AN ABSTRACT OF THE THESIS OF

Jeffrey L. Sharp for the degree of Master of Science in Agricultural and Resource Economics presented on July 8, 2004.

Title: An Economic Comparison of Three Cattle Grazing Management Strategies Intended to Improve Riparian Habitat and Water Quality.

Redacted for privacy

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John A. Tanaka

Grazing of riparian forage by livestock may alter stream channel morphology in ways that impact nearby aquatic habitat, bank stability, vegetative cover and water quality. A number of grazing management practices have been proposed as a means to reduce the amount of time cattle spend in the riparian zone. The effectiveness and long-term economic feasibility of these grazing management practices is largely unknown. Little is known about economic differences resulting from seasonally prescribed grazing. Findings from this research will aid ranch and resource managers in making economically viable and ecologically sound resource decisions for the future.

This study was conducted to analyze the economic and environmental impacts of seasonal grazing and off-stream water development on a 300 head cow-calf ranch in northeastern Oregon. A bio-economic model was developed to analyze and compare three grazing management practices at the ranch level. Economic impacts to the model ranch were analyzed by examining changes in long-run annual revenue and total net present value (NPV) expected for each of the three management practices under various rainfall conditions, cattle market scenarios and discounts rates.

Late summer grazing of riparian pasture with off-stream water development yielded the highest comparable NPV across all rainfall and market price scenarios examined. Changes in the discount rate inversely affected the NPV of future returns, but did not alter the optimal grazing strategy. Only slight differences in NPV were measured between early and late seasonal grazing options.

Water quality monitoring results from the study were inconclusive. Results showed that the optimal strategy for the protection of water quality varied depending upon the limiting factor of highest concern. Cattle distribution indicators such as average distance from stream and streamside fecal counts, point toward early season grazing as the most effective strategy at dispersing cattle away from the stream corridor.

An Economic Comparison of Three Cattle Grazing Management Strategies Intended to Improve Riparian Habitat and Water Quality

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Jeffrey L. Sharp, Author

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INTRODUCTION

BACKGROUND AND PROBLEM STATEMENT

A majority of northeastern Oregon's cattle production is in the form of commercial cow/calf operations dependent upon public land grazing allotments. Many of these public grazing allotments are managed by the U.S. Forest Service and Bureau of Land Management and may include riparian pastures[1]. There is growing concern regarding the impact cattle grazing exhibits on mountain riparian ecosystems (CAST 1996). To address this concern, many riparian grazing experiments have been conducted. Some of those studies have indicated that cattle grazing in the riparian zone can alter stream channel morphology in ways that negatively impact aquatic habitat (Overton et al. 1994, Platts 1990). Although amounting to only 1 to 2% of summer grazing area, these mountain riparian pastures are an extremely important source of forage in the Pacific Northwest, providing as much as 20 to 80% of summer forage for ranging cattle (Bauer and Burton 1993). Any change in current management of these riparian pastures is likely to economically impact the region's beef cattle industry.

If ranch operators are to adopt alternative grazing practices aimed to enhance riparian areas, it is imperative that the proposed grazing alternatives be economically sustainable over the long-term. A desirable riparian grazing strategy is one that protects the economic viability of ranchers, assures proper riparian functioning to address local water quality objectives and complies with State and Federal regulations. There is also a need to provide ranchers with sound economic information in readily understandable terms so that they may have greater confidence to make well-informed management decisions.

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[1] Riparian areas are typically moist, fertile, highly productive areas along, adjacent to, or contiguous with perennial and intermittently flowing rivers and streams producing a disproportionate amount of available forage compared to upland areas of similar size.

A number of riparian management systems have been developed to address concerns regarding the impact cattle have on mountain riparian ecosystems. Researchers in northeastern Oregon have implemented a number of alternative riparian grazing systems to systematically assess measured changes in cattle performance, distribution and influence on riparian environments resulting form alternative practices. Few of these grazing studies have included a practical economic comparison of trade-offs existing at the ranch-level associated with proposed alternative riparian management strategies.

This thesis utilizes a mathematical modeling process based upon economic theory and biological principles to compare three riparian-grazing alternatives intended to alleviate the apparent impact cattle have on mountain riparian ecosystems. The model was regionally parameterized with data collected from a four-year cattle distribution study in northeastern Oregon. The rangeland research was conducted on riparian pastures using a replicated design. The three alternative management practices examined were off-stream water provision on adjacent uplands, early seasonal grazing of the riparian pasture and late seasonal grazing of the riparian pasture.

ORGANIZATIONAL OVERVIEW

This thesis is divided into five chapters and includes appendices. The first chapter provides background on the topics covered, presents a problem statement, offers working hypotheses and outlines the research objectives. The second chapter reviews the theory employed to conduct the analysis and examines existing research on the related subject areas. Chapter three presents the methods and procedures exercised to collect, characterize and apply the economic and natural resource data utilized during the modeling process. The fourth chapter states the programming objective and steps through the mathematical operations of the bio-economic model. The results of the work are presented and explained in the beginning of chapter five and are followed by a discussion on their applicability. All source material for citations is provided and appendices are included at the end to show examples of the model code and solution output.

Working Hypotheses

Grazing management studies have been conducted throughout western rangelands. Many riparian grazing options have been developed and proposed to the rancher (Stillings et al. 2003). Few scientific studies exist that critically examine the long-term economic viability of these management options at the ranch-level (Holechek et al. 1989). Information pertaining to a grazing system's economic feasibility is invaluable to the rancher and critical to the acceptability and application of the proposed management option. Opportunities should be taken to carefully examine and compare the economic trade-offs that exist between dissimilar riparian grazing strategies. An acceptable way to conduct such a comparison is to distinguish economic differences between management strategies applied to similar rangeland environments over time.

Two fundamental hypotheses guide this thesis: (a) one would expect economic returns to differ at the ranch level depending upon which riparian grazing strategy is implemented and (b) it is likely that the optimal, or profit maximizing, riparian grazing strategy is dependent upon annual changes in prices and rainfall and would be sensitive to alternative discount rates applied to assess the current value of future returns from the ranching operation.

Research Objectives

The principal objective of this research is to assist ranchers, public agencies and stakeholders in recognizing the economic tradeoffs that exist when a ranch operator adopts grazing management strategies aimed at improving riparian habitat.

The intent of this thesis is to conduct an economic comparison of three cattle grazing management strategies intended to improve the ecological condition of riparian areas.

The following three management options were analyzed: (a) early summer grazing of riparian pasture, (b) late summer grazing of riparian pasture and (c) late summer grazing of riparian pasture with off-stream water development. All three of the management strategies incorporate the placement of trace-mineralized salt in the upland areas. All three approaches examined are intended to increase the grazing distribution of livestock. Increased distribution promotes more uniform utilization of upland and riparian vegetation, lending itself to more efficient management of the forage resource.

REVIEW OF THEORY AND EXISTING RESEARCH

STRUCTURE OF CATTLE RANCHING IN NORTHEASTERN OREGON

A majority of Oregon's beef inventory is held in ranching operations of 100 to 499 head (USDA 1999). In 1997, the sale of cattle and calves in the State of Oregon accounted for 16.2% of the state's total agricultural sales, ranking it as the second highest valued crop (USDA 1997). Cattle and calves have historically been either first, second, or third in total sales in Oregon. A significant proportion of Oregon's employment and income are thus derived from jobs in livestock production and other natural resource related industries. Cash receipts from the marketing of cattle and calves in Oregon totaled over $361 million in 1998, amounting to 11.7% of all farm commodities marketed in the state during that year (USDA 2000). In 1992 alone, livestock related employment in northeastern Oregon provided over 5,300 jobs, or 8.9% of the region's total employment (Waters et al. 1997).

Ranching operations in the Blue Mountains region of northeastern Oregon support their herds with native and feeder-quality hay, private pasture and public grazing allotments, most of which are managed by the U.S. Forest Service (USFS) (Turner et al. 1998). According to researchers at Oregon State University's Eastern Oregon Agricultural Research Center in Union County, most ranching operations feed their stock on seasonally available forage supplies and transport their herds between public and private pastures throughout the year as suggested in Table 1. It is not uncommon for ranchers in the region to feed hay to their livestock over winter on private land for 4 to 5 months. In early spring, stock is moved onto stringer meadows or improved pastures to graze for 1 to 2 months, at which point the animals are then moved to USFS allotments for summer grazing. In the fall, the stock is again moved onto privately owned or a leased land for the remaining 2 to 3 months of the year until winter feeding is again necessary.

Table 1. Typical forage supply sources for northeastern Oregon ranching operations (developed by author with assistance from Timothy DelCurto PhD., Associate Professor, Dept. of Animal Science, Eastern Oregon Agricultural Research Center, O.S.U., 1998.).

Time of year	Number of months	Seasonal forage supply	Ownership
Dec-April	4-5	Winter Hay	Private Range
April-May	1-2	Spring Range	Privately Owned or Leased Range
June-Sept	3-4	Summer Range (USFS Allotment)	Publicly Leased Range
Sept-Nov	2-3	Fall Range	Privately Owned or Leased Range

A typical ranching operation in the region works their calves and cows during spring and fall gatherings. Pregnancy tests are conducted on the cows and replacement heifers during the fall gathering. Culled cows, replacement heifers, calves and steers are sold in competitive markets in November (Turner et al. 1998). The 300-Cow/Calf Production Flowchart shown as Figure 1, illustrates the typical production decisions and ranching methods used in the region.

At all times throughout the year, the rancher must accommodate his herd by providing them food and water. This resolute obligation demands careful and efficient management of finite ranch resources, most notably the use and availability of pastureland and labor. The following section discusses the relative importance of riparian forage as it relates to the northeastern Oregon rancher and how these riparian areas serve as productive natural environments responsive to livestock grazing.

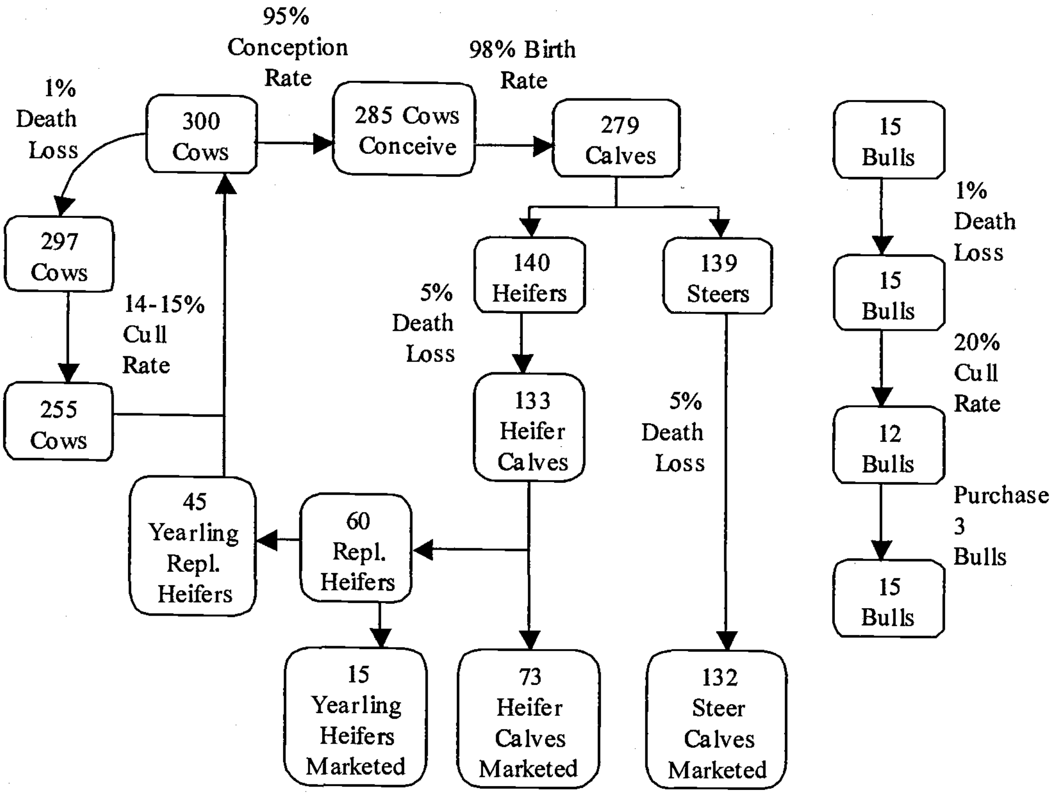

Figure 1. 300-Cow/Calf Production Flowchart, illustrating the typical production decisions and ranching methods used in the Mountain Regions of Northeastern Oregon (Turner et al. 1998). The flowchart assumes that all 45 replacement heifers have been pregnancy tested and are pregnant. The conception rate on the remaining 255 cows in the brood herd is 95%.

