NPV) generated by the beef enterprises.

Table 6.17: Measures of Wealth (Mean NPV Over 20 Years) for Continuous Grazing for Representative Mixed Operations in Three Regions of Alberta ($); (SD)

	Lac Ste. Anne	Ponoka	Newell (Dryland)	Newell (Irrigated)
NPV for Whole Operation	3,394,843.23 (271,090.86)b	3,345,478.05 (272,035.10)	3,985,141.38 (294,015.87)	3,760,831.30 (293,424.36)
NPV for Beef Enterprise	409,987.14 (137,859.30)	360,621.96 (138,849.88)	353,996.74 (120,896.87)	129,686.66 (124,447.06)

6.2.2 Initial Grazing Management Change Results

This subsection analyses the switch from Continuous Grazing to Traditional, Slow AMP and Fast AMP grazing management systems for the representative mixed operations. The assumptions made to model each system, as well as the costs and environmental and financial benefits of each system, were detailed in Chapter 4. Results are broken down into more easily understandable sub-sections. Appendix A1 provides a figure containing the full results of the grazing management system change simulations.

6.2.2.1 Comparison of NPV's Across Systems

Table 6.18 provides a summary of the simulation results for the four representative mixed operations for the different grazing management scenarios. Specifically, this table provides NPV results for the beef enterprises. These results for the mixed operations differed significantly from those presented and discussed earlier for the commercial ranches. First, given the smaller initial herd sizes and size of the land base for pasture, the expected wealth generated by the beef enterprise on the mixed operations was lower than for the corresponding commercial ranches, and this was to be expected. However, the relative performance of the different grazing management scenarios also differed from the earlier results.

Similar to the results for the commercial ranches, Traditional grazing was the wealth maximizing scenario for the Lac Ste. Anne and Ponoka mixed operations; that is, this scenario provided the greatest expected NPV for these two operations, as shown in Table 6.18. Unlike the commercial ranch results, however, Continuous grazing was the wealth maximizing system for both Newell sites, and Continuous grazing performed better than Slow AMP for the Lac Ste. Anne operation.

Given the differences in expected wealth results between the commercial ranches and mixed operations, the viability of more intensive grazing management appeared to be correlated positively with herd size. With fewer animals over which to spread the costs, smaller operations had more difficulty paying for the infrastructure required to adopt such systems. In the case of the arid provincial South and the drier areas of the Palliser Triangle, any intensification at all appeared to be unviable. For Lac Ste. Anne, switching to Slow AMP from Traditional reduced expected wealth to 65% of Traditional; for Newell, it was reduced to 7.8% of the expected wealth for Traditional, and dropped to 7.3% of the wealth maximizing Continuous scenario (Table 6.18).

Table 6.18: Measures of Wealth (Mean NPV Over 20 Years) for Alternative Grazing Systems for Representative Mixed Operations in Three Regions of Alberta ($); (SD)

	Lac Ste. Anne	Ponoka	Newell (Dryland)	Newell (Irrigated)
Continuous	409,987.14 (137,859.30)	360,621.96 (138,849.88)	353,996.74 (120,896.87)	129,686.66 (124,447.06)
Traditional	495,225.75 (163,976.48)	431,194.24 (163,992.74)	328,668.34 (141,623.47)	-70,651.94 (146,998.88)
Slow AMP	321,269.47 (160,241.80)	257,124.43 (159,982.11)	25,677.41 (137,029.73)	-785,719.18 (142,143.37)
Fast AMP	189,041.96 (154,278.01)	125,744.65 (153,651.80)	-196,716.14 (132,571.95)	-1,290,088.48 (138,164.54)

6.2.2.2 Lac Ste. Anne Mixed Results

Table 6.19 presents results for the Lac Ste. Anne mixed operation. For this operation, Traditional was the wealth maximizing scenario, with a 20.8% improvement in expected beef enterprise wealth associated with a transition from Continuous grazing (from $409,987 to $495,226). Different from the commercial ranch results, however, there were no gains relative to Continuous from a switch to Slow AMP. Instead, there was a 21.6% decline in expected beef enterprise wealth (from $409,987 to $321,269). Relative to Traditional rotational grazing, the expected wealth decrease from switching to Slow AMP was 35.1%. It should be noted that the degree of improvement associated with shifting from Continuous to Traditional was greater for the mixed Lac Ste. Anne operation (>20%) than for the Lac Ste. Anne commercial ranch (9%).

Table 6.19 provides an indication of the degree of variability in the beef enterprise wealth results (i.e., standard deviations of the NPVs). To a certain extent the pattern was as expected. The Traditional scenario had the greatest degree of variability, which was expected given that it provided the greatest expected wealth. The variability for the baseline Continuous scenario was the lowest, despite having the second greatest expected wealth, following the trend seen in the ranches where herd size was the driving factor of NPV variance, with NPV standard deviations for Slow and Fast AMP also following this pattern. The same pattern was true, to even a greater degree, if relative variability were considered. The coefficient of variation for both Continuous and Traditional scenarios was approximately equal to 0.33. However, the equivalent measure for Slow AMP was 0.499, and for Fast AMP was 0.82, increasing as capital expenditure of the transition increased, as with the ranches, but to a much larger degree. With the smaller herd size on the mixed operation, the investment required to adopt more intensive grazing management systems exposed the producer to significantly greater risk. It should be noted, however, that the “gap” was much smaller at the whole operation level given the impact of diversification from the cropping enterprises (i.e., whole operation results in Table 6.19).

The pattern in ending herd size for this mixed operation was similar to what was observed for the commercial ranching results. Under Continuous grazing, the year-to-year variability in pasture productivity resulted in the land base for pasture not being sufficient to support the initial 150 cow herd (i.e., average ending herd size is approximately 137 cows). With more intensive grazing management and associated increases in pasture utilization, ending herd size increased, with Traditional rotational grazing providing the greatest opportunity.

Also similar to the Lac Ste. Anne commercial ranch results, expected NPV per head was greatest for the Continuous grazing scenario, followed by the Traditional scenario (Table 6.19). The explanation for this pattern was also consistent; that is, ultimately the producer gained the benefits from intensifying grazing management through expansion of the herd size.

Further results are detailed in Table 6.19, to provide the same level of information as provided for the ranches. However, since they followed similar patterns to those identified for the ranches and did not provide much additional new information or policy potential, they were not elaborated on for here or for subsequent mixed operations, and were provided simply for completeness. See Section 6.1.2 for a longer discussion of trends seen in per head results and further discussion on variability.

Table 6.19: Lac Ste. Anne Mixed Operation Results ($/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV of Whole Operation	3,394,843.23 (271,090.86)	3,480,081.84 (287,700.39)	3,306,125.56 (285,397.80)	3,173,898.05 (281,751.60)
NPV of Cattle Operation	409,987.14 (137,859.30)	495,225.75 (163,976.48)	321,269.47 (160,241.80)	189,041.96 (154,278.01)
NPV Cattle Operation per Head	2,833.40 (909.83)	2,670.25 (855.90)	1,782.64 (861.81)	1,086.36 (875.55)
Average Net Cash per Head, Years 1-5	309.49 (154.51)	352.30 (150.14)	322.91 (149.40)	293.87 (148.88)
Average Net Cash per Head, Years 15-20	298.78 (158.81)	337.53 (152.30)	311.66 (151.69)	281.80 (151.34)
End Herd Size	136.85 (12.42)	193.07 (17.97)	184.27 (17.54)	172.55 (17.05)

6.2.2.3 Ponoka Mixed Results

Table 6.20 provides results for the Ponoka mixed operation. Generally speaking, the results for the Ponoka mixed operation were very similar to those for the Lac Ste. Anne mixed operation. Traditional rotational grazing provided the greatest expected beef enterprise wealth ($431,194), followed by Continuous, Slow AMP and Fast AMP. The pattern in variability (both absolute and relative) was also similar although the degree of increase in relative variability associated with the AMP strategies was even more pronounced; the coefficient of variation increased from approximately 0.38 for Traditional and Continuous grazing, to 0.622 for Slow AMP and 1.222 for Fast AMP. An equivalent level of investment was required to adopt the AMP scenarios and similar variability in pasture productivity, but lower expected returns from adoption resulted in greater risk exposure for the adopting producer. Lastly, the pattern in ending herd size and expected beef enterprise NPV per head were the same as for the Lac Ste. Anne mixed operation. In all cases, the associated explanations for these patterns discussed earlier were applicable here as well.

Table 6.20: Ponoka Mixed Operation Results ($/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV of Whole Operation	3,345,478.05 (272,035.10)	3,416,050.33 (287,569.53)	3,241,980.52 (284,775.11)	3,110,600.740 (280,816.50)
NPV of Cattle Operation	360,621.96 (138,849.88)	431,194.24 (163,992.74)	257,124.43 (159,982.11)	125,744.65 (153,651.80)
NPV Cattle Operation per Head	2,496.24 (933.02)	2,331.59 (872.99)	1,425.94 (869.18)	719.06 (880.92)
Average Net Cash per Head, Years 1-5	273.84 (158.64)	318.73 (152.10)	292.42 (150.93)	265.57 (149.42)
Average Net Cash per Head, Years 15-20	267.20 (156.04)	305.87 (150.53)	283.21 (150.14)	255.06 (150.75)
End Herd Size	136.69 (12.15)	192.47 (17.89)	184.24 (17.46)	172.74 (16.93)

6.2.2.4 Dryland Newell Mixed Results

Table 6.21 presents the results for the dryland Newell mixed operation. As noted earlier, the Newell mixed operations (both dryland and irrigated) represented the only instances in the entire analysis (both commercial ranch and mixed operation) where Traditional rotational grazing was not the wealth maximizing system. For the dryland mixed operation, adoption of Traditional rotational grazing resulted in a 7.2% decline in expected beef enterprise wealth relative to the wealth maximizing Continuous system (i.e., $328,668 versus $353,997). Performance for both AMP scenarios was significantly worse, with the expected NPV for Slow AMP being barely above zero ($25,677) and a negative expected NPV for Fast AMP (-$196,716). The patterns in variability and NPV per head were consistent with the patterns in expected wealth. The pattern in ending herd size was, however, consistent with the previous results. While the more intensive grazing management systems were not as economically viable as Continuous grazing, the increases in pasture utilization did allow for increased ending herd sizes (Table 6.21).

The significantly larger pasture areas required to sustain the Newell mixed operation herd (i.e., more than double the area for Ponoka and triple for Lac Ste. Anne) resulted in prohibitive cost barriers to grazing system intensification. When the smaller animal sizes were factored in, lowering per head return further compared to the Northern sites, there was no financial viability in intensification.

Traditional rotational grazing was relatively close to the level of expected performance for the Continuous scenario, meaning there could be scenarios where some intensification was economically viable. This was explored in the sensitivity and scenario analyses, below. However, in general there appeared to be little scope for capturing the environmental benefits of rotational grazing, let alone AMP grazing, in the more arid regions of the province.

Table 6.21: Dryland Newell Mixed Results ($/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV of Whole Operation	3,985,141.38 (294,015.87)	3,959,812.98 (307,256.68)	3,656,822.05 (304,073.14)	3,434,428.50 (300,809.97)
NPV of Cattle Operation	353,996.74 (120,896.87)	328,668.34 (141,623.47)	25,677.41 (137,029.73)	-196,716.14 (132,571.95)
NPV Cattle Operation per Head	2,459.37 (839.08)	1,714.74 (740.56)	139.30 (745.26)	-1,154.07 (781.52)
Average Net Cash per Head, Years 1-5	273.10 (146.99)	270.68 (133.39)	206.04 (134.31)	151.49 (137.35)
Average Net Cash per Head, Years 15-20	262.74 (154.58)	264.59 (136.89)	210.23 (138.9)	154.35 (142.19)
End Herd Size	138.38 (9.12)	197.18 (12.83)	186.78 (13.13)	173.11 (13.47)

6.2.2.5 Irrigated Newell Mixed Results

Simulation results for the irrigated Newell mixed operation are presented in Table 6.22. Similar to the results for the commercial ranch at this location, using irrigation to support the beef enterprise had limited economic viability; the cost of irrigating pasture did not result in profitable economic return in average circumstances. When coupled with the significant adoption costs of transitioning to more intensive grazing systems, the results were negative in terms of expected wealth. This was true even for Traditional rotational grazing. Given the nature of these results, it seems unlikely that AMP grazing systems would be viable in this region under irrigated production. As a result, similar to the case for the irrigated Newell commercial ranch, no further analysis was undertaken for this mixed operation.

Table 6.22: Irrigated Newell Mixed Full Results ($/Head); Exempting Herd Size (in Head) and NPV (in $); (SD)

	Continuous	Traditional	Slow AMP	Fast AMP
NPV of Whole Operation	3,760,831.30 (293,424.36)	3,560,492.70 (306,999.56)	2,845,425.46 (299,433.63)	2,341,056.15 (292,627.95)
NPV of Cattle Operation	129,686.66 (124,447.06)	-70,651.94 (146,998.88)	-785,719.18 (142,143.37)	-1,290,088.48 (138,164.54)
NPV Cattle Operation per Head	891.00 (853.56)	-359.49 (748.08)	-4,217.59 (787.25)	-7,426.29 (922)
Average Net Cash per Head, Years 1-5	117.59 (152.90)	109.15 (135.37)	-59.00 (141.57)	-205.06 (155.19)
Average Net Cash per Head, Years 15-20	90.52 (156.33)	104.59 (139.23)	-60.16 (142.79)	-215.35 (149.75)
End Herd Size	141.72 (7.36)	200.85 (11.07)	189.62 (11.01)	174.81 (11.08)

6.2.3 Sensitivity Results

Similar to the analysis conducted for the commercial ranches (i.e., section 6.1.3), sensitivity analysis was done for key parameters in the mixed operation models, wherein one of the model parameters (utilization rate, pasture productivity, rate of gain, AMP adoption costs) was increased or decreased in each of the grazing management systems until the system changed position in the expected beef enterprise wealth rank ordering. As the focus of the project was on the impact on the cow-calf side, it was elected to use breakeven for the cow-calf enterprise expected NPV, rather than the whole operation NPV. As well, three potential policy instruments (an initial subsidy amount paid to offset adoption costs, a yearly subsidy payment, and a price premium paid per head) were introduced one at a time and adjusted until the expected beef enterprise wealth ranking changed. In most cases, this was a shift to being the expected wealth maximizing strategy, but the requirements for Slow AMP to be better than Continuous and Fast AMP to be better than Slow AMP were also calculated.