STRUCTURE AND FUNCTION OF RIPARIAN AREAS IN THE PRESENCE OF LIVESTOCK GRAZING

Riparian zones are considered centers of biodiversity, providing key ecosystem services for terrestrial and aquatic plants and animals (Belsky et al. 1999, Gregory 2000). Riparian areas occupy less than 2% of the total land area in the western U.S. (Chaney et al. 1993). Nonetheless, they are an extremely important component of the landscape, providing a disproportionate amount of forage for livestock and habitat for approximately four-fifths of the region's wildlife species (Elmore and Beschta 1987). A healthy riparian ecosystem is characterized by high faunal and floral diversity, structural complexity, highly productive energy and nutrient exchange and superior resilience to disturbance (Connin 1991, Leonard et al. 1997). The character and value of riparian zones are the result of complex interactions between three important ecosystem components: 1) biota, 2) hydrology and 3) soils/geomorphology. The linkages between these components are shown in Figure 2. Combined these components form the unique structure and function of stream riparian ecosystems (Kauffman et al. 1997). Modification to any component, human or natural, will likely influence all other components in the system.

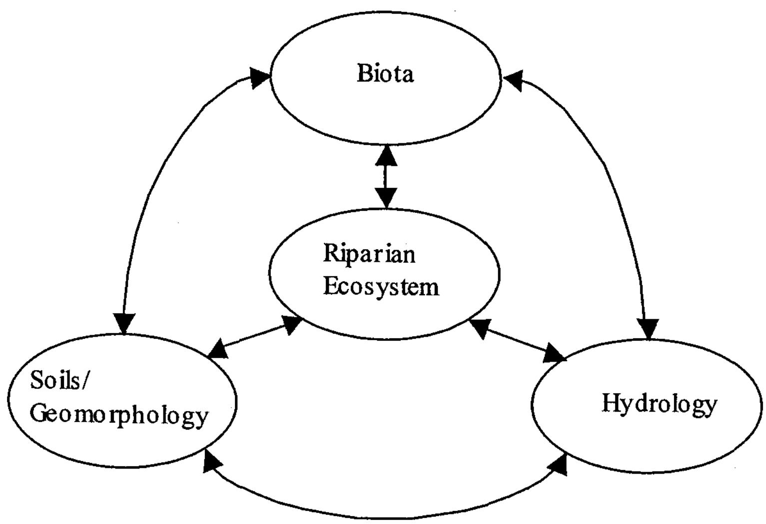

Figure 2. Illustration of the important linkages that exist between the biota, soils/geomorphology and hydrology in riparian ecosystems (adapted from Beschta 1999 and Kauffman et al. 1997).

The effect of cattle grazing on riparian ecosystems depends entirely upon how the grazing is managed (Mosley et al. 1997). Under conditions of intensive livestock grazing, it has been shown that both water quality and riparian habitat may be significantly altered (Li et al. 1994). Riparian areas provide water, forage and loafing sites for domestic livestock (Mosley et al. 1997). Riparian areas are preferential environments for cattle, as they provide a reliable source of water, succulent forage, accessibility, shade and favorable microclimate compared to the surrounding landscape (Bauer and Burton 1993). In these lower topographic zones, palatable vegetation and water continue to prevail much longer than in higher upland areas. Left to their own accord, livestock have been known to over-utilize the riparian zone in their search for forage, water and shelter. It has been documented that cattle spend as much as 5 to 30 times more of their time in riparian areas than on adjacent upland areas (Clary and Webster 1989).

Research and other works have revealed that cattle grazing in the riparian zone can alter the stream channel morphology in ways that negatively impact aquatic habitat through sediment transport, bank stability, vegetation composition and water temperature (Belsky et al. 1999, Overton et. al. 1994, Platts 1990). A disproportionate level of grazing in the riparian zone is capable of generating potential surface water contamination since livestock have the ability to redistribute rangeland nutrients near the stream channel in the form of manure (Sherer et al. 1988). Excessive concentration of animal waste in close proximity to a stream channel can negatively impact water quality, especially when biological contaminants rise above locally established safe standards. Some researchers have discovered that corruption of surface water quality is possible under the presence of livestock grazing and that potential for contamination increases with increased grazing intensity (Reid 1993). The over-utilization of vegetation, trampling of stream banks and proximity of livestock waste to surface waters is a source of non-point source (NPS) pollution and degradation of the riparian corridor. The impacts of NPS pollution and degradation limit other beneficial uses of the water resource such as recreation, municipal consumption and fish and wildlife habitat (Reid 1993).

Public and Legal Concern for Water Quality and Non-Point Source Pollution Control

There are growing public and legal concerns regarding the origins of NPS pollution affecting our nation's waters. Public lobbying and legislative action have brought national attention to NPS pollution related to livestock grazing on public lands (Stephenson and Rychert 1982). State and federal government agencies across the west are under pressure to devise grazing-land policy measures that include regulations and standards to address these developing concerns. This is especially true in the state of Oregon, were nearly 60% of the land is publicly held. Cattle grazing in the riparian zone is a public land use which governmental agencies are critically examining as a potential source of NPS pollution. In recent years there have been a number of federal and state legislative measures concerning the source and control of NPS pollution.

Following the 1987 amendment of Section 319 to the Federal Clean Water Act (CWA), states are required to identify sources of NPS pollution and develop and implement methods to achieve state and national water quality goals (Connin 1991). The goal of the CWA is to "restore and maintain the chemical, physical and biological integrity of the nation's waters" (Bauer and Burton 1993). Section 319 broadens the scope of the CWA, emphasizing the prevention and correction of recognized NPS pollution problems. The 1987 amendment places a burden of responsibility on the states to assess and define sources of NPS pollution activities and to develop management plans to mitigate their effects through watershed restoration projects and NPS pollution control measures (Bauer and Burton 1993).

The CWA is not the only federal act requiring states to develop programs to shelter waters from NPS pollution activities. The 1990 Reauthorization Amendments of the Coastal Zone Management Act (CZMA) require coastal states to protect coastal watersheds from NPS pollution. The CZMA requires Oregon to develop programs with enforceable policies and mechanisms to implement NPS pollution management measures (Bauer and Burton 1993). Other federal acts that specify a need to establish criteria for identifying water polluting sources and to improve the environmental quality of the Nation's waters include: the National Environmental Policy Act, the Federal Water Pollution Control Act and the Federal Land Policy and Management Act (Stephenson and Rychert 1982).

Oregon has approved legislation to address public legal concern over the condition and management of the state's water quality issues. In 1993 the Oregon State Legislature authorized Senate Bill (SB) 1010 mandating the development and implementation of river basin management plans, surface water quality standards and allocation of Total Maximum Daily Loads (TMDLs) within each major river basin. To complement SB 1010, a number of Oregon Administrative Rules were adopted to support local water quality issues as they relate to agricultural practices throughout the state. ORS 603- 090-0000 through 603-090-0120 and 603-095-0010 through 603-095-0040 authorized Oregon's Department of Agriculture to develop and carry out agricultural water quality management area plans that comprehensively outline measures that will be taken to prevent and control water pollution resulting from agricultural activities. These state rules and orders have legally enforceable components and arise from local concerns of NPS pollution affecting the waters of Oregon.

Grazing and Rangeland Management

Grazing and rangeland management concerns itself with effectively governing the supply and security of the rangeland resources by protecting and preserving ecosystem functioning and sustainability. Grazing land management is an optimization problem, balancing the interception and conversion of solar energy into a forage resource and the efficient harvest of that resource by livestock (Heitschmidt and Stuth 1991). Fundamental to this management is that the welfare of plants and animals depend upon each other. Grazing and rangeland management is therefore focused on protection and enhancement of the soil/vegetation complex while maintaining or improving the output of consumable range products such as meat, fiber, wood, water and wildlife (Holechek et al. 1989). Management is conducted through the manipulation of rangeland components to obtain an optimum combination of goods and services for society on a sustainable basis (Holechek et al. 1989).

Since the Forest Reserve Act of 1891, the Organic Act of 1897 and the Taylor Grazing Act of 1934, federal grazing and range management programs have worked on improving the condition of public rangelands, particularly in upland areas. However conditions of riparian areas have not improved to the extent of upland areas (CAST 1996). The Oregon State of the Environment Report 2000 maintains that upland rangelands in the Blue Mountain region of Oregon have recovered significantly from overgrazing in the early 20th century, but finds riparian areas still remain a challenge for rangeland managers (SOER 2000).

Efficient grazing strategies provide an opportunity to improve rangeland riparian areas without large expenditures of money. The placement of in-stream structures such as riprap, gabions, rock and wooden weirs to improve or restore riparian habitat are risky and expensive measures treating symptoms and not problems (Elmore and Beschta 1987). More appropriate measures of restoration may simply be a change in riparian grazing technique, a change in management directly addressing the problem of an under-managed riparian pasture (Chaney et al. 1993). It is possible to graze many riparian areas in a sustainable manner, if it occurs during the appropriate season, over a suitable length of time and utilization levels do not irrevocably damage the vegetation (CAST 1996).

Public grazing allotments have been managed on the basis of an average stocking rate (the amount of land allocated to each animal unit for the entire grazing period) but the use of rangeland by cattle is not uniform (Reid 1993). Stocking rates have long been considered one of the most important grazing management decisions, economically and environmentally. However, strategies that improve the distribution of livestock within rangeland pastures are becoming just as important (Holechek et al. 1989). Increased grazing distribution promotes uniform utilization of the forage resource, spatially and temporally diffusing the influence of livestock within the rangeland ecosystem. Careful employment of grazing management strategies can be a means to attain the benefits riparian areas have to offer while assuring water quality standards and fully functioning riparian ecosystems (Mosley et al. 1997).

Off-Stream Water and Seasonal Grazing

The most successful riparian management strategies are those that include a combination of grazing "prescriptions" or techniques that promote the distribution of livestock (Leonard et al. 1997). In many cases, improved livestock distribution is fundamental to improving the condition of a riparian area (Chew 1991). Off-stream water development and the seasonal timing of grazing are strategies intended to manage or modify the distribution of grazing livestock within riparian pastures (Porath et al. 2002). Uniform distribution throughout rangeland pastures can enhance animal performance, provide better management of the forage resource, improve wildlife habitat and reduce the likelihood of biological, chemical and physiological contamination of surface waters.

Off-Stream Water

Grazing activity occurs near available water. The availability and location of water is a primary influence of livestock distribution and therefore forage utilization (Pinchak et al. 1991, Porath et al. 2002, Stillings et al. 2003). Additional watering locations can serve to improve livestock distribution and increase their productivity (Holechek et al. 1989). Watering sources that accompany natural seeps, springs and streams can usually draw livestock away from riparian areas (Mosley et al. 1997). In most cases the provision of off-stream watering sources on mountain meadow pastures in Oregon reduced the time cattle spent accessing surface streams for water (Ehrhart and Hansen 1997). Researchers at Oregon State University's Eastern Oregon

Agricultural Research Center in Union County observed that cattle in mountain riparian ecosystem exhibit a more uniform average distance from the stream throughout the day when off-stream water was provided compared to cattle in pastures with only stream water for consumption (Porath et al. 2002). Off-stream water provision is widely recognized as a prescriptive grazing strategy, enticing stock away from riparian areas and promoting a more uniform utilization of the rangeland resource. Stillings et al. (2003) found that off-stream water development increased economic returns and resulted in a positive net return on investment for the rancher.

Seasonally Prescribed Grazing

The determination of an appropriate time of year to graze a specific riparian area is a critical first step in developing a riparian grazing plan that meets management objectives (Ehrhart and Hansen 1997). Continuous or season-long grazing is most damaging to streamside areas because livestock concentrate and linger in these areas out of convenience (Holechek et al. 1989). Rangeland ecologists are aware that seasonal defoliation by grazing animals will have different effects on plant vigor and reproduction depending on the life-stage of the individual plants (Kie and Loft 1990). Grazing systems that focus on seasonal use or suitability often involve partitioning the range into pastures based upon vegetation type, climate and topography. No one season is universally suited for all applications. Table 2 lists some management advantages and disadvantages that exist between early-spring and late-fall grazing.

Table 2. Potential management advantages and disadvantages existing with the seasonal-use of riparian pastures (BLM 1997).

	Potential Advantages	Potential Disadvantages
Early Season (Spring) Grazing	• Succulent upland plants reduce time livestock spend in riparian area • Allows for plant re-growth if sufficient moisture remains in the soil • Palatable herbaceous plants reduces pressure on woody plant species	• High soil moisture levels allow compaction and bank trampling • Critical time of plant growth, continued use may alter plant community • Nutritive value of upland forage may be low • May adversely affect wildlife
Late Season (Fall) Grazing	• Most plants have completed growth cycle • Drier soils reduce compaction and bank trampling • Generally less impact on wildlife (i.e. nesting birds)	• Limited plant re-growth insuring plant vigor and riparian functioning capabilities in spring • Animals will graze on green woody species • Upland forage is less palatable, animals tend to congregate in riparian area

A unique grazing season may meet the management goals for one particular site, but may be ineffective when applied to alternative pastures or when applied to the same pasture year after year. Determining which season is best for a particular pasture depends upon the predicted responses of riparian plant communities under the pressure of grazing, the resilience and moisture content of the soils and acknowledgement of critical wildlife habitat requirements (Ehrhart and Hansen 1997).