6.2.3.1 Lac Ste. Anne Mixed Sensitivity Results

Results for this section are presented in Table 6.23. The initial factor by factor breakeven suggested that Traditional grazing had a relatively stable advantage over the Continuous system. For Continuous to overtake Traditional in terms of expected beef wealth (NPV), utilization needed to fall by 14% (0.6 to 0.517), pasture productivity would have had to decline by 20%, AMP costs would need to increase by 280%, or rate of gain would have to decline 18% (0.979 to 0.807). In terms of annual returns, earnings associated with Traditional rotational grazing needed to decline $8500 per year for Continuous to be equally viable.

Slow AMP was shown to have the potential to outperform Continuous, provided significant parameter improvements were accomplished: a 21% (0.725 to 0.88) additional increase in utilization, a 100% additional increase in pasture productivity, 54% reduction in AMP costs, or a 100% increase in rate of gain (over the base of 0.897 kg/day). Subsidies equal to $172,000 ($1150/head) or an annual payment of $18,500 would also have resulted in Slow AMP surpassing Continuous grazing in terms or expected wealth. A price premium of $75/head ($0.18 per lb slaughtered) would also provide Slow AMP with equivalent wealth to the Continuous System.

As with the ranches, the ability of Fast AMP to surpass any system remained unviable, requiring pasture utilization increases of over 100% (103% to surpass Slow AMP and 160% to surpass Traditional). Slow AMP also appeared non-viable compared to Traditional for the mixed operations, with their smaller herd sizes having increased the cost burden per head, resulting in Slow AMP requiring a utilization rate of 105% of available forage to surpass Traditional Grazing. Table 6.23 shows the other parameter changes, and all have similar interpretations. As with the ranches, this resulted in significant costs if these values were extended across the province, equating to some $22.7M per year, or $2.1B or $1.8B upfront, on a per ranch or per head basis, while the cost per pound needed to rise by $0.33, or 6.3%.

Table 6.23: Lac Ste. Anne Mixed Sensitivity Results; N/A Denotes Scenarios Not Run; - Denotes Unfeasible Scenarios

Initial Scenario	Final Scenario	Utilization (% Forage Used)	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Price Premium ($/Head)	Annual Program Support ($/Year)
Traditional	Continuous	-20%	-80%	-280%	0.807	N/A	N/A	-8500
Slow AMP	Traditional	+101%	-54%	-54%	1.83	1150	135	18500
Slow AMP	Continuous	+134%	-25%	-25%	1.6	600	75	9900
Fast AMP	Slow AMP	+161%	-26%	-26%	1.62	910	110	14000
Fast AMP	Traditional	+265%	-66%	-66%	-	2050	250	32000

6.2.3.2 Ponoka Sensitivity Results

Results for the Ponoka factor by factor breakeven are presented in Table 6.24. When comparing the Traditional to Continuous wealth gap and required factor changes to result in Traditional losing its advantage, Ponoka results were similar to Lac Ste. Anne: a 12.5% (0.6 to 0.525) decline in utilization rate, 18% reduction in pasture productivity, 200% increase in adoption costs, or a 17% decline in rate of gain (0.979kg/day to 0.808kg/day). Annual return decline also remained similar, with a $7500 per year decrease in Traditional annual returns making Continuous equally viable.

Due to decreases in pasture productivity relative to Lac Ste. Anne, no other tested breakeven scenario proved to be realistic, with all requiring pasture utilization near or exceeding 100% of available forage, likely unattainable increases in pasture productivity, adoption cost declines beyond what could feasibly be obtained or rate of gain increases beyond biological possibilities, some to the point of not being calculable within the model. Support payments, one time or annual, and price premiums also reached high levels unlikely to be able to be affordable or politically palatable. Even with improvements to adoption costs and outcomes or with significant public financial support, AMP grazing was likely not economically viable in the Aspen Parkland.

Table 6.24: Ponoka Mixed Sensitivity Results; N/A Denotes Scenarios Not Run; - Denotes Unfeasible Scenarios

Initial Scenario	Final Scenario	Utilization (% Forage Used)	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Price Premium ($/Head)	Annual Program Support ($/Year)
Traditional	Continuous	0.525	-18%	+201%	0.808	N/A	N/A	-7500
Slow AMP	Traditional	1.1	+117%	-50%	-	1150	136	18600
Slow AMP	Continuous	0.92	+57%	-22%	2.02	700	84	11000
Fast AMP	Slow AMP	1.025	+63%	-23%	-	890	110	14000
Fast AMP	Traditional	1.55	+181%	-61%	-	2050	250	32000

6.2.3.3 Newell Sensitivity Results

Table 6.25 provides Dryland Newell mixed operation results for factor by factor breakeven. As noted earlier, Continuous grazing was the cow-calf operation wealth maximizing management strategy.

As shown in Table 6.25, it is possible that some producers may see Traditional grazing perform as well as Continuous. An increase in pasture utilization of 9% (0.655 to 0.6) or a 12% increase in pasture productivity for the Traditional system resulted in that strategy becoming the wealth maximizing option. Similar to the Ponoka operation, however, the simulation results suggested there was little likelihood of other scenarios being viable. In many cases, required gains to factors were not only unrealistic but illogical (e.g., pasture utilization greater than 100%). This resulted in required subsidization levels or price premiums beyond what was affordable or politically viable (increases of $0.70 per lb for consumers or $32,000 per year per operation in the Mixed Prairie for Slow AMP to be the highest wealth system). Rotational grazing, and AMP especially, did not appear to be a viable system in the more arid regions of the province.

Table 6.25: Newell Mixed Sensitivity Results; N/A Denotes Scenarios Not Run; - Denotes Unfeasible Scenarios

Initial Scenario	Final Scenario	Utilization (% Forage Used)	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Price Premium ($/Head)	Annual Program Support ($/Year)
Traditional	Continuous	0.655	+12%	-45%	-	205	20	2500
Slow AMP	Traditional	2.18	+206%	-54%	-	2000	235	32000
Slow AMP	Continuous	2.4	+282%	-60%	-	2200	252	34500
Fast AMP	Slow AMP	1.62	+182%	-25%	-	1500	182	24000
Fast AMP	Traditional	N/A	N/A	-66%	-	3500	430	55000

6.2.4 Mixed Multi-Factor Sensitivity Analysis

As was done for the commercial ranches (Section 6.1.4), additional break even analysis was conducted for the representative mixed operations. Specifically, pasture utilization was increased/decreased in 5% increments relative to the initially assumed values for the Slow and Fast AMP systems, and the breakeven results rerun with these new assumed levels to see the effect of multiple improvements at the same time in order to further assess the potential viability of transitioning to AMP. In all cases, the changes were calculated as those required for the AMP strategy to perform as well as the Traditional rotational grazing strategy.[30]

Results for the multi-factor sensitivity analysis are detailed in Tables 6.26 to 6.31 and show only results for increased utilization rates (see Appendix A6-11 for full results). This was due to the viability of AMP being questionable given the initial assumptions of the model. Decreasing utilization only further reinforced this outcome.

[30] Note that for Newell, this did not result in the systems being "best," as Continuous was the best performing grazing management strategy for Newell in terms of expected wealth, but consistency across comparisons was deemed higher priority, especially given the already substantial changes required for the AMP systems to surpass Traditional.

Looking at the accompanying tables, it was evident even with substantial gains to pasture utilization, above what has already been assumed in the base case, that significant improvements to additional parameters or policy support would have been required for AMP grazing to be viable. For the Lac Ste. Anne mixed operation (Table 6.26) to adopt Slow AMP, even with a 20% further increase to utilization rate (to 0.87 from 0.725), Slow AMP still required pasture productivity to increase by 50%, AMP costs to fall by 25%, or rate of gain to increase by 75% (from 0.898kg/day to 1.57kg/day). Support needed to be $90,000 per operation ($600/head) in startup subsidies, or $9500 per year.

Results were of an even larger magnitude for Fast AMP, at both Lac Ste. Anne and Ponoka, and of a similar scale for Ponoka's Slow AMP site. For the Newell operation, the required improvements to surpass Traditional were greater still, and would have been even larger yet to surpass Continuous, which was wealth maximizing in Newell.

As with the ranching operations, a set of scenarios (not shown) were run where utilization rate, pasture productivity, rate of gain and AMP costs were all improved by the same percentage. Even with an improvement of 15% to all factors, none of the AMP systems generated more wealth than the Traditional system. Given these results, it appeared unlikely that AMP grazing was a viable system for small and average sized cow-calf operations, even with significant levels of policy support.

Table 6.26: Lac Ste. Anne Mixed: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
5	0.76125	190	-44	1.8	1000	15500
10	0.7975	170	-36	1.712	875	13500
15	0.83375	160	-31	1.65	735	11000
20	0.87	150	-25	1.57	600	9500

Table 6.27: Lac Ste. Anne Mixed: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Utilization; N/A Denotes Unfeasible Scenarios

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
5	0.81375	240	-59	N/A	1850	29000
10	0.8525	222	-52	N/A	1675	27000
15	0.89125	210	-47	N/A	1550	24750
20	0.93	195	-43	N/A	1425	22250

Table 6.28: Ponoka Mixed: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Utilization; N/A Denotes Unfeasible Scenarios

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
5	0.76125	218	-42	N/A	1000	15750
10	0.7975	200	-35	N/A	875	13700
15	0.83375	186	-30	2.42	735	11500
20	0.87	173	-24	2.206	610	9600

Table 6.29: Ponoka Mixed: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Utilization; N/A Denotes Unfeasible Scenarios

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
5	0.81375	255	-55	N/A	1850	29500
10	0.8525	240	-50	N/A	1700	27500
15	0.89125	220	-45	N/A	1600	25000
20	0.93	205	-41	N/A	1475	23000

Table 6.30: Newell Mixed: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Utilization; N/A Denotes Unfeasible Scenarios

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
5	0.76125	345	-56	N/A	2075	32750
10	0.7975	320	-53	N/A	1960	31250
15	0.83375	300	-50	N/A	1880	29750
20	0.87	280	-48	N/A	1820	28500

Table 6.31: Newell Mixed: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Utilization; N/A Denotes Unfeasible Scenarios

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
5	0.81375	N/A	-66	N/A	3500	55500
10	0.8525	500	-63	N/A	3400	53500
15	0.89125	460	-61	N/A	3300	52000
20	0.93	430	-59	N/A	3200	50500

6.3 BRM Impacts

As discussed in Chapter 5, the assumption was made in modeling the representative operations that they participated in government business risk management (BRM) programs; specifically AgriStability[31]. The impact of BRM participation was examined by running the simulations again, without participation in AgriStability. This generated a large number of results, a redacted number of which are presented here to describe results and trends, and hint at future policy. These included the expected NPV results for the commercial ranch operations in Table 6.32, and the percentage change in expected NPV from switching grazing management strategies in Table 6.33. The specific management shifts examined were

[31] In the case of the mixed operations, participation in AgriInsurance (crop insurance) was also assumed.

Traditional to Continuous, Fast AMP and Slow AMP, from Continuous to Slow AMP, and from Slow AMP to Fast AMP. A tabular presentation of the full set of results is provided in Appendix A5.

The results for all ranches under all of the different grazing management scenarios were as expected; that is, participation in AgriStability resulted in increased expected wealth (NPV) and decreased operation NPV variance. This held for the mixed operations (see Appendix A3 and A4), exempting the Newell mixed operations under Continuous grazing. For these operations, participation in AgriStability resulted in an increase in NPV variance. This was due to the small herd size leading to lower revenues which in turn meant payments made up a larger percentage of income, leading to higher variance.

Table 6.32: Commercial Ranch NPV and Change in Commercial Ranch Expected NPV from Participation in AgriStability, by Grazing Management Strategy in Three Locations in Alberta over 20 Years ($)

	Lac Ste. Anne		Ponoka		Newell (Dryland)		Newell (Irrigated)	
	No BRM	BRM	No BRM	BRM	No BRM	BRM	No BRM	BRM
Continuous	1,855,300 (636,884)	2,355,077 (627,710)	1,840,306 (624,434)	2,334,638 (612,551)	1,800,507 (494,990)	2,071,855 (457,348)	701,165 (504,425)	1,129,278 (454,232)
Difference	499,777		494,332		271,348		428,113	
Traditional	2,176,136 (737,704)	2,566,717 (704,217)	2,143,219 (726,229)	2,523,151 (689,982)	1,871,022 (612,647)	2,141,938 (568,618)	752,618 (631,186)	1,165,118 (567,863)
Difference	390,581		379,932		270,916		412,500	
Slow AMP	2,003,424 (719,739)	2,389,518 (681,296)	1,940,935 (708,208)	2,319,528 (669,157)	1,338,884 (587,751)	1,632,177 (537,904)	218,374 (600,815)	665,759 (535,431)
Difference	386,094		378,593		293,293		447,385	
Fast AMP	1,792,632 (690,118)	2,175,528 (647,242)	1,711,863 (680,068)	2,091,578 (633,317)	880,946 (559,392)	1,197,947 (505,120)	-228,039 (567,420)	255,223 (508,032)
Difference	382,896		379,715		317,001		483,262	

Table 6.33: Selected Percentage Changes to Ranch NPV from Selection of Grazing Strategy, With/Without Participation in AgriStability

	Lac Ste. Anne		Ponoka		Newell (Dryland)	
	No BRM	BRM	No BRM	BRM	No BRM	BRM
Continuous to Traditional	17.29%	8.99%	16.46%	8.07%	3.92%	3.38%
Continuous to Slow AMP	7.98%	1.46%	5.47%	-0.65%	-25.64%	-21.22%
Traditional to Slow AMP	-7.94%	-6.90%	-9.44%	-8.07%	-28.44%	-23.80%
Slow AMP to Fast AMP	-10.52%	-8.96%	-11.80%	-9.83%	-34.20%	-26.60%
Traditional to Fast AMP	-17.62%	-15.24%	-20.13%	-17.10%	-52.92%	-44.07%

Table 6.33 details the differences in wealth for switching between certain systems with the models BRM function off and on and shows some interesting policy implications. For all Mixed operations (not shown), and all Ranches, there was a disincentive to intensify from Continuous to Traditional associated with participation in AgriStability; that is, there were larger gains to wealth from intensifying from Continuous to Traditional if the ranch did not participate in BRM (although in absolute terms expected wealth is lower from non-participation). With participation in AgriStability there was also a reduced incentive or increased disincentive (depending on the ranch) to move from Continuous to Slow AMP. The exception was for the Newell ranch, for which there was a reduced disincentive to adopt Slow AMP compared to Continuous with participation in AgriStability. For the change from shifts from Traditional to Slow AMP, from Traditional to Fast AMP, and from Slow AMP to Fast AMP, there were reduced disincentives associated with switching to the less viable scenario when the ranch participated in AgriStability. This also held for the mixed operations (see Appendix 3) for all sites and scenarios exempting the Newell mixed operation when moving from Slow AMP to Fast AMP.

The impact of AgriStability is discouraging for environmental and economic outcomes in the case of moving producers from Continuous to Traditional grazing. However, it is encouraging that, in the cases for the other more intensive grazing systems, the BRM program is not incentivizing retention of less intensive grazing systems. This means, hopefully, that policy to address environmental issues in range management can work within the existing AgriStability system, or a future version that is revised in such a way to provide incentives to move away from Continuous grazing, as opposed to requiring a massive overhaul to the BRM system to provide positive and cohesive incentives for intensification. Future policy development should consider, however, that there is a disincentive for Continuous operations to intensify, although relatively small in magnitude, and that this may affect future environmental incentive programs if they are not made with this in mind. It would be wasteful to include environmental incentives linked to intensifying within the AgriStability framework as it currently stands, as some of the incentives will be cancelled out due to countervailing disincentives, decreasing program effectiveness.

6.4 Chapter Summary

This project modeled four grazing management systems, in three locations on two sizes of operation per location. In all cases exempting the mixed Newell operation, Traditional (8-Paddock) rotational grazing was the wealth maximizing strategy. Continuous (1-Paddock) grazing was wealth maximizing for the mixed Newell operation. Even when substantial increases were made to the assumed benefits of more intensive grazing systems, the costs of the Slow AMP (50 Paddock) and Fast AMP (115 Paddock) systems were often so large that they seldom became the highest wealth system; more often, the necessary assumptions exceeded biological possibilities. While it was possible that the Lac Ste. Anne and Ponoka ranching operations could see Slow AMP be wealth maximizing if operations could manage higher than average improvements to pasture productivity resulting from a conversion and keep costs down, even this seemed unlikely given the results, and seemed very unlikely for all other operations. The probability of Fast AMP being the wealth maximizing strategy was almost zero, given the results. In most cases the costs of rotational grazing infrastructure were too high, and the improvements too low, for systems much more intense than Traditional 8-Paddock to become wealth maximizing for a given operation.

When measured by Standard Deviation of NPV, risk increased with increased herd size, given the importance of price volatility. However, when measured by Coefficient of Variation, risk increased with the cost of conversion, with the high expense of adopting the more intensive systems having a large impact on the risk faced by operations. This made Continuous grazing the least risky operation by both metrics, with standard deviation putting Traditional highest and then Slow AMP, while using the Coefficient of Variation Fast AMP had the highest risk, followed by Slow AMP.

Chapter 7: Conclusions, Future Work and Limitations of the Study

As a form of resource extraction, grazing cattle is subject to both the wills and whims of economy and environment. Cattle must be raised and sold profitably, but the natural world has a say, imposing restrictions and limitations on how pastures can be used lest they cease to be productive at all. Within the constraints imposed by the market and nature there exist opportunities for producers to make management decisions, however. One of these areas is with respect to grazing management strategies. There are many alternative ways to graze cattle, which has led to a spectrum of grazing practices across the province, each with its own tradeoffs. There exist systems using single pastures with the cattle on for a season, to smaller paddocks that cattle spend only days or even hours in, and everything in between, and each system has associated economic and environmental benefits and losses, for producers and society. Discovering which system is best for the environment, for ranchers, and for wider society, and how to use policy instruments to arrive at the best system, was not something that had previously been examined in Alberta. This thesis is the first to undertake this examination.

The analysis in this thesis focused on the impact of changes to the rotational grazing system on farm wealth, using Monte Carlo analysis to simulate cow-calf operations of differing sizes and locations in Alberta. Representative operations in the Boreal Transition, Aspen Parkland, and Mixed Prairie were modeled, located in Lac Ste. Anne, Ponoka, and Newell counties, respectively, to give a more complete picture of how operations in a range of locations would be affected in terms of expected wealth by a switch to more intensive grazing management. Further, two sizes and systems of operation, a 700 head commercial ranch operation and a 150 head mixed cow-calf and cropping operation, were modeled to see how operation size and structure affect the impact of a change in grazing system.

The stochastic elements in the Monte Carlo model involved beef and feed (barley and hay) prices and pasture productivity (indirectly through modeling stochastic weather). In this way, production and market risk were integrated into the simulation. All scenarios were run over a 20-year time horizon, with Continuous (single paddock), Traditional (8 paddock), Slow AMP (50 paddock) and Fast AMP (115 paddock) grazing systems modeled at each location and for each operation size. The defining characteristics for the grazing systems were developed based on producer survey data from Bork et al. (2021) and were determined using cluster analysis.

Each grazing scenario was simulated with 1000 iterations for each representative operation. The resulting NPVs, amongst other outputs, were compared across systems to assess the economic viability of adopting more intensive grazing management systems. Additional simulation analysis was also performed to test the sensitivity of the results to values of key parameters.

7.1 Discussion of Key Findings

7.1.1 Summary of Simulation Results

While comparisons between the grazing management strategies were discussed in Chapter 6 as the results were being presented, this section provides an assessment for the whole range of results presented and discussed in the thesis. It should be noted that, with an average provincial herd size of 147 head per farm (Canadian Beef 2016), adoption results for the average Albertan beef operation may well be closer to those reported for the mixed operations (i.e., initial herd size is 150 cows) than the results for the representative commercial ranches (700 cow initial herd size). This may then provide insights into the overall cost of any grazing management based environmental improvement policy program.

Based on these results, however, the prospects for the potential adoption of AMP pasture management systems are not encouraging. The representative mixed operations were penalized financially much more by a switch from Traditional to Slow AMP than were the commercial ranches modeled in the analysis. For the mixed operations, expected NPV declined by an average of 55.9% (or 37.7% if the Newell region mixed operation is excluded) when shifting from Traditional to Slow AMP, compared to an average decline of 12.9% (7.5% excluding Newell) in expected NPV for the larger ranches with an equivalent change in grazing management.

Both types of beef production operation experienced large declines in expected NPV from a switch to more intensive grazing systems, but the degree of decline was greater for mixed operations and their smaller herds. This was primarily due to the cost of installing fencing and the herd size: fencing had a high cost per kilometer and with fewer animals to spread the cost over, the smaller operations saw much poorer economic performance. The same could be said for the costs of installing the watering infrastructure.

However, the large costs alone did not provide the whole picture. Much has been argued about the increased biological performance of rotational grazing, and there is a plethora of anecdotal evidence and suggestions by AMP advocates that the increases to utilization rates and productivity will allow for a larger herd, and that the increased performance of the pasture will allow for longer grazing seasons, decreasing winter feed costs. Due to inconclusive evidence in the literature, an increase in pasture productivity was not factored into the initial simulations, but even when included (i.e., sensitivity analyses in Sections 6.1.4 and 6.2.4) gains to productivity did not lead to increased expected wealth for producers when more intensive grazing systems were adopted, relative to Traditional grazing. The same was also true for increased utilization rate, which did not provide enough additional forage and enough additional animals to justify the costs of acquiring it.

A similar inference could be made for the purported increases in the length of grazing season. While increasing the grazing season did decrease winter feed costs, it also decreased the annual carrying capacity of the pasture, resulting in smaller herd sizes for AMP grazing compared to Traditional rotational grazing[32]. The cost savings over winter were not sufficient to make up for the increased cost of fencing and the smaller herd. Modeling suggested that this increased length of grazing season was a detriment to producers: when the Ponoka ranch Slow AMP system was run with the same grazing period as the Traditional rotational grazing system, the decrease in expected NPV from a shift to AMP decreased from 15% to 3%. Unless feed costs were substantially underestimated (see Sections 5.1.1.5 and 5.7 for a discussion of the ration, costs of ration, and verification and validation of the model), a notable result of this study is that rotational grazing operations graze more than they should and feed less. It should be noted, however, that this does not account for the risk of price shocks in the winter feed market nor how drought could stress reliance on grown winter feed. As practiced and therefore modeled, however, the costs associated with a switch to more intensive rotational grazing were not offset by the purported benefits of the system, especially as utilization rate, pasture productivity, and grazing season length were concerned.

That substantial decreases in expected wealth are a clear indicator that, unless the switch to rotational grazing provides truly significant improvements to managing risk significant adoption is unlikely without policy action. This does not appear to be the case, however; that is, simulation analysis suggested that adoption of more intensive grazing management did not reduce risk. The modelling indicated that, as system intensity increases, the coefficient of variance, which measures variability relative to expected value, increased in all operations. This suggested that risk increased with intensification. The degree of increase in relative risk also increased as the size of the operation decreased. When looking at the standard deviation of NPVs, a slightly different pattern appeared, with risk decreasing as herd size decreased. While a switch from Traditional to Slow AMP would decrease risk by this measure, it would increase

[32] As reported by Bork et al. (2021), this result is not seen in the wider project data, which show a tendency for larger herds with increased intensity. This suggests that producers are running a greater number of lighter animals whereas the model in the current study indicates targeting fewer, heavier animals to be wealth maximizing.

risk when moving from Continuous to Slow AMP, which is what the majority of transitioning operations, especially smaller operations, would be doing. Future policy should take this increase in operating risk into consideration.

7.1.2 Policy Implications

With the cost of adopting the more intensive grazing management systems outweighing the financial returns, as well as increasing risk for all operations by one measure and most operations by another, policy intervention will be required if society is to see the environmental benefits of adopting rotational grazing. Discussion of possible policy actions is presented here as the cost of a subsidy paid to producers for adoption. It could also be viewed as the maximum amount producers would be willing to pay to avoid being legislatively required to adopt AMP grazing. Given the previous discussion on the larger income declines faced by smaller operations from a switch, it should not be a surprise that the cost of support, per head, was greater for the smaller mixed operations than for the commercial ranches. The initial one-time subsidy required to support adoption costs in switching from Traditional rotational grazing to Slow AMP was $1150/head for the Northern mixed operations and $2000/head for the Southern operation. The equivalent annual support payments required were $123, $124, and $213/head for the Lac Ste. Anne, Ponoka and Newell mixed operations, respectively. The corresponding levels of support required for the commercial ranches to encourage switching to Slow AMP were $250, $288, and $730 in initial one-time startup subsidies per head for the Lac Ste. Anne, Ponoka and Newell ranches, respectively, and $26, $31, and $77 per head in annual support payments for the Lac Ste. Anne, Ponoka, and Newell. The annual cost of supporting the mixed operations, on a per head basis, was (excluding the Newell ranch) very close to the initial subsidy amount per head required by the ranches. These values are summarized in Table 7.1.

Table 7.1: Required Level of Subsidy to Incentivize Switching from Traditional to Slow AMP by Operation and Type of Subsidy ($/Head)

	Lac Ste. Anne	Ponoka	Newell
	One Time Initial Subsidy		
Commercial Ranch	250	288	730
Mixed Operation	1150	1150	2000
	Annual Subsidy		
Commercial Ranch	26	31	77
Mixed Operation	123	124	213

To support switching from Continuous grazing to Slow AMP, as many smaller operations would be doing, would require slightly lower but still significant policy support. Per head subsidies to offset initial adoption costs were $600, $700, and $2200 for the Lac Ste. Anne, Ponoka and Newell mixed operations, respectively. Alternatively, per head annual producer payments were $66, $73, and $230 annually for the Lac Ste. Anne, Ponoka and Newell mixed operations.