Seasonal timing of grazing and off-stream water development are prescriptive grazing strategies that have long been acknowledged as management tools to modify the distribution of grazing livestock. It is up to the ranch operator to choose the most appropriate grazing strategy based upon management style, site particulars and other forage resources. Increased management can yield beneficial results, but it may also bring substantial costs. Ranch operators must be conscious of the trade-offs that exist between management options and make informed choices. The following section reviews the practice of combining resource economics with rangeland management, the fundamental application of rangeland economics. Rangeland economics is a discipline that focuses on the application of economic theory and methods to complex rangeland resource issues that require detailed analyses to improve management strategies and inform rangeland managers.

Theory And Application of Economics

Resource management objectives should be achievable, measurable and worth the economic and social costs incurred to accomplish them (Leonard et al. 1997, CAST 1996). Riparian pasture management techniques should also be worthy of the monetary costs they sustain. Many rangeland management activities, however, take years to pay off and their economic and social benefits and costs can be difficult to capture, as they are often spatially and temporally related. Thus, there is agreement in the importance of understanding the goals and socioeconomic aspirations of ranch managers and a need to express biological results in economic contexts (Hodgson and Illius 1996). The use of applied economic theory framed in biological principles can prove to be a powerful tool to measure and evaluate the benefits and costs of rangeland management activities that occur over long planning horizons.

Rangeland Economics

Rangeland economics is the science of combining and applying the principles of economics and range management simultaneously to determine the economic consequences of decisions involving the use, development and/or protection of rangelands (Workman 1986). Rangeland economics couples biological principles with economic theory and methods to analyze complex rangeland resource issues. Results from these types of analyses are often expressed in basic economic terms that can be readily understood by range managers, thus providing them the ability to formulate informed management decisions based upon the resources at their disposal and their individual preferences.

Renewable Resources

Rangeland forage can be regarded as a renewable resource, as long as natural levels of fertility allow for regeneration and the demand on the soil resource is not excessive (Perman et al. 1996). It exhibits the characteristics unique to renewable resources (e.g., trees utilized for timber) comprising both a stock and flow of resources. Renewable resources are those that regenerate from a stock and can continually be replenished if managed effectively (Tietenberg 1996). The vitality and size of the renewable resource determines its availability in future time periods. Figure 3 demonstrates the properties of renewable resources with the logistic growth function for a renewable resource. S represents the stock or population of a single biological renewable resource at a given point in time[2]. S_{max} denotes the maximum carrying capacity of the environmental system in which S exists. S_{msy} is the maximum sustainable yield (MSY) or highest perpetual harvest possible of S given the potential flow or growth rate G(S). Theoretically, it is possible to harvest S_{msy} of the resource stock continually, as it will perpetually regenerate itself from the remaining stock. If S is harvested above S_{msy}, the rate of growth G(S) falls, less stock remains for future regeneration and the level of stock over time will be reduced. S_{min} is the critical level of resource S required for its survival. If stock falls below this level, natural mortality outpaces reproduction and S will eventually be exhausted or die out.

[2] These properties are not limited to biological resources, but can be extended to other resources that possess some capacity for replenishment (Perman et al. 1996).

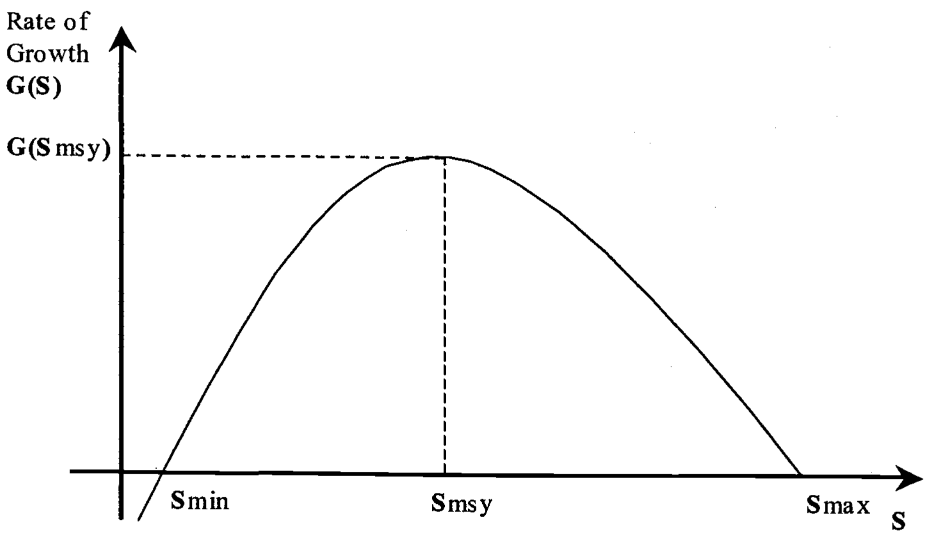

Figure 3. A renewable resource logistic growth function, demonstrating the properties of renewable resources (adapted from Abedin 1995, Pearce and Turner 1990, Perman et al. 1996).

With these fundamental principles of renewable resources at work, successful management of rangeland forage requires an acute knowledge of forage growth functions and an understanding of factors influencing them. Knowledge of rangeland forage MSY is not sufficient to guide range management decisions. Economic conditions surrounding the resource must also be applied. Economically, the MSY may not be the optimal level of resource utilization. Economically optimal levels of rangeland forage consumption can only be determined after monetary values are incorporated into the range management decision process.

Economic Principles

The underlying economic assumption of this thesis is that the ranching operation seeks to maximize profit, the measured difference between total revenue from the sale of beef cattle and the total costs of factors used in producing that output. Maximum profit is characterized by the greatest difference between total revenue and total costs for a given level of output (i.e., number of cattle sold by the ranch). At the profit maximizing output (X* shown in Figure 4) the slopes of the ranch's total revenue and total cost curves are equal, the point at which marginal revenue equals marginal cost (Pearce 1992). Figure 4 graphically illustrates the theoretical characteristics of profit maximization using a firm's hypothetical total cost and revenue curves. At X* the total revenue exceeds total cost by the greatest amount and the slope, or marginal value of the cost and revenue curves are equal (MR=MC). Output greater than X* would result in increasing costs and declining revenue per unit of output. As output increases beyond X*, the slope of the total cost curve (MC) increases and the slope of the total revenue curve (MR) decreases, causing marginal costs to rise and marginal revenue to fall per unit of output.

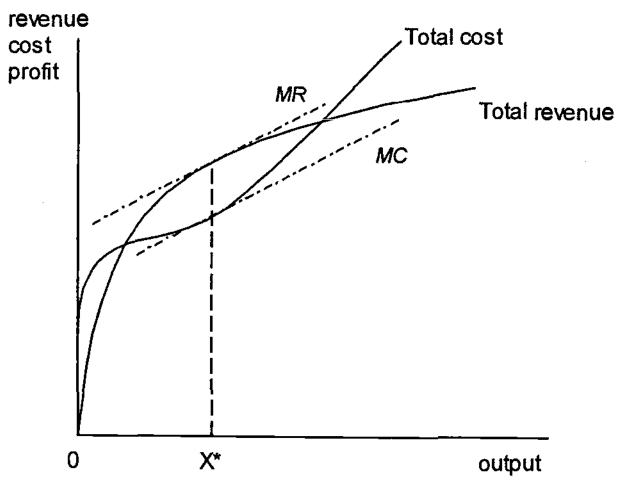

Figure 4. A theoretical characteristic of a profit-maximizing firm using total-cost and total-revenue curves to determine the optimal output of a good (X) (Pearce 1992).

The economic modeling conducted for this thesis captures profit in terms of total gross margin, measured as the ranching operation's revenue minus its variable costs. Profit is derived from total gross margin by subtracting the operation's fixed costs. For the purposes of this thesis total gross margin will be considered synonymous with profit because the fixed costs (beyond the investment of providing off-stream water) are assumed to remain constant under all three riparian grazing management strategies examined (Stillings et al. 2003). Since it is assumed that the ranching operation seeks to maximize profit, the implicit goal of the rancher is to maximize the present value of his total gross margin. The objective of this thesis is to impartially compare the present value of the total gross margin associated with each of the three riparian grazing management strategies.

It is assumed that cattle ranching operations in northeastern Oregon operate in a perfectly competitive market structure. Perfect competition exists when firms (ranches) produce a homogeneous product (cattle), using identical production methods, with perfect information of current and future prices. Firms in competitive markets are free to enter or leave the industry until all competitors observe normal profits. Firms operating in a competitive market are price-takers for their factor inputs and production outputs and are incapable of raising the price of their product without losing their entire market share to competitors. In economic terms, each firm operating in a purely competitive market faces a horizontal demand curve over the long run (Henderson and Quandt 1980, Nicholson 1995).

There are many uncontrollable factors of production associated with cattle ranching operations. Cattle ranching operations face some level of economic risk and uncertainty due to the lack of adequate information and the additional uncertainties concerning input and output prices (Lambert and Harris 1990). Profitability in rangeland cattle production is largely determined by fluctuating precipitation and market price volatility (Rodriguez and Taylor 1988). Available rangeland forage is chiefly determined by unpredictable precipitation levels (Sneva and Hyder 1962a) that often vary from year to year and within each season. Thus the rancher is faced with making business, budgeting and capital investment decisions (i.e., cattle production decisions) in a highly variable and unpredictable economic and natural environment.

Ranch production decisions (what, how and how much to produce) are based upon the operation's production function. A production function is the theoretical relationship between the output of a good and the inputs or factors of production required to manufacture that good (Pearce 1992). The general form of a firm's production function and the relationship between factor inputs and output can be described mathematically as (Nicholson 1995):

$$q = \int(K, L, M, ...) \qquad (1)$$

Where:
q represents a firm's output of a particular good during a period
K is the capital usage during the period
L is the unit of labor input
M represents the raw materials used

Ranch managers are akin to managers of firms. They are faced with the same decisions of what, how and how much to produce based upon their operation's ability to effectively employ inputs of land, labor and capital. Given that most rangeland cattle production decisions are inherently determined by fluctuating precipitation, market price volatility for both inputs and outputs and the changing cost of capital (i.e., varying interest rates), ranch managers are faced with controllable and uncontrollable factors of production (Lambert and Harris 1990, Rodriguez and Taylor 1988, Sneva and Hyder 1962a). With this in mind, the production function of a ranch enterprise is better depicted by (Stillings et al. 2003):

$$Y = \int(x_1 ... x_k, x_{k+1} ... x_n, z_1 ... z_n) \qquad (2)$$

Where:
Y represents the range enterprise's output
$x_1 ... x_k$ represents controllable (decision) variables
$x_{k+1} ... x_n$ represents predetermined variables for the planning period
$z_1 ... z_n$ represents uncontrollable (inherent) variables

The ranch enterprise production function demonstrates the relationships between all possible combinations of controllable and uncontrollable factors of production (variables) and the ensuing output. This theoretical relationship of inputs and output directs the ranch manager's production decisions of what, how and how much to produce.

Under the assumption that the rancher seeks only to maximize monetary profit, the cattle ranch, like any firm, will remain in business as long as it is profitable to do so. During the short run, the period in which the operation has only limited management flexibility, the ranch will continue to produce cattle as long as the gross margin (revenue minus variable costs) is positive. Over the long run, the period in which all factors of production may vary, the ranching operation has greater flexibility and control over its operational costs and will remain in business as long as it generates a positive net return or profit[3]. Profit can be calculated by subtracting total costs from total revenue. The calculation of a firm's profit can be shown as:

$$\Pi = \sum_{j=1}^{n} p_j y_j - \sum_{i=1}^{n} c_i x_i \qquad y_j, x_i > 0 \tag{3}$$

Where:
Π represents profit
p_j represents a matrix of price coefficients of outputs, $y_j \, \forall j$
y_j represents a matrix of output quantities, $\forall j$
c_i represents a matrix of cost coefficients of inputs, $x_i \, \forall i$
x_i represents a matrix of inputs, $\forall i$

Cattle-ranching operations are constrained by the limited availability of productive resources (i.e., namely pasture availability and rangeland forage yields). The rancher's ability to maximize profit is inhibited by a set of resource constraints.

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[3] For the purposes of this thesis fixed costs were held constant, assuming they are equal among the three management options studied, thus "profit" was measured in terms of total gross margin.