For the larger commercial ranch operations in Lac Ste. Anne, a shift from continuous grazing to Slow AMP improved financial performance and so no policy intervention would be required, although there was less of a gain than switching to traditional rotational grazing. For the Ponoka and Newell commercial ranches, the required subsidies to offset initial adoption costs of switching from continuous grazing were $15 and $625 per head, respectively. The equivalent annual producer payment required was $3 or $66 for Ponoka and Newell. These results are summarized in Table 7.2.

Table 7.2: Required Level of Subsidy to Incentivize Switching from Continuous to Slow AMP by Operation and Type of Subsidy ($/Head); N/A Denotes Scenario with Existing Positive Incentives

	Lac Ste. Anne	Ponoka	Newell
	One Time Initial Subsidy		
Commercial Ranch	N/A	15	625
Mixed Operation	600	700	2200
	Annual Payment		
Commercial Ranch	N/A	3	66
Mixed Operation	66	73	230

The switch to more environmentally friendly grazing management systems will be expensive for the majority of the Albertan cattle herd. If currently available information on average return per cow wintered, of $140.09 (Government of Alberta 2018) in Alberta or $155 per cow (Government of Manitoba 2020), is representative of the experience of most cow-calf producers in Alberta, the cost of converting to more environmentally sustainable grazing systems threatens to reduce or eliminate (depending on the starting system) producer profit margins in the absence of significant conversion support from government.

The cost of government support required to encourage significant adoption of more intensive grazing management would be considerable. Using the per head conversion values from Ponoka mixed operation results[33] to illustrate, fully funding adoption of Slow AMP would necessitate subsidies in the order of $1.3B or $1.1B upfront, depending on whether numbers of operations or numbers of cows are used as the basis. Using the annual subsidy figure calculated for Ponoka mixed operations multiplied across every animal in Alberta, this works to $135M annually in support. These estimates assume that there is full conversion from continuous grazing to Slow AMP, and that adoption costs are fully subsidized. Neither of these

33 The Ponoka mixed operation was used because a) it is somewhat central in the province and b) the herd size of 150 cows was close to the provincial average.

assumptions is realistic, but the calculation provides an indication of the scope of support required if there were efforts made to encourage significant levels of adoption. Further, it bears remembering that the costs incurred by producers are incurred again after 20 years, as the infrastructure wears out. Start-up support would not likely be a one and done cost. The cost would likely be lower in future, as producers would not incur revenue decreases as they hold back animals to expand their herds, but not substantially. Improving the Albertan range environment through shifting grazing management practices appears to be significantly expensive. Given the annual per head costs detailed in Tables 7.1 and 7.2, and the margins on wintered cows, there is also only minimal cost sharing potential for producers that can be undertaken while still leaving enough per head profit to making cow-calf production an attractive career, or even a viable one when factoring in risk.

One commonly cited way of reducing the government support required for environmental programs involving range management is the creation and use of carbon markets. While there is some evidence of grazing management decisions reducing carbon in other parts of the world and generating carbon offset credits (Bosch et al. 2008), it is uncertain whether this would work in Alberta. Research by Shresta et al. (2020), completed as a component of the larger project, concluded that AMP soils sequester more carbon in the form of CH_4, but that this increased uptake of methane was not enough to counteract CO_2 emissions. This suggests that any credit paid to producers from the carbon sequestration benefits would be pay-to-avoid emission, paying producers to keep the carbon already in the ground there, not pay to sequester, which again falls back on the need for public or NGO financial support, which the carbon market was ideally meant to complement. Given the other variables that significantly effect sequestration additional to grazing reported in the Shresta et al. (2020) paper (i.e., effect of temperature, moisture, season), the evidence suggests that building a standardized and verifiable carbon market of sufficient scale to support itself is unlikely given current evidence.

Hewins et al. (2018) report conflicting evidence on soil organic carbon (SOC) sequestration in their literature review, finding evidence that grazing can have no effect, increase sequestration, or lead to net carbon emissions. Their paper goes on to find a slight increase in SOC from grazing, but under light to moderate grazing. This continues a trend in Alberta grazing SOC papers comparing grazing against no grazing, as opposed to a spectrum of grazing options, making it difficult to compare across papers and grazing system intensities. Work in Alberta is also generally concentrated on low to moderate intensity systems, making it difficult to determine what impact a transition to AMP grazing would have on both carbon sequestration and potential carbon markets relative to lower intensity systems.

Breitkreuz et al. (Unpublished) are in the process of analyzing data on AMP versus non-AMP grazing impacts on SOC in Alberta, using the paired ranches from this project. While their preliminary data analysis found no difference in total carbon, analysis of SOC and soil inorganic carbon is pending. Further work on the carbon market field will be needed, likely with a dedicated project to develop a province wide and systematic carbon sequestration inventory to meet international standards. If the carbon sequestration level can be determined, and if it does increase significantly with intensity, there is a possibility of successful carbon markets to subsidize conversion. Using the per head annual payments in Table 7.1, and converting them from per head to per hectare, would give the Ponoka Mixed operation at Slow AMP intensity a sequestration payment requirement of $25.50/ha/year to breakeven relative to Traditional. Whether or not the amount of carbon sequestered is significantly different to overcome this significant breakeven, or if prices climb high enough to surmount a smaller gap, should be a subject of future study.

Without carbon markets, the creation of a market for other Ecosystem Goods and Services and Ecosystem Processes provided by a switch to AMP grazing is complex, falling back into the understanding and use of non-market economic valuation techniques (Clucas et al. 2015) or into a natural capital-ecosystem stocks framework for valuation (Dominanti et al.

2014). Stated and Revealed preference methods work by understanding how people value ecosystem services, such as the value they place on scenic views or wildlife diversity, by either asking outright or valuing them by determining how much people are willing to spend to travel and see more scenic/diverse places as opposed to closer, less scenic or diverse ones (Clucas et al. 2015). Natural Capital-Ecosystem stocks value ecosystem services by estimating the cost required to provide a system naturally provided by the environment, should it be decreased or vanish (increased water treatment costs if soils filter less water or valuing the services of pollinators) (Dominanti et al. 2014).

Döbert et al. (2021) concluded that AMP grazing has water infiltration benefits, and Döbert et al. (2019) found that the number of native prairie specialist bird species increased with AMP grazing on tame pastures. Thus, there are environmental benefits to be had from AMP grazing in Alberta. Whether these environmental processes can be translated into ecosystem services is largely unknown. Previous research (Dominati et al. 2014; Clucas et al. 2015) further showed there may be value to be had in these services. However, getting accurate Willingness to Pay (WTP) data and quantifying the benefits in Alberta from AMP grazing would be a massive undertaking, as the required data do not currently exist. Further, while beneficial to have the WTP values for environmental outcomes such as bird diversity and water infiltration to help "sell" support programs to producers for adoption of AMP grazing to the public, most support to conserve these assets comes from governments, meaning that the initial estimated figures have not been decreased by this diversion. Finally, finding people who directly benefit from these environmental improvements will likely be difficult, if not impossible, again forcing support back on the government as no market or group willing to pay is likely to exist.

Government expenditures would still be required to pay for any support programs, although perhaps with a more rationalized justification for the massive costs.

While it is possible that the benefits of AMP grazing could attract NGO or other conservation groups to provide support, the scale of the required support means that any charitable support will likely provide only minimal benefit to producers. Ducks Unlimited Canada, one of the largest Canadian charities focused on the environment and conservation, had total conservation expenditures of $79.8M in 2019 (Ducks Unlimited Canada 2019). While a considerable amount of money, it is substantially less than the $135M annual cost of subsidization or $1.1-1.3B upfront cost required for the AMP conversion, and this is the expenditure of a large national charity. Further, as 40.2% of Ducks Unlimited Canada's funding comes from government (Ducks Unlimited Canada 2019), the charitable sector would only do a small part to reduce government expenditures on AMP support.

Given the substantial costs associated with a transition to AMP grazing and the limited potential for non-government funding, as well as the difficulties in conceptualizing benefits, the costs of supporting an AMP transition are likely higher than the value of the benefits received by the public. This would argue against the use of government support to incentivize the change. However, with a large number of producers still using Continuous grazing, there is potential for some gains of rotational grazing to be made for a net gain to society, as Traditional grazing generally outperforms Continuous grazing. With some extension and minimal financial support, society and producers could capture some of the benefits of rotational grazing gains However, capturing the gains of the AMP system remains unlikely, given the economic results arising from the analyses in this current research effort.

7.2 Conclusions

Examination of the economic aspects of adopting AMP grazing in Alberta has proved to be nuanced and requires considerable compromises and hard trade-offs. While AMP grazing delivers some environmental benefits and is a profitable system to graze cattle in most of Alberta, it is by no means wealth-maximizing. Producers adopting AMP grazing will be facing substantial reductions to their wealth and increasing risks from adopting AMP systems in comparison to current proven grazing practices.

The environmental benefits that may result from adopting AMP Grazing are also not significant in terms of market or non-market economic values. Payments for Carbon sequestration and storage are likely not viable for the province's cattle producers. Other benefits, such as increased water infiltration, are probably enjoyed by few citizens directly and would be hard to associate with market or non-market economic values.. These factors suggest that the adoption of AMP grazing, which would impose significant costs of adopters, would not pass a benefit cost test in support of government support to producers to incent the adoption. Furthermore, it is difficult to envision ENGOs in the nonprofit sector finding significant enough resources to incent adoption as well.

The economic analyses in this present study are not entirely negative, however, as the wealth maximizing system for most cattle operations in Alberta, was found to be rotational grazing which is already a common practice and if not, would require fewer costly changes to existing ranch infrastructure than the AMP systems. This is valuable information, giving extension officers and producer organizations something concrete to provide to producers unsure of what to make of all of the conflicting current information on grazing management. The findings suggest there are possibilities for many operations to convert to a more valuable system, increasing rural incomes across the province. While not an exciting conclusion, especially on the environmental front, this is useful, contributing to the debate on which system should be used by producers aiming to support themselves and their families and maximizing their wealth, and providing direction, potential policy and costs for environmental and conservation agencies looking to find ways to improve the Albertan environment.

7.3 Study Limitations

There is a significant degree of heterogeneity in the Albertan beef sector, and as such, the use of representative farm analysis is limited in that it must assume a single structure. While significant effort has been made to build representative operations that reflect how cow-calf operations in Alberta operate, building enough representative operations to cover the diversity of agriculture in the province would be a massive undertaking. As such, assumptions about herd management, enterprise costs, and capital structure, amongst other such considerations that could change the quantitative results, were necessary, with the understanding that changes to these assumptions could potentially change the qualitative nature of the results. There were two large structural assumptions made, beyond generally attempting to build “representative” operations. The first was assuming no change to the operation’s labour requirement and costs from a change in pasture management system. This was due to a lack of good data concerning the change in labour requirements from a shift in grazing management; specifically, the impact of a change to grazing management system on labour is uncertain. As such, assuming no change in costs was judged to be the course that would generate the clearest and most generalizable results. The second was to how to fund the transition between grazing management systems. It was assumed that the costs were all paid by the operation in year one, with no debt or financing. While not the likeliest way for this to occur, it generated the clearest results, and made it easier to understand how other capital system assumptions could change the relative wealth than if some other system had been assumed.

Two further assumptions, and corresponding limitations, were made to make the size of the thesis and the generated results manageable. This was to model four grazing management systems, over two operation sizes. Both size and system are spectrums, but it was necessary to identify a finite set of alternatives to be modeled. The watering and fencing requirements for these systems and sizes then had to be determined. There will be significant heterogeneity in practice, but there is confidence that the assumptions made were feasible and given the cluster analysis and expert opinion to determine sizes and system intensities, that the modeled scenarios are reflective of the reality. The second assumption was to the environmental results of a change to grazing management system. There are limited data available on how biological factors, such as utilization rate, pasture productivity, and rate of gain, would change as a system changes. Baseline assumptions were necessary, but given the level of sensitivity analysis undertaken, the results provide enough output to understand how the results may change for different values of these biological factors.

7.4 Further Work

Having established that AMP grazing is not wealth maximizing, and that switching to these systems is expensive for producers, further work examining how to capture the benefits of more intensive systems should be undertaken. Given the significant adoption costs and inability for carbon markets to support the transition in whole or in part, other mechanisms will need to be explored. While there are benefits of interest to the public (i.e., native bird diversity, as noted by Döbert et al. 2019), how payment for these eco-services would be managed requires study, as little work has been done in an Alberta context on policy instruments involving producer payments outside of conservation easements and wetland restoration. The role of and affordability to nonprofits and government in generating these benefits for society via payment for conservation would need to be studied. Another route is to designate AMP grazing a BMP and adopt some sort of cost share model for adoption. While expensive for producers and government, there may be a possible role for the insurance companies and agricultural support programs. This model does not incorporate extreme weather events, such as droughts, but Wang et al.'s (2021) findings that AMP can improve drought resilience for some producers and the Döbert et al. (2021) finding of improved water infiltration, which could aid in drought management, provides a possible avenue for the source of cost share funding. Decreased insurance premiums for AMP adoption, coupled with some government cost sharing with producers to capture the benefits of potential drought resilience is a promising avenue of future study, especially given the long term weather forecasts for climate change in Alberta. This insurance market route would have to be careful to incorporate the fact that this thesis found that risk goes up for AMP producers, however, making this a difficult task requiring substantial work and policy design.

Further work should be undertaken to address the data limitations encountered while building the model. The lack of good data on how a change in grazing management system would impact farm labour requirements, or how any farm labour requirement would change from BMP or policy adoption, should be addressed. Further study on the biological factors of Alberta ranches- utilization rate, pasture productivity, rate of gain- and how they change as grazing management changes would be valuable further work. A provincial inventory of pasture health could not be found when researching for this project. Building such an inventory would provide valuable research data.