With the desire to take full advantage of their business, ranchers are faced with a constrained maximization problem. Calculating ranch profits under a condition of constrained (limited) resources can be accomplished if the constraints are considered in the ranch's profit function, where:

$$\Pi = \sum_{j=1}^{n} p_j y_j - \sum_{i=1}^{n} c_i x_i \qquad y_j, x_i > 0 \tag{4}$$

$$\text{subject to: } g(x_i) = b_i$$

Where:
Π represents profit
p_j represents a matrix of price coefficients of outputs, $y_j \, \forall \, j$
y_j represents a matrix of output quantities, $\forall \, j$
c_i represents a matrix of cost coefficients of inputs, $x_j \, \forall \, i$
x_i represents a matrix of inputs, $\forall \, I$
b_i represents a resource constraint matrix for $x_i \, \forall \, i$

The objective of the rancher becomes one of optimization or maximization of profit (Π) subject to a set of resource constraints ($g(x_i) = b_i$). An accepted method for solving a constrained maximization problem is the Lagrange-multiplier method (Chiang 1984, Nicholson 1995). The Lagrangian Method is a mathematical operation that can be used to solve a set of equations that has more variables than equations[4]. The technique introduces an additional variable, the Lagrange-multiplier (λ) that helps to solve the constrained optimization problem by balancing n+1 equations with n+1 unknowns (Nicholson 1995). The addition of the multiplier also has a useful economic interpretation that will be discussed later.

Using the Lagrangian technique to transform the constrained profit function provides the following constrained Lagrangian profit function for the ranch:

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[4] A set of equations is over-determined when there is at least one additional equation (the constraint in this case) but no additional variables.

$$\mathcal{L} = \sum_{j=1}^{n} p_j y_j - \sum_{i=1}^{n} c_i x_i + \lambda[b_i - g(x_i)] \qquad y_j, x_i > 0 \tag{5}$$

Where:
$\mathcal{L}$ represents is the Lagrangian function
λ represents the Lagrangian-Multiplier

The transformed profit function ($\mathcal{L}$) is solved by obtaining the necessary first-order conditions (by setting the partial derivatives of x_i and y_i and λ equal to zero) and by checking the second-order conditions (confirming the input and output ratios produce a maximum or minimum) to verify optimization. The first-order conditions locate critical points on the objective function ($\mathcal{L}$) where the slope of the function equals zero and marginal cost is equal to marginal revenue. The unique set of variables (x_i... x_n, y_j ... y_n and λ) in the solution obeys the constraint and makes $\mathcal{L}$ (and therefore Π) as large as possible.

The Lagrangian-multiplier (λ) provides a measure of sensitivity of $\mathcal{L}$ (profit) to a shift or change in the resource constraint (Chiang 1984). Optimization theory has shown that at the optimal (maximum) solution, the marginal benefit of increasing an input (x_i) is equal to the marginal cost of that input and should be equal across all inputs (x_n). In light of this fundamental theory of optimization, the Lagrangian-multiplier (λ) can be interpreted as benefit-cost ratio for all inputs (Nicholson 1995).

$$\lambda = \frac{\text{marginal benefit of } x_i}{\text{marginal cost of } x_i} \tag{6}$$

The Lagrangian-multiplier captures how a relaxation of an input constraint (i.e., one additional acre of rangeland pasture) would affect the value of the objective function (ranch profits), essentially providing a "shadow price" for the relaxed constraint. The constraint with the largest multiplier (λ) value has the highest benefit-cost ratio and therefore the greatest potential to affect the objective if it were to be "relaxed." The converse is also true. Constraints that are not at all binding have a value of zero (Nicholson 1995).

Time Preference of Money, Discounting and Net Present Value

Individuals tend to place a higher value on current income than income derived in the future. A positive rate of time preference is attributed to the opportunity cost of money; the fact that the future is uncertain and individuals prefer benefits now rather than later (Workman 1986). Other arguments for a positive rate of time preference include the occurrence of rising income over time (particularly in the case of a growing economy), effectively making today's earnings less valuable in the future, and the advent of technological progress that increases the possibility of future consumption (income), making it worth less (Perman and McGilvray 1996). A positive rate of time preference indicates that a time value of money exists.

Discounting is a general mathematical means of calculating the present value of a future flow of costs and returns (Workman 1986). The general formula for discounting an annual flow is given as:

$$V_0 = R\frac{\left[1-(1+i)^{-n}\right]}{i} \tag{7}$$

Where:
V_0 is the present value of a future flow
R is the net annual return received or net annual cost paid out
i is the interest (discount) rate
n is the number of years that R is received or dispersed

Present value (V_0) is the worth of a future stream of returns or costs in terms of their value today (Pearce and Turner 1990, Pearce 1992). The practice of discounting is controversial (Perman and McGilvray 1996). Assigning an appropriate numerical value for the discount rate (i) is debated by resource economists. The higher the discount rate the lower the importance attached to the future (Pearce and Turner 1990). Generally, a project (or investment) would not be undertaken unless the total present value of future benefits received equals or exceeds the present value of the stream of costs.

Rangeland improvements often involve an initial investment (a stock) with net returns accruing as a flow, or income stream, over time (Workman 1986). A standardized comparison of alternative range improvements or grazing strategies is valuable and requires converting stocks and flows to a common point in time. In order to compare present-day benefits and costs associated with the three cattle grazing management strategies studied, this thesis utilizes the following net present value (NPV) calculation:

$$NPV = \sum_{t=0}^{t=T} \frac{NB_t}{(1+i)^t} \tag{8}$$

Where:
NPV is the net present value
NB is the net benefit (revenue minus costs) in time t
i is the discount rate
t is the number of years NB is received or dispersed
T is the planning horizon in years

Knowing the present value of potential net benefits associated with a rangeland management decision is very useful. Net present value furnishes the rancher with insightful decision-making information. The application of economic theory, coupled with an appreciation of renewable resources and regard for net present value, can help ranch managers render complex rangeland systems and their economic value into understandable terms to gauge long-term business decisions. Economics alone, however, does not generally dictate which rangeland management practice should be employed. Social, institutional and personal preferences often figure into the manager's decision-making process. It is possible that a rancher may choose a grazing option that yields a zero or even negative net present value (USDA 1996).

ECONOMIC MODELING AND UNCERTAINTY

Rangeland productivity and the ecological condition of riparian corridors are dependent upon controllable and uncontrollable factors (Stillings et al. 2003). Although a number of animal production models have been developed in well-controlled conditions, such models are not useful under rangeland conditions due to the uncertainty and complex nature of plant and animal community interactions over space and time (Hodgson and Illius 1996). Variability in forage yield, unstable market prices and monetary policy are all factors creating risk and uncertainty for a ranching operation (Standiford and Howitt 1992).

From an economic standpoint, the optimum rangeland production level is where revenues exceed costs by the greatest margin. Due to the uncertainty and complex nature of rangelands, producing at the economic optimum is challenging and often involves a level of risk and uncertainty. Consider the economically optimum stocking rate suggested in Figure 5.

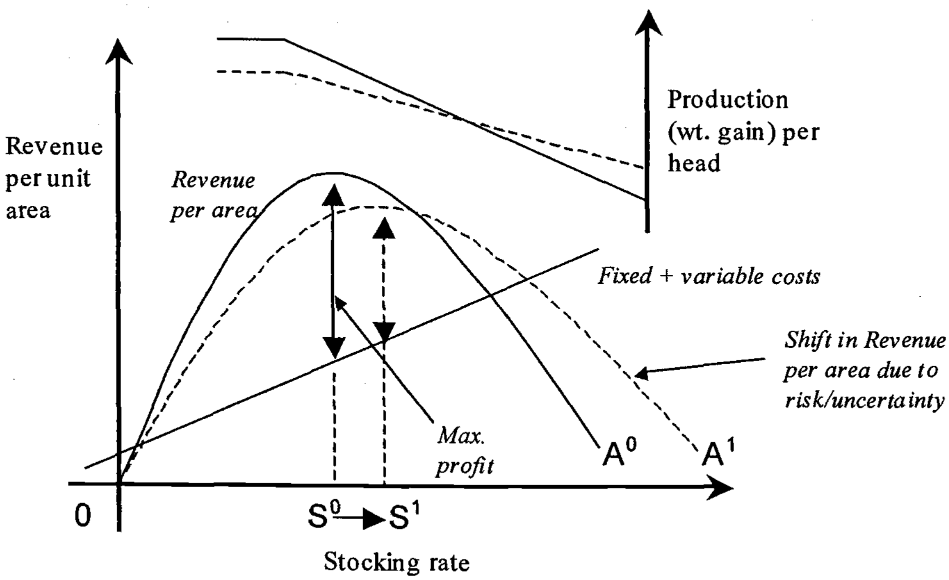

Figure 5. A graphical representation of a shift in the economically optimal stocking rate due to risk and uncertainty, adapted from Hodgson and Illius (1996).

The optimal stocking rate presented (S^0) ignores risk and uncertainty and uses basic linear relationships of forage intake and availability. The simple production relationships illustrated are generally valid for small enclosures, but fail to mimic spatial and temporal aspects of large paddocks. In rangeland situations, straightforward relationships break down, rainfall varies from year-to-year, stocking numbers exhibit temporal autocorrelation, large paddocks are not utilized evenly by herbivores and spatial differences unavoidably occur within management units, making no two alike (Hodgson and Illius 1996). Thus the optimal stocking rate is not known with certainty. Figure 5 shows an increase in the optimal stocking rate ($S^0 \rightarrow S^1$) due to an unforeseeable shift in revenue per area ($A^0 \rightarrow A^1$) that was a result of a change in a factor such as greater than expected rainfall resulting in more available forage.

Developments in mathematical programming techniques and the advent of high-speed computer processing have allowed for the solution of large complex models in a relatively straightforward manner, using algebraic statements and intuitive programming language to modify model specifications (Brooke et al. 1992). As a result, more complexity can be introduced into the modeling process in an attempt to mimic expected conditions wherever possible. Because livestock ranching is dependent upon a number of biological relationships under stochastic conditions, mathematical programming is an appropriate analytical instrument to meet the research objectives of this thesis. It should be recognized however, that models, by design, are simplified characterizations of reality, useful abstractions that should always be viewed with some level of uncertainty (Tietenberg 1996). The acceptance of a mathematical model as an accurate and useful depiction of the world necessitates recognition of its simplifying assumptions and limitations.

METHODS, PROCEDURES AND DATA SOURCES

THE MILK CREEK DISPERSION PROJECT

Currently, there is a growing acceptance to take an interdisciplinary approach in developing and implementing grazing management strategies at the watershed-scale. This ecosystem approach requires a detailed understanding of riparian functioning in order to maintain high biological diversity in the system and promote long-term productivity of stream-side pastures (Elmore and Kauffman 1994). Effective resource management at the ecosystem level involves specialized knowledge in many diverse disciplines. This systems approach may be beyond the ability of the individual rancher, as it requires comprehensive knowledge of social and biological relationships. It requires an understanding of riparian functioning and how livestock grazing can modify that functioning and knowledge of the economic impacts and social acceptability of alternative grazing strategies. Social acceptance is a key factor in determining whether the proposed techniques will be implemented. Consequently, there is a need to fully examine specific riparian grazing techniques with prudent scientific research, evaluating them based upon their application, intended results and economic feasibility. To fulfill this necessity, a multidisciplinary research project addressing livestock impacts on riparian ecosystems was undertaken in northeastern Oregon.

The Milk Creek Dispersion Project (MCDP) is an on-going study, integrating cattle grazing and the physical factors of a mountain riparian ecosystem into a ranch model to demonstrate sustainable natural resource use. The project was a multi-state cooperative study initiated in 1995 by Oregon State University, University of Idaho and the Blue Mountains Natural Resources Institute. The goal of the MCDP was to integrate the environmental and economic aspects of cattle ranching into a sustainable livestock production/resource-use model and create a demonstration site for community education and outreach. The project was multidisciplinary in nature and focused its investigations in four areas: (1) animal behavior and performance, (2) riparian area assessment, (3) biodiversity and (4) economic feasibility. This thesis is focused on the economic feasibility component of the MCDP.

A study site was selected and used to evaluate grazing management strategies that may improve livestock distribution in mountain riparian pastures. A 108-hectare site was developed on the Eastern Oregon Agricultural Research Center's Hall Ranch, located in the foothills of the Wallowa Mountains of northeastern Oregon. The site was subdivided into three research blocks along the riparian corridor of Milk Creek, a small tributary to Catherine Creek[5]. Cross fencing partitioned the site into nine paddocks. Each of the paddocks, approximately 12 hectares in size, were supplied with roughly 260 meters of stream reach and contained riparian, meadow and upslope vegetation. Site configuration created three research blocks and nine pastures, allowing for the replication of three treatments in a complete three-block, nine-paddock design.

During the first two years of the MCDP (1996-97), the study site was equipped to study the use of off-stream water development and upland salt to modify cattle grazing behavior. The objectives of that research were to quantify the effect of off-stream water and trace mineralized salt on cattle distribution relative to riparian areas and to determine the long-term economic feasibility of providing off-stream water and salt for a 300 head cow/calf operation. This early research randomized three management treatments among each of the three research blocks: (1) access to Milk Creek with the provision of off-stream water and trace-mineralized salt, (2) access to Milk Creek with no off-stream water and (3) an ungrazed control. Sixty cow/calf pairs were used to graze the study site from the mid-July to late August for a total of 42 days. Porath et al. (2002) and Stillings et al. (2003) detailed the methods and procedures conducted during these first two years of the MCDP. The work of Porath et al. (2002) primarily examined the animal behavior and distribution component of the

[5] Catherine Creek is recognized by the Oregon Department of Fish and Wildlife as a salmon rearing stream.

study and included extensive analysis of the forage resource, whereas Stillings et al. (2003) concentrated on the economic feasibility of the management practice.

During the next two years of the MCDP (1998-99), the research site was modified to study the influences of early and late seasonal grazing on the riparian zone and cattle performance, behavior and distribution. The three treatments randomized in each research block for the study were: (1) early seasonal grazing, (2) late seasonal grazing and (3) an ungrazed control. Early-season grazing was from mid-June to mid-July and late-season was from mid-August through mid-September. Sixty-two cow/calf pairs were randomly chosen and allowed to graze for 28 days in each "seasonal" treatment. During the mid-summer season of each study year, all the animals were moved off-site to graze on nearby upland pastures. In this later study Parsons et al. (2003) analyzed a number of rangeland factors and conducted animal behavior and distribution research.

The methods and procedures conducted during this final segment of the MCDP were designed to achieve the following objectives: (1) integration of two alternative cattle grazing methods within a mountainous riparian ecosystem to illustrate an environmentally sustainable ranching model, (2) conduct range and riparian bio-assessments of the riparian ecosystem to determine the impacts of the two grazing treatments, (3) verify the economic implications associated with each of the management options and (4) disseminate findings to stakeholder groups through tours, demonstrations and advisory meetings. These objectives guided the research and helped to determine the most effective methods and procedures for data collection during these two years of the MCDP.

Data from both study periods (1996-97 and 1998-99) are utilized for this comparative analysis, making it important to understand the data collection methods and procedures used during both research periods. Since the methods conducted during the initial two years of the project are documented in the earlier works of Porath et al. (2002) and Stillings et al. (2003), the following sections outline the methods and procedures undertaken during the final two years of the MCDP, when the research site was fitted to analyze the effects of seasonal riparian grazing. For a detailed discussion on the animal and rangeland science methods employed during the final two years of the MDCP, one should refer to Parsons et al. (2003). The earlier findings of Porath et al. (2002) and Stillings et al. (2003) were coupled with later results from the 1998-99 seasonal-use research to accomplish the objectives of this thesis, a comparative economic analysis of all three of the riparian grazing strategies applied over the four-year MCDP research effort.

Animal Performance, Behavior and Distribution

Animal performance was measured and tracked using body weight and condition scores. Before and after each seasonal-grazing treatment, the cattle were placed in a dry-lot with no access to food or water overnight. The following morning, the cows and calves were weighed and a body-condition score was assessed for each cow. Trained evaluators applied the body condition scores, with each animal being given a score of 1 to 9 (1 = extremely emaciated and 9 = overly fat; see Wagner et al. 1988). This record of weights and body-condition scores was used to calculate and track cow weight, body-condition changes and calf average daily gains during each of the 28-day treatment periods.

Animal behavior and distribution were documented during each grazing season by field observations, geographical information system (GIS) mapping and individualized animal monitoring equipment. Every daylight hour, throughout each grazing season, the location of each cow was mapped on geo-rectified aerial photographs. Each cow location was then digitized into a GIS database. In addition to hourly location, every observation noted the animal's activity as resting, grazing or drinking. Spatial stream and vegetative maps created by Porath et al. (2002) were used as informational overlays and established quantitative measures of distance and distribution from the stream channel and mapped the dominant forage preference of each cow over space and time. This information spatially and temporally correlated animal behavior to naturally changing environmental and biological conditions as they occurred throughout each grazing season.

Individual animal monitoring equipment was used to record temporal grazing behavior under both seasonal treatments. Vibracorders, chronometric devices designed to monitor the duration and intensity of grazing action of ranging livestock, were randomly assigned to seven cows in each of the three treatment blocks during the second and third week of each 28-day grazing season. In total, these individualized monitoring devices continuously recorded 336 animal-days of grazing behavior over the two-year study. Coupling the information gathered from these devices with the GIS data, linked the animal's grazing intensity with its location in each seasonal pasture.

Forage utilization estimates were conducted in each treatment pasture at the end of each prescribed grazing season. An ocular estimation technique was used in accordance with USFS and BLM interagency standards (BLM 1996). After each grazing treatment, field technicians were trained in residual forage estimation using the ungrazed control pastures as a benchmark. The technicians walked six transects, perpendicular to Milk Creek and the riparian zone, evenly spaced across the width of each pasture. Percent of forage utilization, stubble height and dominant vegetation class were recorded every 7.6m (25ft) along the length of each transect. Forage utilization mapping depicted the cattle's grazing behavior relative to the riparian zone.

After each grazing treatment, the number of fecal deposits within 1m (3.28ft) of the stream was documented. Fecal counts were used to assess the relative time cattle spent along the stream bank and as an indicator of potential for fecal coliform contamination[6].

Parsons et al. (2003) and Porath et al. (2002) conducted analyses of the spatial GIS data, field observation notes, grazing activity records, utilization estimates and

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[6] Under simulated rainfall conditions Buckhouse and Gifford (1976) found that month-old fecal deposits within 1m (3.28ft) of a stream can significantly increase the likelihood of stream fecal coliform contamination (Parsons et al. 2003, Porath et al. 2002).

fecal deposits, creating a comprehensive set of range and animal distribution and behavior indicators for the four-year cattle distribution study.

ENVIRONMENTAL MEASURES

Environmental data were collected to complement the animal performance, behavior and distribution measures. These data included air and water temperatures, water quality measures, forage quality assessment and photographic monitoring of pre- and post-grazing conditions.

Air and water temperatures were routinely recorded during each grazing observation period. Every hour, corresponding to cattle observations, the ambient air temperature was measured and recorded using a handheld thermometer. During the final year of the study, detailed temperature measurements were gathered from remote recording data loggers. Temperature sensing Hobo Data Loggers were placed in strategic locations to sample the temperature profile in Milk Creek, in the adjacent riparian community, on the open meadow grassland and in the forested upland. Both Porath et al. (2002) and Parsons et al. (2003) attributed changes in animal behavioral with changes in air and water temperature. The temperature data were not, however, utilized in the study's economic modeling.

Effectiveness monitoring (MacDonald et al. 1991) was used to discern how each of the riparian grazing strategies influenced water quality. This method required chosen water quality parameters to be sampled before and after each grazing period, upstream and downstream of each treatment pasture. The water quality parameters were selected primarily on their relevant sensitivity and descriptive value of livestock grazing impacts (Bauer and Burton 1993, Moore 1979). The parameter selection process followed U.S. Environmental Protection Agency (EPA) recommendations, using the following notational format (from MacDonald et al. 1991):

Selected parameter(s) = f [monitoring objectives, designated stream uses, management activities, cost, and environmental setting] (9)

Monitored parameters were assessed on their relative importance and their ability to work within the constraints of the project. This selection yielded seven monitoring parameters listed in Table 3.

Table 3: Selected water quality parameters based upon monitoring objectives, designated stream uses, management activities, cost and environmental setting.

Parameter	Measurement
E. Coli	number/100 ml
Total Coliforms	number/100 ml
Total Phosphorus	mg/L
Ortho Phosphorus	mg/L
Nitrite+Nitrate	mg/L
Temperature	^{0}C
Stream Flow	cfs (ft^3/second)

Two sterile sampling vials were utilized, one for chemical analysis and one for bacteria concentration levels. Each collection period was conducted at the same hour of the day. Samples were first drawn downstream and sampling progressed upstream accordingly. The following procedure was employed at each sampling point identified:

1. Chemical sampling, performed by dipping a vial directly into the center of the water column.
2. Bacteria sampling, conducted by re-suspending stream bottom sediments and filling a vial two meters downstream in the passing sediment plume (Sherer et al. 1988, Stephenson and Rychert 1982).
3. Stream velocity measurement and
4. Temperature measurement

All samples were cold-packed and immediately shipped to the University of Idaho's Analytic Sciences Laboratory in Moscow, Idaho for analysis.

Changes in the monitored parameters due to treatment effect were calculated with the following difference equation[7]:

$$\begin{bmatrix} \left(Downstream_{after} - Downstream_{before}\right) - \\ \left(Upstream_{after} - Upstream_{before}\right) \end{bmatrix} = NetChange \tag{10}$$

Where:
$Downstream_{after}$ - downstream parameter value after grazing treatment
$Downstream_{before}$ - downstream parameter value before grazing treatment
$Upstream_{after}$ - upstream parameter value after grazing treatment
$Upstream_{before}$ - upstream parameter value before grazing treatment
Net Change - net treatment affect on water quality parameter

The difference or net-change method attempts to account for spatial and temporal variability of the parameters. In the case of measured E. coli and Total Coliform, sample values were mathematically logged to deal with the inherent exponential growth characteristics of bacterium.

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[7] Derived by personal consultation with Robert L. Beschta, Ph.D., Dept. of Forest Engineering, O.S.U. and James A. Moore, Ph.D., Bioresource Engineering Dept., O.S.U., May 1999.

$$\begin{bmatrix} (\ln(Downstream_{after}) - \ln(Downstream_{before})) - \\ (\ln(Upstream_{after}) - \ln(Upstream_{before})) \end{bmatrix} = ColiformNetChange \qquad (11)$$

Where:
Downstream$_{after}$ - downstream parameter value after grazing treatment
Downstream$_{before}$ - downstream parameter value before grazing treatment
Upstream$_{after}$ - upstream parameter value after grazing treatment
Upstream$_{before}$ - upstream parameter value before grazing treatment
Net Change - net treatment affect on water quality parameter

Forage quality samples were gathered during the final week of each grazing period. Twenty 0.25 m^2 plots were randomly clipped in each treatment pasture, 10 located throughout the upland areas and 10 located in low-lying meadows and riparian areas. The samples were weighed, dried and re-weighed to calculate dry matter yields. The clipped matter was ground to pass through a 1 mm screen, then processed and analyzed for crude protein, neutral detergent fiber and acid detergent fiber content (Parsons et al. 2003).

Photographic reference points were established for the final year of the study. The photographs were primarily used to document pre- and post- grazing conditions in a number of different biomes on the study site. All of the photographs were taken from a distance of 15 feet at eye level. A Canon EOS 650 with a 50mm 2.8 AF lens was used. The images were exposed on Kodachrome ASA 64 film. A meter stick was placed in each photograph for visual reference. The location of each photo point was recorded by logging it on an aerial photograph of its corresponding pasture. Although not presented in this thesis, the photographs were digitally archived onto a compact disk and stored at the Eastern Oregon Agricultural Research Center.

Economic and Resource Supply Information

To compare three dissimilar riparian grazing strategies, it was necessary to collect and combine animal performance data with economic and resource supply information. Economic information used to characterize the ranch model was gathered from agricultural statistical databases, university Extension Service economists and through personal interviews of local ranchers and industry professionals. Information on ranching costs and returns were collected from regionally specific enterprise budgets (Turner et al. 1998) and historical price data from the U.S. Department of Agriculture. The prices paid in the model for factors of production were adjusted to reflect year 2002 pricing using the Prices Paid Indices published by the Agricultural Statistics Board (USDA 2002). The indices capture industry changes in prices paid by farmers and ranchers for goods and services utilized for commodity production. Table 4 lists the annual and monthly variable costs per cow used in the ranch model taken from a 1998 enterprise budget and the index by which the specified cost was escalated to year 2002 prices. Based upon the data collected, the variable operating costs per cow associated with a typical 300 head cow/calf operation increased 13.26% from 1998 to 2002.

Table 4: Annual and monthly variable costs per cow for 300 head cow/calf operations in mountain regions.

Variable Cost	1998 $/Cow[a]	Prices Paid Index[b]			% Change[c]	2002 $/Cow
		1998	2002	Index Name		
Salt	3.20	116	124	Supplements	6.9	3.42
Minerals	2.40	116	124	Supplements	6.9	2.57
Fuel, Lube, Mach. & Equip.	9.49	84	110	Fuels	31.0	12.43
Interest – Operating Capital (10% for 7.5 mo)	7.44	104	109	Interest	4.8	7.80
Hired Labor	30.00	129	152	Wage Rates	17.8	35.35
Repairs, Mach. & Equip.	8.17	121	134	Repairs	10.7	9.05
Fence Repair Materials	3.33	118	122	Build. Materials	3.4	3.44
Supplies	3.33	115	124	Supplies	7.8	3.59
Utilities	8.00	112	121	Livestock Sector	8.0	8.64
Vet. & Medicine	14.17	115	120	Farm Services	4.3	14.79
Brand Inspection	1.65	112	121	Livestock Sector	8.0	1.78
Bull Purchase	20.00	88	101	Livestock/Poultry	14.8	22.95
Horse Purchase	2.50	88	101	Livestock/Poultry	14.8	2.87
Marketing Fees	11.65	115	120	Farm Services	4.3	12.16
Accounting	4.00	115	120	Farm Services	4.3	4.17
Legal & Related Services	3.33	115	120	Farm Services	4.3	3.47
Family Labor	44.50	129	152	Wage Rates	17.8	52.43
Miscellaneous	5.00	112	121	Livestock Sector	8.0	5.40
Annual	**182.16**					**206.32**
Change Costs 1998 to 2002	**13.26%**					

(a) Turner et al. (1998). (b) Base year 1990-92 = 100, USDA (2002). Wherever possible, an index sub-component was chosen. In all others, a representative industry sector index was used. (c) [(2002 index - 1998 index) / 1998 index] x 100.