Finally, while the model results show that AMP grazing leads to a decrease in wealth, the wider project still found many ranchers in Alberta using AMP grazing systems (Bork et a. 2021). Trying to understand why this is the case warrants further study, as while there is significant heterogeneity across ranches, it seems unlikely given the model results that as many producers can increase wealth from AMP grazing as indicated by current practice (Bork et al. 2021). Some of this discrepancy may be attributable to producers self-identifying as AMP while in reality practicing something far less intense. However, other causes for this discrepancy warrant investigation. This model does not analyze the impact of drought years, and given Wang et al. (2021)'s findings of improved drought resilience by AMP ranchers, these benefits during drought years could be sufficient to result in economic benefits of adoption. Also possible is that producers could have switched systems during a good year, or sequence of good years, and are attributing improvements to AMP grazing and not weather and market cycles. There is also the possibility of non-economic reasons for AMP conversion, and that the non-market benefits of a switch due to lifestyle changes or achieving personal environmental goals, are worth the economic costs to some ranchers.

References

Adams, B.W., Ehlert, G., Stone, C., Alexander, M., Lawrence, D., Willoughby, M., Moisey, D., Hincz, C., Burkinshaw, A., Richman, J., France, K., DeMaere, C., Kupsch, T., France, T. Broadbent, T., Blonski, L., and Miller, A.J. 2016. Rangeland health assessment for grassland, forest and tame pasture. AEP, Rangeland Resource Stewardship Section. (https://open.alberta.ca/publications/9781460127858) accessed 10/26/2021

Alberta Agriculture and Forestry (AAF). 2018. Environmentally Sustainable Agriculture Survey. Government of Alberta. Accessed 7/20/2020. https://open.alberta.ca/dataset/4eb85c95-c8de-40c3-ace5-7acc129ff663/resource/db7a2ef7-8ed8-4303-a1da-4717127ee0af/download/2018-environmentally-sustainable-agriculture-tracking-survey-052018.pdf

Alberta Agriculture and Forestry (AAF). 2019. Alberta Climate and Atlas Maps. Government of Alberta, https://agriculture.alberta.ca/acis/climate-maps.jsp

Agriculture and Agri-Food Canada (AAFC). 2006. Environmental Farm Planning in Canada: An Overview. https://publications.gc.ca/collections/collection_2011/agr/A125-15-2011-eng.pdf accessed 10/2/2021

Agriculture Financial Services Corporation (AFSC). 2019. AgriStability Program Handbook Effective Years 2018-2019. https://afsc.ca/wp-content/uploads/2021/05/AgriStability-Handbook-2018-2019.pdf accessed 6/3/2021

AFSC 2020. WLPIP Program Handbook https://afsc.ca/wp-content/uploads/2020/01/WLPIP-Handbook-2020.pdf accessed 6/3/2021

Alberta Agriculture and Forestry (AAF). 2019a. AgriProfit$ 2018 Cost and Return Benchmarks for Crops and Forages, Black Soil Zone. Government of Alberta https://open.alberta.ca/dataset/32bfb43c-6d2f-4a5c-8629-4f1a3f5c1958/resource/38bde3ec-3b19-4c2c-bb5b-33d1556ef9bc/download/af-2018-cost-return-benchmarks-crops-forages-black-soil-2019-10.pdf accessed 9/10/2021

Alberta Agriculture and Forestry (AAF). 2019b. AgriProfit$ 2018 Cost and Return Benchmarks for Crops and Forages, Brown Soil Zone. Government of Alberta https://open.alberta.ca/dataset/39b50111-2aff-4381-895c-ed7cfcd88d52/resource/700c7cd7-2d33-41b4-b45e-b5f3cc3b4ca2/download/af-2018-cost-return-benchmarks-crops-forages-brown-soil-2019-10.pdf accessed 9/10/2021

Alberta Agriculture and Forestry (AAF). 2020. AgriProfit$2015-2019 Economic, productive and financial performance of Alberta cow/calf operations. Government of Alberta https://open.alberta.ca/dataset/39b50111-2aff-4381-895c-ed7cfcd88d52/resource/700c7cd7-2d33-41b4-b45e-b5f3cc3b4ca2/download/af-2018-cost-return-benchmarks-crops-forages-brown-soil-2019-10.pdf accessed 9/10/2021

Alberta Parks. 2014. Natural Regions and sub-regions of Alberta. Government of Alberta https://www.albertaparks.ca/media/6256258/natural-regions-subregions-of-alberta-a-framework-for-albertas-parks-booklet.pdf accessed 9/10/2021

Alberta Prairie Conservation Forum. (2011). Alberta's Natural Areas Map. Accessed 8/30/2021 from https://www.albertapcf.org/wp-content/uploads/2020/08/gr_map_alberta_2011.gif

AARD (Alberta Agriculture and Rural Development). (Unknown). Municipal Map of Alberta. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/sdd14037/$FILE/map.pdf accessed 8/30/2021

Alemu, A.W., Kröbel, R., McConkey, B.G., Iwaasa, A.D. 2019. Effect of Increasing Species Diversity and Grazing Management on Pasture Productivity, Animal Performance, and Soil Carbon Sequestration of Re-Established Pasture in Canadian Prairie. Animals, 9(4), 127. https://doi.org/10.3390/ani9040127

Alberta Agriculture and Rural Development (ARFD). 2015. Soil Group Map /of Alberta. Government of Alberta. https://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap accessed 07/20/2020

Batbaatar, A., E. W. Bork, T. Broadbent, M. J. Alexander, J. F. Cahill Jr., and C. N. Carlyle. 2021. Grazing alters the sensitivity of plant productivity to precipitation in northern temperate grasslands. Journal of Vegetation Science 32:e13008.

Bao, T., Carlyle, C., Bork, R, Becker, M., and Alexander, M. 2019. Survey of cattle of pasture management practices on focal pastures in Alberta. Canadian Journal of Animal Science, 99(4), 955-961.

Beef Cattle Research Council (BCRC). 2018. Economics of Raising or Buying Heifers for Beef Cow Replacement. http://www.beefresearch.ca/blog/economics-of-raising-or-buying-heifers-for-beef-cow-replacement/#:~:text=The%20estimated%20cost%20per%20bred,2017%20at%20%241%2C921%20per%20head accessed 6/3/2021

Beef Cattle Research Council (BCRC). 2021. Bull Valuation Calculator. http://www.beefresearch.ca/research/bull-valuation.cfm accessed 6/2/2021

Beef Cattle Research Council (BCRC). 2021. Carrying Capacity Calculator. https://www.beefresearch.ca/research/carrying-capacity.cfm accessed 9/10/2021

Bechini, L. and Stockle, C.O.. Integration of a Cropping Systems Simulation Model and a Relational Database for Simple Farm-Scale Analyses. Agronomy Journal 99: 1226-1237.

Bedford, E. 2021. Average retail price for ground beef in Canada 2015-2021. Statista. Accessed 8/4/2021 from https://www.statista.com/statistics/443386/average-retail-price-for-ground-beef-in-canada/

Blais, J., Duff, K., Schindler, D., Smol, J., Leavitt, P., Agbeti, M. 2000. Recent Eutrophication Histories in Lac Ste. Anne and Lake Isle, Alberta, Canada, Inferred Using Paleolimnological Methods, Lake and Reservoir Management, 16(4), 292-304, DOI: 10.1080/07438140009354237

Brethour, C., Sparling, B., Cortus, B., Klimas, M., Moore, T. 2007. An Economic Evaluation of Beneficial Management Practices for Crop Nutrients in Canadian Agriculture. Prepared for the Crop Nutrients Council by George Morris Centre. https://ageconsearch.umn.edu/record/289841/files/BMP_Final_Report.pdf accessed 5/7/2021

Breitkreuz, S., Sobrinho, L., Stachniak, L., Chang, S. Unpublished Poster Presentation. Can the Adaptive Multi-Paddock Grazing System Increase Carbon Sequestration in Alberta's Grassland Soils?. WISEST Special Edition Poster, 2(2) 2019. Accessed 11/03/2021 from https://albertaacademicreview.com/index.php/aar/article/view/52

Briske, D. D., Derner, J.D., Brown, J.R., Fuhlendorf, S.D., Teague, W.R., Havstad, K.M., Gillen, R.L., Ash, A.J., and Willms, W.D.. 2008. Rotational Grazing on Rangelands: Reconciliation of Perception and Experimental Evidence. Rangeland Ecology & Management 61:3–17.

Bork, E., Thomas, T., and McDougall, B. 2001. Herbage Response to Precipitation in central Alberta Boreal Grasslands. Journal of Range Management 54, 243-248.

Bork, E. W., Döbert, T.F., Grenke, J.S.J., Carlyle, C.N., Cahill, J.F., and Boyce, M.S. 2021. Comparative Pasture Management on Canadian Cattle Ranches With and Without Adaptive Multipaddock Grazing. Rangeland Ecology & Management 78:5–14.

Bork, E. W., L. L. Raatz, C. N. Carlyle, D. B. Hewins, and K. A. Thompson. 2020. Soil carbon increases with long-term cattle stocking in northern temperate grasslands. Soil Use and Management 36:387–399.

Bosch, D., Stephenson, G., Groover, G., Hutchins, B. (2008). Farm returns to carbon credit creation with intensive rotational grazing. Journal of Soil and Water Conservation, 63 (2), 91-98; DOI: https://doi.org/10.2489/jswc.63.2.91

Boxall, P. 2017. Evaluation of Agri-Environmental Programs: Can We Determine If We Grew Forward in an Environmentally Friendly Way? Canadian Journal of Agricultural Economics, 66(2), 171-186

Boyd, C. 2020. Personal email communication with Curtis Boyd of AFSC, September 9 2020.

Canadian Agricultural Partnership. 2019. Environmental Stewardship and Climate Change (ES&CC) Producer Program Funding List. https://cap.alberta.ca/CAP/download/AGUCMINT-7557029 accessed 5/6/2021 accessed 9/10/2021

Canadian Cattlemen's Association. 2013. Beef Production 101. https://www.cattle.ca/cca-resources/animal-care/beef-production-101/ accessed 9/10/2021

Canadian Encyclopedia. 2020. History of Agriculture to the Second World War. https://thecanadianencyclopedia.ca/en/article/history-of-agriculture accessed 9/10/2021

Canadian Beef. 2016. Fast facts: Canada's Beef Industry. https://canadabeef.ca/wp-content/uploads/2016/06/FastfactsENGJune8.pdf accessed 7/22/2021

Canfax Research Services. 2018. The Cattle Cycle. CRS Special Addition Fact Sheet. https://www.canfax.ca/CRS/2018%2009%20The%20Cattle%20Cycle.pdf accessed 10/2/2021

Canfax Research Services. 2012. The Beef Industry's Contribution to the Canadian Economy. https://www.albertabeef.org/files/site-content/rt4ffUbMJEUdCd1oRCZWSPUOYIEa7XrVD9H94M8e.pdf accessed 9/10/2021

Chaubey, I., Chiang, L., Gitau, M., Mohamed, S. 2010. Effectiveness of best management practices in improving water quality in a pasture-dominated watershed. Journal of Soil and Water Conservation. 65 (6), 424-437; DOI: https://doi.org/10.2489/jswc.65.6.424

Chetner, S. and Sasaki, D. 2001.Agricultural Air Emission Inventory for Alberta and Literature Review, Developed for the Intensive Livestock Operations Working Group. https://open.alberta.ca/dataset/1c3eb7e0-b2e0-420e-85cc-50ffbcc77398/resource/c3124a8e-a29e-496d-b116-fc315459ea6d/download/af-alberta-agritural-air-emission-inventory-2001.pdf accessed 5/12/2021

Cheung, K. and Meyer, B. 2009. Chemical And Isotopic Characterization Of Shallow Groundwater From Selected Monitoring Wells In Alberta: Part I: 2006-2007. Water For Life, Alberta Environment. https://open.alberta.ca/dataset/27848883-588d-4251-be79-1d68b6ec8793/resource/9d192c5a-303f-4a9b-9056-bd9c23a01739/download/chemicalisotopicgroundwater-part1-may2009.pdf accessed 5/12/2021.

Clucas, B., Rabotyagov, S., Marzluff, J.M. (2015). How much is that birdie in my backyard? A cross-continental economic valuation of native urban songbirds. Urban Ecosyst 18, 251–266. https://doi.org/10.1007/s11252-014-0392-x

Copeland, T., and Weston, J.F. 1988. Financial Theory and Corporate Policy, Third Addition, Addison Wesley Publishing.

Csaki, C. 1985. Simulation and systems analysis in agriculture. Elsevier, Amsterdam, the Netherlands.

Davies, E., Dyck, M., Jeffrey, S., Qui, F., and Untershultz, J. 2017. Final Report to the Alberta Land Institute: Systems modelling for sustainable land and water policy in Alberta's irrigation sector. Alberta Land Institute. https://www.albertalandinstitute.ca/public/download/documents/44771accessed 7/22/2020

Day, Mike. 1999. Mating Capacity of Bulls; Bull to Cow Ratio. Ohio State University. https://u.osu.edu/beef/1999/03/10/mating-capacity-of-bulls-bull-to-cow-ratio/ accessed 5/27/2021

Dent, J.B., and Blackie, M.J. 1979. Systems Simulation in Agriculture. Springer Science + Business Media, Dordrecht.