The ranch model developed for this thesis utilizes four forage supply options: owned pasture, publicly leased pasture, privately leased pasture and hay. Cattle forage supply costs were derived from the same regionally-specific enterprise budget used earlier (Turner et al. 1998) and the prices were adjusted to reflect year 2002 pricing in the same manner using USDA Prices Paid Indices (PPI) (USDA 2002). Table 5 lists the monthly and daily forage costs per cow for each of the forage supply options available in the ranch model. Total forage supply costs are provided in terms of dollars per animal unit month ($/AUM). This cost is the amount one would pay to pasture a cow and her calf for one month on the forage supply option presented.

Table 5: Monthly and daily forage supply costs per cow for 300 head cow/calf operations in Oregon mountain regions.

Forage Supply Option	1998 $/AUM[a]	Prices Paid Index[b]			% Change[c]	2002 $/AUM
		1998	2002	Index Name		
Owned Pasture						
Maintenance	2.50	121	134	Repairs	10.74	2.77
Lease	0.00	135	143	Cash Rent	5.93	0.00
Miscellaneous	0.00	112	121	Supplies/Repairs	8.04	0.00
Monthly Total (per AUM)						**2.77**
Daily Total (per AUD)						**0.091**
Publicly Leased Pasture						
Maintenance	1.97	121	134	Repairs	10.74	2.18
Lease	1.80	135	143	Cash Rent	5.93	1.91
Miscellaneous	1.48	112	121	Supplies/Repairs	8.04	1.60
Monthly Total (per AUM)						**5.69**
Daily Total (per AUD)						**0.187**
Privately Leased Pasture						
Maintenance	0.69	121	134	Repairs	10.74	0.76
Lease	7.77	135	143	Cash Rent	5.93	8.23
Miscellaneous	0.05	112	121	Supplies/Repairs	8.04	0.05
Monthly Total (per AUM)						**9.05**
Daily Total (per AUD)						**0.298**
Feed Purchased						
Native Hay	24.00	116	121	Hay/Forages	4.31	25.03
Alfalfa Hay	30.00	116	121	Hay/Forages	4.31	31.29
Monthly Total (per AUM, w/4:1 mix)						**26.29**
Daily Total (per AUD, w/4:1 mix)						**0.864**

(a) Turner et al. (1998). (b) Base year 1990-92 = 100, USDA (2002). Wherever possible, an index sub-component was chosen. In all others, a representative industry sector index was used. (c) [(2002 index - 1998 index) / 1998 index] x 100.

Annual ranch revenue from the sale of cattle was calculated using a historical twenty-year data series specific to Oregon. The ranch model assumes the sale of cattle in November. Empirical field data collected for the model demonstrated that selling weights for calves best fit the 500-599 lbs. range in the series. Because of price variation, annual revenue generated from the sale of culled cows and heifer and steer calves in each market period was computed individually using prices reflective of the animal's class. It was assumed that all sales were at the market price. Table 6 shows the historical prices and provides the mean price and standard deviation for each class of animal sold by the model ranch.

Table 6: Twenty-year Oregon cattle price series for real prices received ($/cwt) during the month of November FY1980-1999 (unpublished data supplied by David Weaber, Cattle-Fax, Inc., Centennial, Colo., Sept. 8, 2000).

	Animal Class		
Year	**Cows (Culled)**	**Heifers 500-599lbs**	**Steers 500-599lbs**
1980	78.19	127.39	146.87
1981	63.12	94.68	112.01
1982	55.04	92.23	109.23
1983	50.00	87.87	104.13
1984	50.95	87.02	104.11
1985	44.32	81.01	95.53
1986	47.91	83.00	97.33
1987	56.12	110.26	121.09
1988	55.05	111.48	120.48
1989	56.24	105.70	115.62
1990	54.91	105.84	112.56
1991	49.93	99.50	105.55
1992	48.69	95.18	102.81
1993	44.56	96.13	103.84
1994	36.17	80.13	87.08
1995	28.88	59.38	66.43
1996	25.11	56.51	63.03
1997	27.34	78.40	89.36
1998	24.00	69.08	77.46
1999	31.06	80.31	89.21
Mean	**46.38**	**90.05**	**101.19**
Std. Dev.	**14.01**	**17.64**	**19.44**

Price sensitivity of the ranch model was tested with high, medium and low price ranges for each animal class sold (e.g., culled cow, heifer and steer). Under each animal class, the series mean was considered to be the medium price. The mean plus or minus one standard deviation provided high and low price ranges for each respective class. The price ranges were then inflated to 2002 dollars using the USDA Prices Received Index (PRI) for Livestock and Products (base year 1990-92=100). Table 7 provides the high, medium and low prices used in the ranch model derived from the twenty-year price series with the final prices adjusted to year 2002.

Table 7: Cattle prices received ($/cwt) adjusted to 2002 prices, using USDA Prices Received Index (PRI) for Livestock and Products, where 1999 PRI = 95, 2002 PRI = 91, Base Year 1990-92=100 (USDA 2002).

2002 Prices	Cows	Heifers 500-599lbs	Steers 500-599lbs
Low	31.00	69.36	78.31
Medium	44.43	86.26	96.93
High	57.85	103.16	115.54

The available annual rangeland forage resource was calculated using a regionally calibrated forage forecasting equation supported by empirical data collected at the field research site, historical rainfall patterns and biological growth curves. Rangeland forage yields can vary as much as 75-90% in response to changing precipitation levels (Sneva and Hyder 1962a). Sneva and Hyder (1962a, 1962b) conducted a study of western rangelands and found a constant relationship between changes in forage yield and changes in precipitation. They mathematically documented the relationship as the following:

$$\hat{Y} = 1.11X - 10.6 \qquad (12)$$

Where:
$\hat{Y}$ is estimated yield index (%)
X is precipitation index, calculated as X = (rainfall in inches/mean rainfall in inches)*100%

To account for this naturally occurring variability, Sneva and Hyder's "response line" was used to determine the percent change in annual forage yield for the ranch study site under known precipitation levels. Sneva and Hyder's yield index ($\hat{Y}$) was used to calculate forage yield under low, average and high rainfall scenarios using local historical precipitation records (Taylor et al. 1993). The annual forage resource supplies were calculated by multiplying $\hat{Y}$ with the research site's normal vegetation production estimates derived by Porath et al. (2002) and Parsons et al. (2003).

Seasonal variation in annual forage supply estimates was accomplished with information from USDA Natural Resource Conservation Service (NRCS) Grazing Land Application (GLA) curves[8]. The NRCS developed numerous GLA curves to predict the timing of plant growth in various locations and soil types across the west. The GLA curve that characterized western mountain soils was used in the ranch model and is provided as Figure 6. Incorporation of curve's cumulative growth values into the ranch model, allows the amount of available forage to be seasonally weighted, thereby adjusting the model in accordance with the biological growth cycle of the forage resource.

[8] The USDA's Natural Resource Conservation Service Grazing Land Application Model, courtesy of Hal W. Gordon, Agricultural Economist, NRCS, Portland OR, 1998.

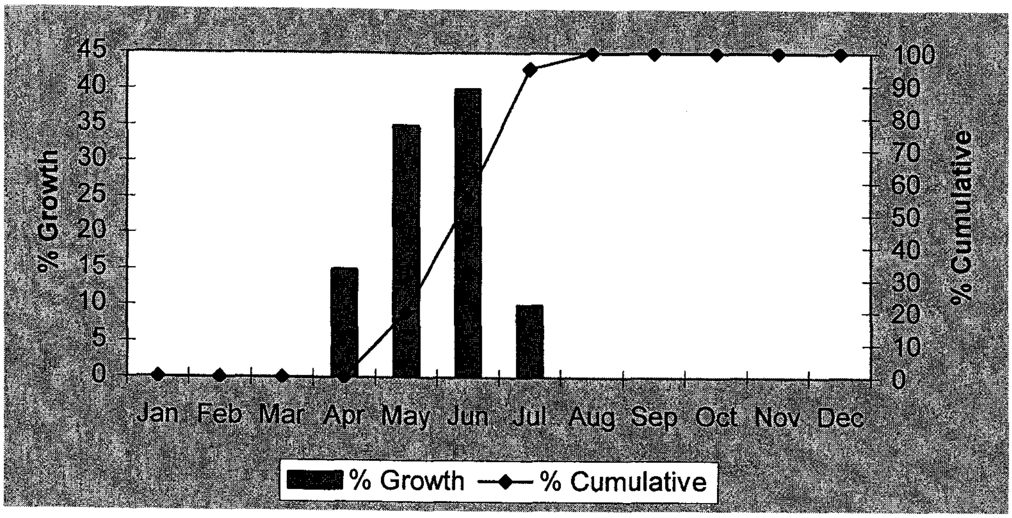

Figure 6. Grazing Land Application (GLA) curve used in the model to characterize plant growth on Western Mountain Soils, adapted from USDA's Natural Resource Conservation Service Grazing Land Application Model, courtesy of Hal W. Gordon, Agricultural Economist, NRCS, Portland OR, 1998.

The GLA growth curve presented in Figure 6 describes plant growth in the mountain regions of Oregon taking place in April through July, with a majority of the growth occurring in June (40%). This is an important consideration since the ranch model examines two different seasons of grazing, early spring and late fall. The model's early grazing period begins in June, when only 75% of the forage growth calculated for that crop year is available for cattle consumption. During the late grazing period, mid-August through mid-September, 100% of the estimated forage supply is available. This seasonal, or cyclic difference in forage supply was accounted for in the model by multiplying the expected annual forage yield of each pasture by a season-of-use correction coefficient. The season-of-use correction coefficients used in the ranch model were taken directly from the GLA cumulative curve in Figure 6 that coincides with the grazing season examined (courtesy of Hal W. Gordon, Agricultural Economist, NRCS, Portland OR, 1998).

MODELING TECHNIQUE

Because of the temporal and dynamic nature of grazing-land management, a multi-period mathematical programming model was designed to meet the research objectives. A representative 300-head cow/calf ranching operation of northeastern Oregon was mathematically replicated using economic theory and a set of economic and biological assumptions. The model was developed and run using General Algebraic Modeling System[9] (GAMS). An example of the model code is provided in Appendix A. Model estimates were compared to assess the economic tradeoffs at the ranch level of the three riparian grazing strategies: (a) early summer grazing of the riparian area, (b) late summer grazing of the riparian area and (c) late summer grazing of the riparian area with off-stream water development. The ranch simulation model was regionally and temporally specified using empirical data collected over a four-year study period and parameterized with economic, production and biological resource data associated with each of the three riparian management options. A listing of the model's exogenous subscripts and parameters is provided in Table 8. The endogenous, or decision variables computed by the model are a function of time and are listed in Table 9. The ranch model calculates each endogenous variable for each decision period t_n and uses the computed value in the next decision period t_{n+1}, making it a multi-period model.

[9] General algebraic modeling system integrated development environment 1.30.6, Module 2.50C. Lic date Sep 30, 1999. GAMS Development Corporation, Washington, DC.

Table 8: A Listing of the subscripts and exogenous parameters and variables used in the ranch model.

Subscripts	Description
T	Time period: Year(s) 1 - 60
L	Forage supply: L1 – Owned pasture, L2 – Public lease, L3 – Private lease, L4 – Winter Hay, L5 – Over utilized public lease
G	Public Forage location: G1 – Riparian zone, G2 – Riparian Upland, G3 – Upland 1, G4 – Upland 2
AS	Cattle age and sex: AS1 – Cow, AS2 – Yearling heifer, AS3 – Heifer calf, AS4 – Bull calf
Parameters	
CLF	Calving %, equals conception rate less calf birth and death rate
LEASELMT	Limit of Animal Unit Days (AUDs) from private lease
OWNLMT	Limit of AUDs on owned rangeland
CULL	Cow culling rate
DEATH	Cow death rate
COWCST	Variable cost per cow per month less forage cost
DISC	1/(1+DELTA), where DELTA is the discount rate employed
RHO_T	Discount factor
CP_T	Control period
PRECP	Median precipitation of crop year
C_L	Cost of forage per AUD by supply
$YEILD_G$	Normal yield of dry forage per acre on public lease
$UTILSTD_G$	Utilization standard on public lease based on (USFS allotments)
$ACRE_G$	Acres of public forage available (3% riparian pasture)
Exogenous According to Management	
PCST	Annual off-stream water development pump and maintenance cost
RIPUTIL	Utilization ratio in riparian pasture based upon grazing option
UPUTIL	Utilization ratio in upland pasture based upon grazing option
GLA_G	Percent of forage growth available depending upon grazing option
Exogenous States of Nature	
DELTA	Discount rate
RAIN	Drought, Normal or Wet rainfall condition, altered depending on model run
WT_{AS}	Cattle selling weights (cwt), altered to reflect grazing option employed
MKTCOW	Low, Average and High price received for culled cow, based upon market conditions
MKTCALFF	Low, Average and High price received for heifer calf, based upon market
MKTCALFM	Low, Average and High price received for bull calf, based upon market

Table 9: A listing of endogenous decision variables computed by the ranch model.