DeBruijn, S.L., Bork, E.W., 2006. Biological control of Canada thistle in temperate pasture using high density rotational cattle grazing. Biological Control 36, 305-315.

Derner, J., Hart, R., Smith, M., and Waggoner,J. 2008. Long-term cattle gain responses to stocking rate and grazing systems in northern mixed-grass prairie. Livestock Science, 117(1), 60-69.

Döbert, T., Randall, J., Iravani, M., and Boyce, M. 2019. Grazing management influences grassland bird communities across the Canadian prairies. Unpublished University of Alberta Presentation Slides.

Döbert, T., Bork, E., Apfelbaum, S., Carlyle, C., Chang, S., Khatri-Chhetri, U., Sobrinho, L., Thompson, R., Boyce, M. 2021. Adaptive multi-paddock grazing improves water infiltration in Canadian grassland soils. Geoderma, 401, 115314, ISSN 0016-7061, https://doi.org/10.1016/j.geoderma.2021.115314.

Dominati, E., Mackay, A., Green, S., Patterson, M. 2014. A soil change-based methodology for the quantification and valuation of ecosystem services from agro-ecosystems: A case study of pastoral agriculture in New Zealand. Ecological Economics, 100, 119-129, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2014.02.008.

Donahue, W.F., Allen, E.W. and Schindler, D.W. 2006. Impacts of Coal-Fired Power Plants on Trace Metals and Polycyclic Aromatic Hydrocarbons (PAHs) in Lake Sediments in Central Alberta, Canada. J Paleolimnol 35, 111–128. https://doi.org/10.1007/s10933-005-7878-8

Ducks Unlimited Canada. 2019. 2019 Annual Report. Accessed 8/25/2021 from https://www.ducks.ca/assets/2019/08/AR-2019_EN_web.pdf

Encyclopedia Britannica. 2020. Rangeland. https://www.britannica.com/science/rangeland accessed 9/10/2021

Evans, J.R. and Olson, D.L. 2002. Introduction to Simulation and Risk Analysis. second edition., Prentice Hall, Upper Saddle River, New Jersey, USA.

Fu, B., Wang, S., Su, C., and Forsius, M. 2013. Linking ecosystem processes and ecosystem services. Current Opinion in Environmental Sustainability, 5(1), 4-10.

Funnel, B. 2013. Economics of Beef Cow Longevity. Proceedings of the NAVC Conference Large Animal, https://www.vetfolio.com/learn/article/economics-of-beef-cow-longevity accessed 6/3/2021.

Ganti, A. 2021. Capital Market Line (CML). Investopedia. https://www.investopedia.com/terms/c/cml.asp accessed 5/21/2021

Gerrish, J. 2003. Optimizing Pasture and Animal Production through Planned Grazing. Presented at the 2003 Washington State Graziers' Conference; October 30, 2003, WSU Extension. https://extension.wsu.edu/animalag/content/optimizing-pasture-and-animal-production-through-planned-grazing/ accessed 6/28/2021

Government of Alberta. 2000. *Agricultural Operation Practices Act* (2000) https://www.qp.alberta.ca/1266.cfm?page=A07.cfm&leg_type=Acts&isbncln=9780779814879 accessed 9/10/2021

Government of Alberta. 2000. *Water Act* (2000) https://www.qp.alberta.ca/1266.cfm?page=W03.cfm&leg_type=Acts&isbncln=9780779805570 accessed 9/10/2021

Government of Alberta. 2004. Beneficial Management Practices: Environmental Manual for Alberta Cow/Calf Producers. https://open.alberta.ca/dataset/752ea785-9cb3-4cf3-a924-290188ffa3bf/resource/91a6129a-0b41-4094-a04b-bf58b799e05e/download/2004-420-28-2.pdf accessed 5/6/2021 accessed 9/10/2021

Government of Alberta. 2009. *Alberta Land Stewardship Act* (2009). https://www.qp.alberta.ca/1266.cfm?page=A26P8.cfm&leg_type=Acts&isbncln=9780779777259 accessed 9/10/2021

Government of Alberta. 2010. Beneficial Management Practices: Environmental Manual for Livestock Producers in Alberta. https://open.alberta.ca/dataset/cabbed8f-980e-4084-996f-

1c445717ee73/resource/6900ed5d-809c-4709-9c68-78402475c520/download/4851540-2010-Beneficial-Management-Practices-Environmental-Manual-Livestock-Producers-400-28-2.pdf accessed 5/6/2021

Government of Alberta. 2015. Custom Rates Survey. Alberta Agriculture and Forestry, Economics and Competitiveness Branch, Statistics and Data Development Section. https://open.alberta.ca/dataset/f278f0d4-1b9f-44b2-9358-7ef5aa6ee20c/resource/5ba7f7b5-e8b9-41c0-b2cd-5ae01e1a15bd/download/2015-livestock-operations.pdf accessed 08/10/2020

Government of Alberta. 2016. Rangeland Health Assessment: For Grassland, Forest and Tame Pasture. https://open.alberta.ca/dataset/51cad211-09f6-49bd-86ef-ca3162f2ea7a/resource/2cadf8f4-ef65-4e48-812e-10f8daf027a8/download/rangelandhealthassessment-2017.pdf accessed 9/10/2021

Government of Alberta. 2017. Alberta Statistics Yearbook 2017. https://open.alberta.ca/dataset/1927-4106 accessed 08/17/2020

Government of Alberta. 2018. 2013-2017 Economic, Production and Financial Performance of Alberta Cow/Calf Operations. AgriProfit$. Retrieved from https://open.alberta.ca/dataset/781f2072-bdb5-40be-a7df-a0a44a760017/resource/c19ad19f-22a8-46c0-b05a-0a604c4b0814/download/cowcalfbenchmarks2017.pdf accessed 8/5/2021.

Government of Alberta. 2020a. Alberta History- Conventional Oil. http://history.alberta.ca/energyheritage/oil/default.aspx accessed 9/10/2021

Government of Canada. Species at Risk Act. 2002. https://laws.justice.gc.ca/eng/acts/S-15.3/ accessed 9/10/2021

Government of Alberta. 2020. Explained in Brief; Livestock/Cattle: State of the Industry 2020, https://open.alberta.ca/dataset/c0929f2b-f369-4a2e-8179-8f24f9587908/resource/98141eee-b419-4a23-a62c-c375108ab871/download/af-ecb-explained-in-brief-soti-2020-livestock.pdf accessed 5/7/2021.

Government of Manitoba. 2020. Beef Cow-Calf Production Costs Based on 150 Head Herd-Hay Ration. https://www.gov.mb.ca/agriculture/farm-management/production-economics/cost-of-production.html#livestock accessed 10/19/2020

Hao, X., Chang, C. 2003. Does long-term heavy cattle manure application increase salinity of a clay loam soil in semi-arid southern Alberta? Agriculture, Ecosystems & Environment, 94(1), 89-103, ISSN 0167-8809,
https://doi.org/10.1016/S0167-8809(02)00008-7.

Halpin, Brendan. 2016. “Cluster Analysis Stopping Rules in Stata.” SocArXiv. July 19. doi:10.31235/osf.io/rjqe3.

Heitschmidt,R. K., Conner, J. R., Canon, S. K., Pinchak,W. E., Walker, J.W, and Dowhower, S.L. 1990. Cow/Calf Production and Economic Returns from Yearlong Continuous, Deferred Rotation and Rotational Grazing Treatments. Journal of Production Agriculture, 3(1), 92-99.

Hewins, D.B., Lyseng, M.P., Schoderbek, D.F., Alexander, M., Willms, W., Carlyle, C., Chang, S., and Bork, E. 2018. Grazing and climate effects on soil organic carbon concentration and particle-size association in northern grasslands. Sci Rep 8(1336)

Hillenbrand, M., Thompson, R., Wang, F., Apfelbaum, S., Teague, R. 2019. Impacts of holistic planned grazing with bison compared to continuous grazing with cattle in South Dakota shortgrass prairie. Agriculture, Ecosystems and Environment, 279, 156-158

Holechek, J., Gomez, H., Molinar, F., and Galt, D. 1999. Grazing Studies: What We've Learned. Rangelands, 21(2) 12-16.Hornung, J., Rice, C..2003. Odonata and wetland quality in southern Alberta, Canada: a preliminary study. Odonatologica , 32 (2), 119- 129

IronSearch (2020). https://ironsearch.com/ accessed 10/8/2020

Jakoby, O., Quaas, M.F., Baumg.rtner, S., Frank, K., 2015. Adapting livestock management to spatio-temporal heterogeneity in semi-arid rangelands. J. Environ. Manage. 162, 179–189.

Lardy, G. and Dalhen, C. 2017. Early Weaning Beef Calves. North Dakota State. Accessed 6/18/2021 https://www.ag.ndsu.edu/drought/livestock/feeds-and-feeding/early-weaning-beef-calves

Lant, C., Ruhl, J., Kraft, S. 2008. The Tragedy of Ecosystem Services. BioScience, 58 (10), 969–974, https://doi.org/10.1641/B581010

Lantinga, E. 1985. Productivity of grasslands under continuous and rotational grazing. Wageningen University Staff Research. https://library.wur.nl/WebQuery/wurpubs/81000 accessed 9/10/2021

Lee, Timothy. Undated. Optimization versus Simulation: White Paper. https://www.kisters.net/NA/fileadmin/KNA/Products/Optimization_vs_Simulation.pdf accessed 5/21/2021

Lund, H., Arler, F., Østergaard, P.A., Hvelplund, F., Connolly, D., Mathiesen, B.V., Karnøe, P. 2017. Simulation versus Optimisation: Theoretical Positions in Energy System Modelling. Energies, 10, 840. https://doi.org/10.3390/en10070840

Lyseng, M., Bork, E., Hewins, D., Alexander, M., Carlyle, C., Chang, S., Willms, W. 2018. Long-term grazing impacts on vegetation diversity, composition, and exotic species presence across an aridity gradient in northern temperate grasslands. Plant Ecology, https://doi.org/10.1007/s11258-018-0824-4

Ma, Z., Shrestha, B., Bork, E., Chang, S., Carlyle, C., Döbert, T., Sobrinho, L.S., Boyce, M. 2021. Soil greenhouse gas emissions and grazing management in northern temperate grasslands. Science of the Total Environment, 796, https://doi.org/10.1016/j.scitotenv.2021.148975.

McMeekan, C., & Walshe, M. 1963. The inter-relationships of grazing method and stocking rate in the efficiency of pasture utilization by dairy cattle. The Journal of Agricultural Science, 61(2), 147-166. doi:10.1017/S0021859600005888

Medina-Roldán, E., Arredondo Moreno, J., García Moya, M., Martín Huerta Martínez, F. 2007. Soil Water Content Dynamics Along a Range Condition Gradient in a Shortgrass Steppe, Rangeland Ecology & Management, 60 (1), 79-87

Meteer, T. 2015. How Much Can I Afford to Pay for Bulls? Drovers. https://dy604qses7th.cloudfront.net/news/how-much-can-i-afford-pay-bull accessed 8/18/2021

Mitchell, P. 1999. Water Quality Management in Lac Ste. Anne and Lake Isle: A Diagnostic Study. Prepared for the Lac Ste. Anne and Lake Isle Water Quality Management Society. https://open.alberta.ca/dataset/8a1a3c41-16e2-44f2-bdd7-7905c07dfb6f/resource/20b1f4bc-152e-41ac-b6c5-18375f08a8a9/download/5804.pdf, accessed 5/12/2021.

Mossback Farm. 2013. Hanging weight and final weight: some information. http://www.mossbackfarm.com/2013/06/hanging-weight-and-final-weight-some-information/ accessed 8/23/2021

Novales, A. 2000. The role of simulation methods in macroeconomics. Departamento de Economía, Cuantitativa Universidad Complutense. https://www.ucm.es/data/cont/media/www/pag-41882/ser.pdf accessed 6/28/2021

OECD. 2016. Agriculture and Climate Change: Towards Sustainable, Productive and Climate-Friendly Agricultural Systems. https://www.oecd.org/agriculture/ministerial/background/notes/4_background_note.pdf accessed 5/7/2021

Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). 2015. Cull Cow Body and Carcass Composition. http://www.omafra.gov.on.ca/english/livestock/beef/facts/05-075.htm accessed 6/29/2021

Paterson, B.A. and Lindwall, C.W. 1992. Agricultural Impacts On Water Quality In Alberta In National Workshop Proceedings Agricultural Impacts On Water Quality: Canadian Perspectives, edited by Milburn, P., Nicholaichuk, W. and Topp, C.

https://atrium.lib.uoguelph.ca/xmlui/bitstream/handle/10214/15078/FDMR_ag_impacts_watqual_carc92.pdf?sequence=1#page=79 accessed 5/12/2021

Powell, B. 2019. Agricultural Lands: Law and Policy in Alberta. Environmental Law Centre, https://elc.ab.ca/wp-content/uploads/2019/11/Agricultural-Lands-Law-and-Policy-in-Alberta-November-2019.pdf accessed 5/6/2021

Prairie Conservation Action Plan. 2008. Rangeland Health Assessment. https://www.pcap-sk.org/rsu_docs/documents/Native_Grassland_and_Forest-Red.pdf, accessed 11/02/2021

Prociuk, K. and Nielson, J. 1998. From Start to Finish: An Illustrated History of Cattle Feeding in Alberta. Alberta Cattle Feeders Association, Calgary AB. https://www.cattlefeeders.ca/wp-content/uploads/2016/01/From-Start-to-Finish-Cattle-Feeding-History.pdf accessed 9/10/2021

Pitts, J., and Bryant, F. 1987. Steer and vegetation response to short duration and continuous grazing. Journal of Range Management, 40(5), 386-389

Pyle, L., Hall, L., and Bork, E. 2018. Linking management practices with range health in northern temperate pastures. Canadian Journal of Plant Science, 98, 657-671.