Subscripts	Description
Z	Objective function, present value of total gross margin
$SELLCALFF_T$	Number of heifer calves sold
$SELLCALFM_T$	Number of steers/bull calves sold
$SELLCOW_T$	Number of cows culled and sold
$SELLYEAR_T$	Number of yearling/first calf heifers sold
COW_T	Number of mature cows in the herd
$HERD_T$	Size of the herd
$REPL_T$	Number of heifers in herd for replacement
$FIRST_T$	Number of first calf heifers in herd
TERM	Terminal Value of the herd sold at the end of the planning horizon
NR_T	Gross margin
$VARCST_T$	Total variable cost
$INCOME_T$	Revenue
$X_{L,T}$	AUDs of forage consumed by the herd by supply
$SUMFOR_{G,T}$	Pounds of forage available on public lease
$OVERUSE_T$	AUDs of forage utilized over the public lease limit
$OVER_{G,T}$	Over utilization rate on public lease

The ranch model is a multi-period profit-maximizing model. The ranching operation is assumed to take place over a sixty-year planning horizon (T=60). The sixty-year planning horizon allows sufficient time (i.e., adjustment periods) for the model to reach equilibrium. It was further assumed to be a reasonable comparable life span for the ranch model. Production activities include the transfer of resources (cattle) from one year to the next through the use of equations of motion. The level of production during any given year is limited by the model's constraints, the amount of resources transferred/interacting between years and the level of available resources in the current period.

The objective function of the model is to maximize the net present value (NPV) of total gross margin plus a terminal value of the representative ranch over a sixty-year planning horizon. A terminal value was added to the ranch model based upon the assumption that the rancher will sell the entire herd at the end of the 60-year planning horizon. The mathematical framework for the model's terminal value can be expressed as:

$$TermValue_{60} = \left(\frac{R}{i}\right) - R\left(\frac{1-(1+i)^{-60}}{i}\right) \tag{13}$$

where, $TermValue_{60}$ is equal to the discounted revenue of the herd sold at the end of the planning horizon minus the herd's infinitely discounted revenue[10]. This objective is equivalent to maximizing returns over an infinite planning horizon, since the use of a positive discount rate for returns beyond 60 years amounts to a NPV that is nearly zero.

The objective function is solved with a GAMS algorithm[11], or mathematical process. The algorithm calculates the current resource base in each decision period and maximizes (optimizes) the objective function by adhering to all the constraints written into the model. To efficiently maximize profit (NPV), the ranch model has the flexibility to modify the herd size, lease additional private pasture, feed hay or over-utilize the public forage resource, which will incur a penalty the following year.

Sensitivity analyses were conducted on the model by systematically running it under nine alternative states of nature (using varying combinations of precipitation and market prices) and three alternative discount rates. In each state of nature, the rational (i.e., profit maximizing) management choice was observed. Systematically running the model under alternative price, rainfall and discount scenarios rather than having the model elect the optimal strategy, allowed for comparison of the objective function value for each of the three management practices.

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[10] In the general formula for discounting (see Equation 7), when $n \to \infty$, $(1+i)^{-n} \to 0$; as n approaches ∞ the formula can then be rewritten as (R/i)

[11] MINOS 5, Modular In-core Non-linear Optimization System

General Model Assumptions

Use of mathematical programming necessitates the acceptance of a number of restrictive assumptions to clearly frame the bounds of the model and allow for reasonable and realistic outcomes. In its purest form, the objective of this thesis is aligned with the four general mathematical programming assumptions of 1) problem appropriateness, 2) competitive market conditions, 3) resource additivity and divisibility, and 4) ample access to productivity information[12]. For the purpose of this analysis, it is assumed that the ranching model is supported by accepted economic theory and assumptions categorizing a profit-maximizing firm operating under competitive market conditions. It is further assumed that all production decisions available to the ranch manager are only those incorporated into the model.

The ranch model allows for exogenous and endogenous grazing management scenarios. The assortment of management options available to the rancher makes up the technology choice set. The suite of available management choices (i.e., technology) allowable in the ranch model is shown in Table 10. Those options that are exogenously predetermined are done so to meet the comparison objective of the thesis. The options that are endogenously determined by the model result from the interaction of the model's state and control variables. The variables utilized and the equations of motion (the mathematical expressions that transfer conditions from one decision period (t_n) to the next (t_{n+1})) are assumed to mimic cow-calf operations endemic to northeastern Oregon.

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[12] Graduate course "Special Topics: Mathematical Programming Using GAMS," instructed by Gregory M. Perry, PhD., AREC Dept., Oregon State University, Corvallis OR, 1999.

Table 10: The rancher's technology choice set (or management options), based upon rangeland ownership and the means by which the model selects the technology or management options provided.

Rangeland Ownership	Technology Choice Set, or Management Options	Means of Model Selection
Public	Graze Early	Exogenously
	Graze Late	
	Graze Late w/Off-stream Water	
	Over Graze Public Range	Endogenously
	No Grazing on Public Range	
Private	Graze Deeded Range	
	Lease Private Range	
	Feed Hay	

To achieve a realistic outcome, various constraints were incorporated into the ranch model to bind its solution set. One critical constraint is available quantity of public rangeland for summer grazing. A representative U.S. Forest Service summer allotment designed to sustain a 300-head cow-calf operation was specified and incorporated into the ranch model. It was assumed that three percent (87 acres) of a public grazing allotment contains riparian forage. Figure 7 diagrammatically characterizes the summer public grazing allotment used to parameterize the ranch model. During each grazing season the rancher utilizes all three pastures, but has the choice to graze the riparian pasture (Pasture C in Figure 7) early in the season (first) or late in the season (last). A fourth (rested/rotated) pasture may exist, but does not need to be accounted for, given the nature of the analysis. The size of each pasture is constrained in the model to effectively utilize the empirical animal and range data collected during the MCDP. The model constrains the use of each pasture by the amount of available forage during that season, the number of animals carried over from the previous year, measured rangeland utilization estimates and utilization standards set by public policy. For the purpose of this analysis, the quantity of public rangeland, approximately 2890 acres (1170 ha), is held constant across all three management options studied.

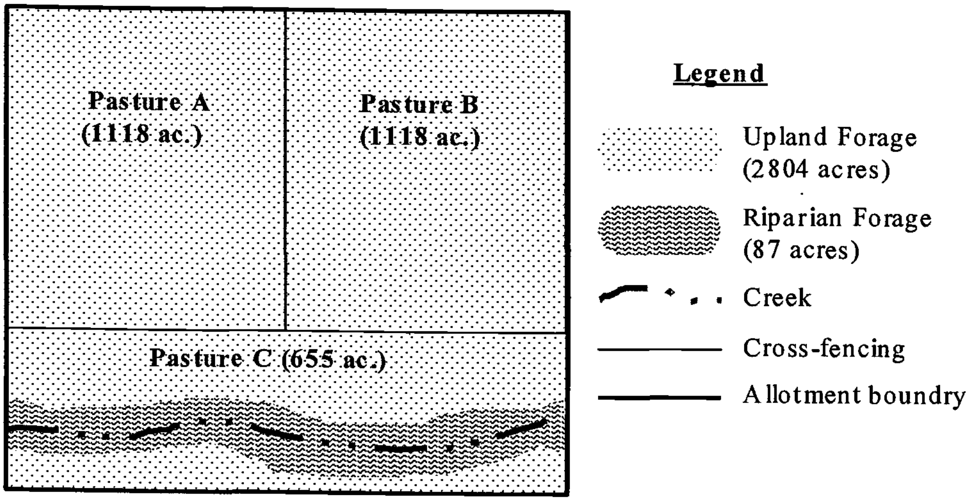

Figure 7. A diagrammatic characterization of a U.S. Forest Service summer grazing allotment for a 300-head cow-calf operation that contains riparian as well as upland pasture, used to render the ranch model.

The model allowed for the unique combination of biological and economic information into a computer-driven resource decision tool. Proper use of any tool requires knowledge of how it works and an understanding of its limitations. The appropriate use of the ranch simulation model also requires an understanding and acceptance of a number of restrictive assumptions and how those limitations are employed to create the model code. The next section addresses how the economic theory, modeling assumptions and empirical data were combined into a bio-economic model using GAMS programming language.

MATHEMATICAL PROGRAMMING AND OPERATIONS

PROGRAM OBJECTIVE

The two fundamental hypotheses that guide this thesis are: (1) economic returns will differ at the ranch level depending upon which riparian grazing strategy is implemented and (2) the optimal, or profit maximizing, riparian grazing strategy is dependent upon annual changes in prices, rainfall and interest rates. These hypotheses also directed the objective of the modeling program. Mathematical programming was used as a modeling tool because of the biological and economic complexities of the problem. The approach combined ranch production assumptions of a 300 head cattle ranch, economic theory and empirical data into a bio-economic model. A method of constrained optimization was utilized to maximize the net present value (NPV) of ranching profits over a 60 year planning horizon under a limited, yet renewable resource base. A discounted terminal value was added to the objective function, simulating the sale of the operation at the end of the planning horizon. The following equation mathematically portrays the objective of ranch model:

$$MaxZ = \sum_{t=1}^{60} [Discount \times (Income_t - VariableCost_t)] + TermValue_{60} \qquad (14)$$

To test the hypothesis whether economic returns differ depending upon which riparian grazing strategy is implemented, the model was parameterized in three distinct ways to reflect the three riparian grazing options examined. To test the hypothesis that the optimal grazing strategy is dependent upon annual changes in prices, rainfall and interest rates, three varied states of nature were included in the model. The following is an explanation of the programming text and mathematical operations conducted by the program.

MATHEMATICAL OPERATIONS

The ranch model was written and executed in GAMS programming language. An example of the model code is provided in Appendix A. The mathematical operations (equations) used in the model are presented below in the programming dialect of GAMS. Each equation is accompanied by a brief explanation of the calculation performed and how the result is used within the context of the modeling program.

The program's objective function (Z), Equation 15, is the summation of annual discounted net revenue (NR(T)) over the course of time T (where T = 60 years) plus the discounted terminal value of the herd, where RHO(T) is the calculated discount factor for each corresponding year of time T.

```
Z=E=Sum(T,NR(T)*RHO(T))+TERM                                    (15)
```

Calculation of the discount factor, RHO(T), and the sequential ordering of each discrete year, or control period within the specified time of T, is accomplished with the use of Equation 16.

```
RHO(T) = DISC**(ORD(T))                                         (16)

Where:
DISC = 1/(1+DELTA)
```

In Equation 16, DISC is being raised (**) to the power equal to each ordered control period in the model (ORD(T)). DELTA is the exogenously determined discount rate employed for each run. The three discount rates used for this study are shown in Table 11. Sensitivity analysis was conducted using each of the three chosen rates (low, moderate and high) under average pricing and normal rainfall conditions to determine if the profit maximizing grazing strategy differs under varying opportunity costs.

Table 11: A listing of the discount rates (DELTA) used to test the model's sensitivity to changing opportunity costs.

Discount Rate	Value	Description
3%	0.03	Low
7%	0.07	Moderate
10%	0.10	High

After simplifying with basic algebra, substituting *R* with revenue from the herd in year 60, ((COW('60')+FIRST('60')-SELLCOW('60'))*181.42), and factoring out the discounting operations, the terminal value equation of the ranch model is expressed by Equation 17.

TERM=E=((COW('60')+FIRST('60')-SELLCOW('60'))*181.42)*
((1/DELTA)-((1/DELTA)-((1/DELTA)*(1/((1+DELTA)**60))))) (17)

Annual net revenue is determined for the model ranch with Equation 18, where annual net revenue (NR(T)) is calculated by subtracting annual variable costs from annual income.

NR(T)=E=(INCOME(T)-VARCST(T)-PCST) (18)

PCST is the annual pumping and maintenance costs associated with the management option of grazing the riparian area late in the season with off-stream water[13]. PCST is set to equal $438.40 in the model when the off-stream water option is analyzed and $0.00 in all other trials.

Annual income is evaluated each year in the ranch model using Equation 19.