Robert, M. and Stenger, A. 2013. Can payments solve the problem of undersupply of ecosystem services? Forest Policy and Economics, 35, 83-91.

Rotz, C., Muhtar, H., and Black, J. 1983. A Multiple Crop Machinery Selection Algorithm. Transactions of the ASAE, 26(2), 1644-1649

Savory, A. 2013. How to fight desertification and reverse climate change. TED Talks. https://www.ted.com/speakers/allan_savory accessed 9/10/2021

Scarf, H. 1989. Mathematical Programming and Economic Theory. Cowles Foundation for Research in Economics at Yale University, Cowles Foundation Discussion Paper No. 930. https://cowles.yale.edu/sites/default/files/files/pub/d09/d0930.pdf accessed 6/28/2021

Shresta, B., Bork, E., Chang, S., Carlyle, C., Ma, Z., Döbert, T., Kaliaskar, D., and Boyce, M. 2020. Adaptive Multi-Paddock Grazing Lowers Soil Greenhouse Gas Emission Potential by Altering Extracellular Enzyme Activity. Agronomy, 10, 1781.

Smoliak, S. 1986. Influence of Climatic Conditions on Production of Stipa-Bouteloua Prairie over a 50-year Period. Journal of Range Management 39(2): 100-103.

Sobrinho, L. 2021. Managing Grassland Grazing to Boost Soil Carbon Sequestration. Unpublished. Received in personal email from Scott Jeffrey, April 14 2021.

Statistics Canada. 2006. 2006 Census of Agriculture. www.statscan.gc.ca accessed 9/10/2021

Statistics Canada. 2015. Lesson #2: What are ecosystem goods and services? https://www150.statcan.gc.ca/n1/pub/16-507-x/2014001/ppt02/ppt02-eng.htm accessed 5/5/2021

Statistics Canada. 2016. 2016 Census of Agriculture. www.statscan.gc.ca accessed 9/10/2021

Statistics Canada. 2019. Farm Products Price Index, monthly.https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3210009801 accessed 08/17/2020

Statistics Canada. 2019. Gross domestic product (GDP) at basic prices, by industry, provinces and territories (x 1,000,000). https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3610040201

Statistics Canada. 2020. Number of cattle, by class and farm type (x1,000). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210013001&pickMembers%5B0%5D=1.10&pickMembers%5B1%5D=2.1 accessed 9/10/2021

Statistics Canada. 2020. Farm Input Price Index, Quarterly. Q12002-Q12019. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810025801 accessed 9/10/2021

Statistics Canada. 2020. Machinery and equipment price index, by industry of purchase, quarterly. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810027001 accessed 9/10/2021

Sulewski, P. and Kłoczko-Gajewska, A. 2014. Farmers’ risk perception, risk aversion and strategies to cope with production risk: an empirical study from Poland, Studies in Agricultural Economics 116, 140-147

Teague, R., and Dowhower, S.L. 2003. Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. Journal of Arid Environments, 53(2), 211-229.

Teague, R., Provenza, F., Norton,B., Steffens, T., Barnes, M., Kothmann, M., Roath, R. 2008. Grasslands: Ecology, Management and Restoration, NOVA Science Publishers, UK, edited by Hans G. Schroder, chapter 1 pages 1-40

Teague, R., and Barnes, M. 2017. Grazing management that regenerates ecosystem function and grazingland livelihoods. African Journal of Range and Soil Science, 34, 77-86.

USDA. 2019. How long can I keep a bull, and at what age can a young bull start mating cows?. https://beef-cattle.extension.org/how-long-can-i-keep-a-bull-and-at-what-age-can-a-young-bull-start-mating-cows/#:~:text=A%20generally%20accepted%20guideline%20is,for%204%20to%205%20years. accessed 5/27/2021

Waldner CL, Parker S, Campbell JR (2019) Identifying performance benchmarks and determinants for reproductive performance and calf survival using a longitudinal field study of cow-calf herds in western Canada. PLOS ONE 14(7): e0219901. https://doi.org/10.1371/journal.pone.0219901

Walton, P., Martinez, R., and Bailey, A.W. 1981. A comparison of continuous and rotational grazing. Journal of Range Management, 34(1), 19-21.

Wang, T., Teague, W.R., Park, S., and Bevers, S. 2018. Evaluating long-term economic and ecological consequences of continuous and multi-paddock grazing - a modeling approach. Agricultural Systems, 165, 197-207.

Wang, T., Jin, H., Kreuter, U., and Teague, R. 2021. Understanding producers' perspectives on rotational grazing benefits across the US great plains. Renewable Agriculture and Food Systems. 1-12. doi:10.1017/S1742170521000260

Appendix

Table A1: Full Results, Ranch Operations

		Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated			Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated
Continuous	Average Annuity per Head	2,972	2,946	2,646	1,372	Traditional	Average Annuity per Head	2,707	2,680	2,406	1,556
	S.D.	730	720	549	559		S.D.	659	650	536	539
	NPV	2,355,078	2,334,638	2,071,855	1,129,278		NPV	2,566,717	2,523,151	2,141,938	1,165,118
		627,710	612,551	457,348	454,232			704,217	689,982	568,618	567,863
	Average Margin	255,596	254,005	250,976	135,671		Average Margin	325,600	322,530	300,875	186,405
		60,608	59,105	47,029	48,076			79,857	78,079	64,273	65,721
	NPV/head	3,527	3,506	3,109	1,706		NPV/head	2,590	2,554	2,135	1,155
		898	887	672	668			693	694	578	565
	Net Cash/Head (1-5)	387	384	332	211		Net Cash/Head (1-5)	341	338	296	200
		125	125	95	90			113	114	99	93
	Net Cash/Head (15-20)	335	334	303	143		Net Cash/Head (15-20)	305	305	272	176
		145	141	107	109			126	123	100	102
	End Herd Size	697	695	691	693		End Herd Size	1,148	1,144	1,140	1,124
		37	36	32	29			93	93	85	77

Table A1: Full Results, Ranch Operations, Continued

		Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated			Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated
Slow AMP	Average Annuity per Head	2,829	2,790	2,354	1,468	Fast AMP	Average Annuity per Head	2,845	2,798	2,246	1,296
	S.D.	651	643	529	534		S.D.	636	632	520	533
	NPV	2,389,518	2,319,528	1,632,177	665,759		NPV	2,175,528	2,091,578	1,197,947	255,223
		681,296	669,157	537,905	535,431			647,243	633,317	505,120	508,033
	Average Margin	319,352	314,433	264,130	148,725		Average Margin	301,531	295,510	225,616	109,449
		77,282	75,966	61,558	62,543			73,297	72,260	58,154	58,518
	NPV/head	2,489	2,419	1,702	692		Net Cash/Head (1-5)	2,366	2,275	1,322	283
		687	685	569	556			677	672	560	562
	Net Cash/Head (1-5)	356	351	290	194		Net Cash/Head (15-20)	360	354	282	182
		112	113	94	91			109	109	90	89
	Net Cash/Head (15-20)	321	319	268	166		Net Cash/Head 2	323	321	256	145
		124	123	99	101			122	121	99	101
	End Herd Size	1,100	1,097	1,084	1,065		End Herd Size	1,036	1,034	1,014	989
		93	91	86	76			90	89	86	76

Table A2: Full Results, Mixed Operations

		Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated			Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated
	Average Annuity per Head	3,394,843	3,345,478	3,985,141	3,760,831		Average Annuity per Head	3,480,082	3,416,050	3,959,813	3,560,493
	S.D.	271,091	272,035	294,016	293,424		S.D.	287,700	287,570	307,257	307,000
	NPV	409,987	360,622	353,997	129,687		NPV	495,226	431,194	328,668	-70,652
		137,859	138,850	120,897	124,447			163,976	163,993	141,623	146,999
	Average Margin	2,833	2,496	2,459	891		Average Margin	2,670	2,332	1,715	-359
		910	933	839	854			856	873	741	748
Continuous	NPV/head	309	274	273	118	Traditional	NPV/head	352	319	271	109
		155	159	147	153			150	152	133	135
	Net Cash/Head (1-5)	299	267	263	91		Net Cash/Head (1-5)	338	306	265	105
		159	156	155	156			152	151	137	139
	Net Cash/Head (15-20)	137	137	138	142		Net Cash/Head (15-20)	193	192	197	201
		12	12	9	7			18	18	13	11
	End Herd Size	3,394,843	3,345,478	3,985,141	3,760,831		End Herd Size	3,480,082	3,416,050	3,959,813	3,560,493
		271,091	272,035	294,016	293,424			287,700	287,570	307,257	307,000

Table A2: Full Results, Mixed Operations, Continued

		Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated			Lac Ste. Anne	Ponoka	Newell Dryland	Newell Irrigated
	Average Annuity per Head	3,306,126	3,241,981	3,656,822	2,845,425		Average Annuity per Head	3,173,898	3,110,601	3,434,429	2,341,056
	S.D.	285,398	284,775	304,073	299,434		S.D.	281,752	280,817	300,810	292,628
	NPV	321,269	257,124	25,677	-785,719		NPV	189,042	125,745	-196,716	- 1,290,088
		160,242	159,982	137,030	142,143			154,278	153,652	132,572	138,165
	Average Margin	1,783	1,426	139	-4,218		Average Margin	1,086	719	-1,154	-7,426
		862	869	745	787			876	881	782	922
Slow AMP	NPV/head	323	292	206	-59	Fast AMP	NPV/head	294	266	151	-205
		149	151	134	142			149	149	137	155
	Net Cash/Head (1-5)	312	283	210	-60		Net Cash/Head (1-5)	282	255	154	-215
		152	150	139	143			151	151	142	150
	Net Cash/Head (15-20)	184	184	187	190		Net Cash/Head (15-20)	173	173	173	175
		18	17	13	11			17	17	13	11
	End Herd Size	3,306,126	3,241,981	3,656,822	2,845,425		End Herd Size	3,173,898	3,110,601	3,434,429	2,341,056
		285,398	284,775	304,073	299,434			281,752	280,817	300,810	292,628

Table A3: BRM Results, Mixed

		Lac Ste. Anne		Ponoka		Newell, Dryland		Newell, Irrigated	
		No BRM	BRM	No BRM	BRM	No BRM	BRM	No BRM	BRM
Continuous	NPV	3,381,973	3,394,843	3,332,044	3,345,478	3,939,438	3,985,141	3,703,716	3,760,831
	S.D.	276,51b2	271,091	275,333	272,035	308,167	294,016	309,078	293,424
	NPV of Ranch	397,117	409,987	347,188	360,622	308,293	353,997	72,572	129,687
		135,751	137,859	134,524	138,850	105,840	120,897	108,246	124,447
	NPV Ranch /head	2,743	2,833	2,403	2,496	2,140	2,459	497	891
		894	910	904	933	730	839	741	854
	Net Cash/Head (1-5)	298	309	263	274	235	273	69	118
		151	155	155	159	122	147	124	153
	Net Cash/Head (15-20)	287	299	253	267	224	263	45	91
		158	159	155	156	128	155	130	156
	End Herd Size	137	137	137	137	138	138	142	142
		12	12	12	12	9	9	7	7

		Lac Ste. Anne		Ponoka		Newell, Dryland		Newell, Irrigated	
		No BRM	BRM	No BRM	BRM	No BRM	BRM	No BRM	BRM
Traditional	NPV	3,473,274	3,480,082	3,407,869	3,416,050	3,922,726	3,959,813	3,682,381	3,560,493
	S.D.	291,562	287,700	290,638	287,570	319,171	307,257	321,108	307,000
	NPV of Ranch	488,418	495,226	423,013	431,194	291,582	328,668	51,237	-70,652
		163,764	163,976	162,591	163,993	133,321	141,623	137,916	146,999
	NPV Ranch /head	2,632	2,670	2,287	2,332	1,520	1,715	261	-359
		850	856	865	873	694	741	702	748
	Net Cash/Head (1-5)	349	352	315	319	250	271	124	109
		149	150	152	152	124	133	126	135
	Net Cash/Head (15-20)	331	338	297	306	240	265	114	105
		154	152	153	151	127	137	129	139
	End Herd Size	193	193	192	192	197	197	201	201
		18	18	18	18	13	13	11	11

Table A3: BRM Results, Mixed Continued

		Lac Ste. Anne		Ponoka		Newell, Dryland		Newell, Irrigated	
		No BRM	BRM	No BRM	BRM	No BRM	BRM	No BRM	BRM
Slow AMP	NPV	3,298,503	3,306,126	3,233,073	3,241,981	3,616,198	3,656,822	3,377,120	2,845,425
	S.D.	289,648	285,398	287,939	284,775	316,890	304,073	318,279	299,434
	NPV of Ranch	313,646	321,269	248,217	257,124	-14,947	25,677	-254,025	-785,719
		159,967	160,242	157,934	159,982	127,624	137,030	131,063	142,143
	NPV Ranch /head	1,739	1,783	1,376	1,426	-85	139	-1,365	-4,218
		858	862	857	869	694	745	706	787
	Net Cash/Head (1-5)	319	323	288	292	183	206	53	-59
		148	149	150	151	124	134	127	142
	Net Cash/Head (15-20)	304	312	274	283	180	210	49	-60
		153	152	152	150	126	139	129	143
	End Herd Size	184	184	184	184	187	187	190	190
		18	18	17	17	13	13	11	11

		Lac Ste. Anne		Ponoka		Newell, Dryland		Newell, Irrigated	
		No BRM	BRM	No BRM	BRM	No BRM	BRM	No BRM	BRM
Fast AMP	NPV	3,164,421	3,173,898	3,100,375	3,110,601	3,388,846	3,434,429	3,153,659	2,341,056
	S.D.	286,632	281,752	284,358	280,817	314,745	300,810	315,132	292,628
	NPV of Ranch	179,565	189,042	115,518	125,745	-242,299	-196,716	-477,486	-1,290,088
		153,599	154,278	151,271	153,652	122,000	132,572	123,788	138,165
	NPV Ranch /head	1,030	1,086	658	719	-1,422	-1,154	-2,751	-7,426
		871	876	866	881	729	782	740	922
	Net Cash/Head (1-5)	288	294	260	266	123	151	-20	-205
		147	149	148	149	125	137	130	155
	Net Cash/Head (15-20)	272	282	245	255	119	154	-23	-215
		152	151	152	151	126	142	129	150
	End Herd Size	173	173	173	173	173	173	175	175
		17	17	17	17	13	13	11	11

Table A4: BRM Change Results, Mixed

	Lac Ste. Anne		Ponoka		Newell Dryland	
	No BRM	BRM	No BRM	BRM	No BRM	BRM
Continuous to Traditional	22.99%	20.79%	21.84%	19.57%	-5.42%	-7.15%
Continuous to Slow AMP	-21.02%	-21.64%	-28.51%	-28.70%	-104.85%	-92.75%
Traditional to Slow AMP	-35.78%	-35.13%	-41.32%	-40.37%	-105.13%	-92.19%
Slow AMP to Fast AMP	-42.75%	-41.16%	-53.46%	-51.10%	1521.04%	-866.11%
Traditional to Fast AMP	-63.24%	-61.83%	-72.69%	-70.84%	-183.10%	-159.85%

Table A5: BRM Results, Ranch

		Lac Ste. Anne		Ponoka		Newell, Dryland		Newell, Irrigated	
		No BRM	BRM	No BRM	BRM	No BRM	BRM	No BRM	BRM
Continuous	Average Annuity per Head	2,326	2,972	2,309	2,946	2,292	2,646	874	1,372
	(S.D)	735	730	718	720	588	549	601	559
	NPV	1,855,300	2,355,078	1,840,306	2,334,638	1,800,507	2,071,855	701,165	1,129,278
		636,884	627,710	624,434	612,551	494,990	457,348	504,425	454,232
	Average Margin	256,542	255,596	254,943	254,005	251,873	250,976	136,262	135,671
		60,788	60,608	59,280	59,105	47,165	47,029	48,210	48,076
	NPV/head	2,802	3,527	2,788	3,506	2,717	3,109	1,086	1,706
		918	898	910	887	730	672	744	668
	Net Cash/Head	285	387	283	384	277	332	111	211
		150	125	152	125	118	95	121	90
	Net Cash/Head	268	335	268	334	265	303	98	143
		158	145	152	141	123	107	125	109
	End Herd Size	697	697	695	695	691	691	693	693
		37	37	36	36	32	32	29	29
Traditional	Average Annuity per Head	2,306	2,707	2,288	2,680	2,128	2,406	1,185	1,556
	(S.D)	676	659	666	650	2,132	536	571	539
	NPV	2,176,136	2,566,717	2,143,219	2,523,151	1,871,022	2,141,938	752,618	1,165,118
		737,704	704,217	726,229	689,982	612,647	568,618	631,186	567,863
	Average Margin	326,738	325,600	323,658	322,530	301,940	300,875	187,178	186,405
		80,082	79,857	78,297	78,079	64,454	64,273	65,903	65,721
	NPV/head	2,195	2,590	2,169	2,554	1,865	2,135	747	1,155
		730	693	732	694	619	578	626	565
	Net Cash/Head	291	341	289	338	265	296	141	200
		135	113	136	114	116	99	117	93
	Net Cash/Head	256	305	256	305	237	272	136	176
		139	126	136	123	114	100	116	102
	End Herd Size	1,148	1,148	1,144	1,144	1,140	1,140	1,124	1,124
		93	93	93	93	85	85	77	77

Table A5: BRM Results, Ranch Continued

		Lac Ste. Anne		Ponoka		Newell, Dryland		Newell, Irrigated	
		No BRM	BRM	No BRM	BRM	No BRM	BRM	No BRM	BRM
	Average Annuity per Head	2,433	2,829	2,400	2,790	2,059	2,354	1,070	1,468
	(S.D)	672	651	662	643	561	529	570	534
	NPV	2,003,424	2,389,518	1,940,935	2,319,528	1,338,884	1,632,177	218,374	665,759
		719,739	681,296	708,208	669,157	587,751	537,905	600,815	535,431
	Average Margin	320,512	319,352	315,580	314,433	265,150	264,130	149,452	148,725
		77,501	77,282	76,180	75,966	61,733	61,558	62,716	62,543
Slow AMP	NPV/head	2,086	2,489	2,024	2,419	1,396	1,702	227	692
		733	687	728	685	616	569	623	556
	Net Cash/Head	302	356	299	351	249	290	120	194
		135	112	135	113	115	94	117	91
	Net Cash/Head	274	321	272	319	234	268	126	166
		138	124	135	123	114	99	116	101
	End Herd Size	1,100	1,100	1,097	1,097	1,084	1,084	1,065	1,065
		93	93	91	91	86	86	76	76
	Average Annuity per Head	2,446	2,845	2,404	2,798	1,928	2,246	861	1,296
	(S.D)	661	636	656	632	555	520	569	533
	NPV	1,792,632	2,175,528	1,711,863	2,091,578	880,946	1,197,947	-228,039	255,223
		690,118	647,243	680,068	633,317	559,392	505,120	567,420	508,033
	Average Margin	302,668	301,531	296,634	295,510	226,568	225,616	110,101	109,449
		73,506	73,297	72,465	72,260	58,321	58,154	58,680	58,518
Fast AMP	NPV/head	1,949	2,366	1,861	2,275	972	1,322	-253	283
		731	677	727	672	616	560	627	562
	Net Cash/Head	302	360	296	354	229	282	90	182
		134	109	134	109	114	90	117	89
	Net Cash/Head	277	323	274	321	222	256	105	145
		136	122	134	121	113	99	115	101
	End Herd Size	1,036	1,036	1,034	1,034	1,014	1,014	989	989
		90	90	89	89	86	86	76	76

Table A6: Lac Ste. Anne Mixed: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.61625	2.8	0.08	N/A	1750	27500
-10	0.6525	2.55	0.25	N/A	1550	24000
-5	0.68875	2.3	0.37	1.87	1350	21500
5	0.76125	1.9	0.56	1.8	1000	15500
10	0.7975	1.7	0.64	1.712	875	13500
15	0.83375	1.6	0.69	1.65	735	11000
20	0.87	1.5	0.75	1.57	600	9500

Table A7: Lac Ste. Anne Mixed: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.65875	3.45	0.05	N/A	2650	42000
-10	0.6975	3.1	0.15	N/A	2425	38000
-5	0.73625	2.83	0.25	N/A	2200	35000
5	0.81375	2.4	0.41	N/A	1850	29000
10	0.8525	2.22	0.475	N/A	1675	27000
15	0.89125	2.1	0.53	N/A	1550	24750
20	0.93	1.95	0.57	N/A	1425	22250

Table A8: Ponoka Mixed: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.61625	3.08	0.16	N/A	1750	27500
-10	0.6525	2.8	0.3	N/A	1550	24100
-5	0.68875	2.55	0.405	N/A	1350	21200
5	0.76125	2.18	0.58	N/A	1000	15750
10	0.7975	2	0.65	N/A	875	13700
15	0.83375	1.86	0.7	2.42	735	11500
20	0.87	1.73	0.76	2.206	610	9600

Table A9: Ponoka Mixed: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.65875	3.7	0.12	N/A	2650	42000
-10	0.6975	3.35	0.215	N/A	2425	38000
-5	0.73625	3.05	0.32	N/A	2200	35000
5	0.81375	2.55	0.45	N/A	1850	29500
10	0.8525	2.4	0.5	N/A	1700	27500
15	0.89125	2.2	0.55	N/A	1600	25000
20	0.93	2.05	0.59	N/A	1475	23000

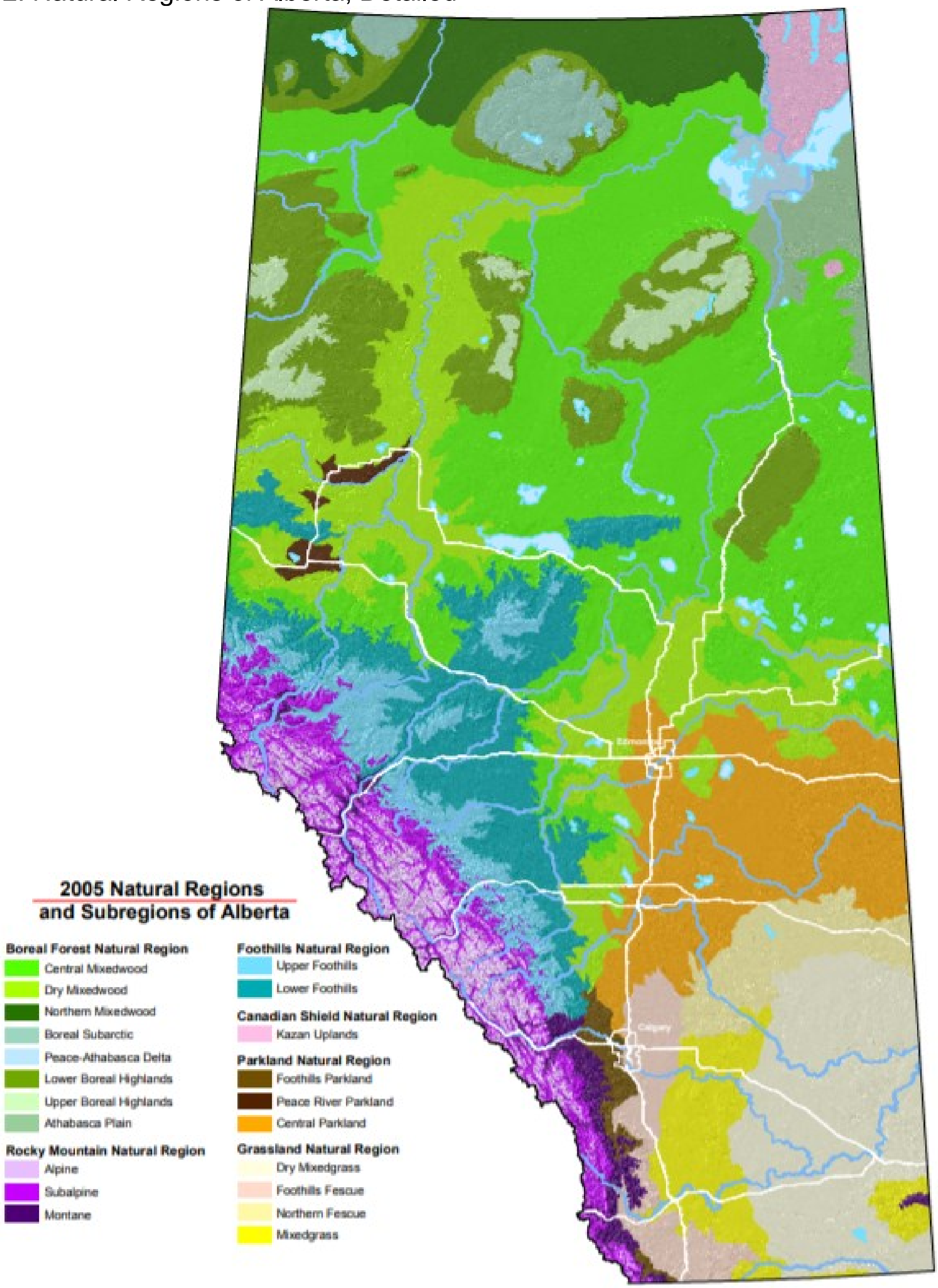
Table A10: Newell Mixed: Change to Variable Factors Needed for Slow AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.61625	4.9	0.24	N/A	2650	41500
-10	0.6525	4.45	0.3	N/A	2475	39000
-5	0.68875	4.05	0.36	N/A	2300	36500
5	0.76125	3.45	0.44	N/A	2075	32750
10	0.7975	3.2	0.47	N/A	1960	31250
15	0.83375	3	0.5	N/A	1880	29750
20	0.87	2.8	0.52	N/A	1820	28500

Table A11: Newell Mixed: Change to Variable Factors Needed for Fast AMP to See Higher Wealth than Traditional for Given Changes to Pasture Utilization

Percentage Change in Utilization	Utilization Value	Pasture Productivity (Δ%)	AMP Costs (Δ%)	Rate of Gain (kg/day)	Initial Subsidy ($)	Annual Program Support ($/Year)
-15	0.65875	N/A	0.18	N/A	4125	65000
-10	0.6975	N/A	0.22	N/A	3975	63000
-5	0.73625	N/A	0.26	N/A	3825	60000
5	0.81375	N/A	0.34	N/A	3500	55500
10	0.8525	5	0.37	N/A	3400	53500
15	0.89125	4.6	0.39	N/A	3300	52000
20	0.93	4.3	0.41	N/A	3200	50500

A12: Natural Regions of Alberta, Detailed



(Alberta Parks 2014)