INCOME(T)=E=(((SELLCOW(T)*WT('AS1'))+
(SELLYEAR(T)*WT('AS2')))*MKTCOW)+
((SELLCALFF(T)*WT('AS3'))*MKTCALFF)+
((SELLCALFM(T)*WT('AS4'))*MKTCALFM) (19)

Income for each control period (T) is determined by multiplying the endogenously determined numbers of each animal class sold in that period by its empirically determined selling weight (WT(AS)), then multiplying each weight and class by its corresponding selling price. Cows and yearlings are assumed to have equal market value (MKTCOW).

The weight class parameters (WT(AS)) used in Equation 19 are exogenously altered depending upon which management option is being analyzed. Table 12 provides the cattle weight classes derived from the empirical field research for each of the three grazing management options studied. Yearling heifer selling weights were not assessed during field study and therefore were assumed constant across all management options at 800 lbs.

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[13] The value of PCST was taken from Stillings et al. (2003) based on their work in determining the economic feasibility of off-stream water provision to reduce grazing pressure in riparian areas.

Table 12: Empirical weight classes (WT(AS)) used in the model listed by management option studied.

Management Option	Class, WT(AS) in cwt			
	Cow	Yearling	Heifer Calf	Steer Calf
Graze Early	10.74	8.00	6.15	6.92
Graze Late	10.78	8.00	6.18	6.95
Graze Late w/Water	10.95	8.00	6.32	7.04

The market prices used in Equation 19 to calculate income are exogenously altered to evaluate the model's sensitivity to changing market conditions. The high, average and low market prices used for each class of animal sold were derived from a 20-year historical price series and are provided in Table 7.

Annual net revenue is determined by subtracting annual variable costs from annual income. The model calculates annual variable costs using Equation 20,

$$\text{VARCST(T)=E=(12*(COWCST*(COW(T)+FIRST(T))))} \\ \text{+Sum(L,X(L,T)*C(L))} \qquad (20)$$

where VARCST(T) is the summation of two cost factors, operating costs per animal and forage costs by forage supply per animal. The equation multiplies monthly ranch operating costs per animal (COWCST) by the number cows and first-year heifers in the herd, it then annualizes the quotient by multiplying it by 12. Annual forage costs are calculated by summing the annual amount of forage utilized by the herd after first multiplying the amount utilized (X(L,T)) by its cost (C(L)). Table 13 presents the forage supply costs used in the model.

Table 13: Forage supply costs per AUD (C(L)) listed by supply source, used in conjunction with operating costs per animal (COWCST) to calculate annual variable costs for the model ranch.

(L)	Supply Source	$ per AUD
1	Owned Range	0.0910
2	Public Lease	0.1870
3	Private Lease	0.2976
4	Winter Hay	0.8644
5	Over utilization	0.0000

The model was constrained by a number of resource-limiting factors. One such constraint is an upper bound on the allowable size of the ranching operation. Equation 21 constrains the size of the herd in any given control period (T) to less than 500 head.

$$\text{HERD(T)=L=500} \tag{21}$$

The annual supply of forage resource available for cattle consumption is also a limiting factor in the model. The amount of summer forage available on publicly leased lands (i.e., U.S. Forest Service allotments) is calculated in animal unit days (AUDs) using Equation 22, where:

$$\begin{aligned}&\text{SUMFOR(G,T)=E=((((((((rain/precp)*111)-10.6)/100)*}\\&\quad\text{YIELD(G))*ACRE(G))*GLA(G))*}\\&\quad\text{(UTILSTD(G)-2*OVER('G1',T-1)))/25}\end{aligned} \tag{22}$$

Equation 22 is an adaptation of Sneva and Hyder's (1962a, 1962b) forage yield response model. It utilizes exogenously determined rainfall conditions, pasture size and location, season of use, grazing utilization standards and includes a levied penalty for over utilization of the public forage resource. With a given set of rainfall and grazing land parameters, its calculation determines the number of publicly leased grazing days available each year in the ranch model. The rainfall parameters (RAIN, PRECP) used in the model are provided in Table 14.

Table 14: The rainfall parameters (RAIN, PRECP) used to determine the quantity of rangeland forage available and the model's sensitivity to drought, normal and wet rainfall conditions.

Rainfall Conditions (in/yr)			Precipitation (in/yr)
Drought	Normal	Wet	Average
10.43	12.59	14.98	12.59

The grazing land parameters used in Equation 22 are based upon forage location (upland or riparian), empirical forage yields (YIELD), theoretical pasture size (ACRE), the season in which the pasture was grazed (early or late) and an assumed utilization standard (35% of riparian forage and 50% of upland forage). The numerical values for the grazing land parameters used in the model are provided in Table 15. The values under GLA (early) and GLA (late) were employed to capture the seasonal availability of the forage resource. For example, if early seasonal grazing of the riparian pasture is being examined the model was parameterized using the weighting values in the column GLA (early) to reflect the fact that only 75% of the forage growth is available for cattle consumption. The numerical values chosen were based upon information from USDA Natural Resource Conservation Service (NRCS) Grazing Land Application (GLA) curve discussed earlier and illustrated in Figure 6.

Table 15: A listing of grazing land parameters (G) used to calculate the annual amount of forage available for cattle consumption, based upon forage location, expected yield, pasture size, seasonal availability (GLA) and established utilization standards.

(G)	Forage Location	YIELD (lbs/ac)	ACRE	GLA (early)	GLA (late)	UTILSTD
G1	Riparian Zone	1158.8	87	0.75	1.00	0.35
G2	Upland Riparian	722.5	568	1.00	0.75	0.50
G3	Upland 1	722.5	1118	1.00	1.00	0.50
G4	Upland 2	722.5	1118	1.00	1.00	0.50

The ranch model has the option of over-utilizing the public rangeland beyond the assumed limits set by the public resource managers. It is assumed in the model that the public range utilization limit is fixed at 35% (0.35) for areas in the riparian zone and 50% (0.50) for areas in the upland zone. Utilization beyond the established limits is allowed, however it comes at a price, or penalty, levied during the subsequent control period (T+1). The penalty for over-utilizing the public rangeland results in a reduction of the current period's (T) available summer forage by an amount equal to twice that of the riparian forage used above the utilization limit during the previous period (T-1). In other words, if an operator chooses to over-utilize the riparian forage base in year 1, available riparian forage in year 2 will be reduced by two times the amount over-utilized in year 1. This option is allowed by the last subtractive operation in Equation 22, which subtracts twice the amount (2*) of over-utilized riparian forage during the prior period (OVER('G1',T-1)) from the assumed utilization standard (UTILSTD(G)) in the current period (T). Equation 23 determines the amount of over-utilized forage in the riparian zone using the same method and parameters employed in Equation 22; only the calculated forage supply is specified only for the riparian zone ('G1').

OVERUSE(T)=E=((((((((rain/precp)*111)-10.6)/100)*
YIELD('G1'))*ACRE('G1'))*GLA('G1'))*OVER('G1',T))/25 (23)

Observed forage utilization data collected during the field study established the utilization ratios between the riparian and upland forage resources for each of the three grazing management options. This empirical information was incorporated into the model to portray a realistic weighting scale of forage consumption by the herd. Equation 24 holds the model's over-utilization of forage (OVER(G,T)) in a fixed proportion equal to that which was observed during the field study. The utilization values used under each of the three management options are provided in Table 16.

OVER('G1',T)*UPUTIL=E=OVER('G2',T)*RIPUTIL (24)

Table 16: Listing of assumed riparian and upland grazing utilization ratios (RIPUTIL, UPUTIL) used by public land managers to protect the long-term functioning of the rangeland resource.

Management Option	Riparian Pasture (RIPUTIL)	Upland Pasture (UPUTIL)
Early Season Grazing	0.32	0.36
Late Season Grazing	0.51	0.35
Late Season Grazing w/Water	0.35	0.50

It is assumed that public land managers will not allow utilization of the riparian area above 75%. To incorporate this assumption, the ranch model places a limiting constraint (i.e., upper bound) on the availability of public riparian forage ('G1'). The limit on public riparian forage is established by Equation 25, which states that the combined utilization of the riparian forage in the public pasture cannot exceed 75%.

OVER('G1',T)+UTILSTD('G1')=L=.75 (25)

Ranching is a year-round business and is not solely dependant upon summer pasture. Realistically, there must be a large enough forage supply to support the herd all year. In economic terms, the herd's demand for feed during any given year must be equal or less than that year's supply. The herd must have enough feed to sustain itself throughout the entire control period (T). Equation 26 is used in the model to establish a supply-demand relationship between the size of the herd and the amount of available forage across all supply options (L). Because the model calculates forage supply in Animal Unit Days (AUD's), it is necessary to multiply the size of the herd by 365 days to obtain yearly demand. It is assumed that replacement heifers (REPL(T)) consume 25% less than that of mature cows (COW(T)) and first-calf heifers (FIRST(T)).

(365*(Cow(T)+FIRST(T)+.75*REPL(T)))-SUM(L,X(L,T))=L=0 (26)

The ranch model establishes finite limitations on the availability of forage across sources of supply (L). Equations 27 through 29 either constrain forage supply by placing upper limits on its availability or balance the supply depending upon the demand.

Equation 27 maintains a land constraint on the rancher's own spring and fall range ('L1') less than or equal to the owned rangeland capacity (OWNLMT). In this case, the rancher owns approximately 31,740 AUD's, or roughly 1,040 AUM's of spring and fall rangeland to accommodate his herd for a limited time, approximately 2-3 months, depending on the size of the herd.

X('L1',T)=L=OWNLMT (27)

The ranch model equates the amount of summer forage available on public lands to that of the supply source ('L2') by use of Equation 28. The total amount of public forage available for consumption during the summer months ('L2') is determined by summing the amount of available forage calculated in all of the pastures (G) during each control period (T).

$$X('L2',T)=E=SUM(G,SUMFOR(G,T)) \tag{28}$$

As a general rule, the amount of private pasture offered for lease is in limited supply. Accordingly, Equation 29 places a constraint in the ranch model limiting the amount of privately owned rangeland available for lease by the rancher ('L3'). For this analysis, it was assumed that only 10,350 AUD's are available for lease, or around 339 AUM's.

$$X('L3',T)=L=LEASELMT \tag{29}$$

The rancher is assumed to maintain his herd over the winter by feeding hay. Hay is therefore available in the ranch model for 152 days, or about 5 months during the winter. The supply of hay ('L4') in any given year (T) must be greater than or equal to the amount demanded by the herd. Equation 30 establishes a supply-demand relationship between hay and the size of the herd.

$$X('L4',T)=G=(152*(COW(T)+FIRST(T)+.75*REPL(T))) \tag{30}$$

The final source of forage supply available in the ranch model is over-utilized public forage ('L5'). It is held in balance with the amount of riparian over-utilized forage available (OVERUSE(T)) and the amount consumed through Equation 31.

$$X('L5',T)=E=OVERUSE(T) \tag{31}$$

Preliminary herd values are needed in the model and serve two purposes. First, preliminary or initial values realistically establish a starting point from which the model's equations of motion can adjust the flow and stocks of resources in preceding control periods. They are used to start the model's iterative process within the bounds of the feasible solution area. A starting point of a zero herd size would be unfeasible given the equations of motion used to transfer cattle from one year to the next. Secondly, initial values serve to move the model toward a stable long-run equilibrium more rapidly than would otherwise take place, thereby reporting more reasonable economic information over the planning horizon. They represent an initial resource endowment and the programmer's best guess for those key parameters. Equations 32 through 34 endow the model with a starting herd. The combined initial values depicted amounts to a preliminary herd (T=1) of 360 (or, 255 mature cows, 45 first-calf heifers and 60 replacement heifer calves).

$$COW('1')=E=255 \tag{32}$$

$$FIRST('1')=E=45 \tag{33}$$

$$REPL('1')=E=60 \tag{34}$$

Marketing decisions in the ranch model are controlled by cattle equations of motion. The equations are derived from typical production decisions and ranching methods used in the region for which the model was parameterized. Essentially five classes of cattle are controlled in the model: heifer calves, steer calves, yearling replacement heifers, first calf heifers and cows.

Equation 35 and 36 determine the quantity of heifer and bull calves held in the herd during any given year. Calves are weaned at a rate of 88.4% (CLF), resulting from a 95% conception rate, a 98% birthrate and a calf survival rate of 95%. Half of the calves born to the herd are heifers and half are steers (*.5). All of the steer calves (SELLCALFM(T)) and all of the heifer calves, less those retained as replacement heifers for the subsequent year (SELLCALFF(T)+REPL(T+1)) are sold.

(COW(T)+FIRST(T))*CLF*.5=E=SELLCALFF(T)+REPL(T+1) (35)

(COW(T)+FIRST(T))*CLF*.5=E=SELLCALFM(T) (36)

Equation 37 calculates the annual quantity of yearling replacement heifers retained in the herd during any given year. Yearlings are those heifer calves maintained in the herd for a year after birth, pregnancy tested in the fall and either held in the herd for next year as first-calf heifers (FIRST(T+1)) or are sold as yearling heifers (SELLYEAR(T)).

REPL(T)=E=FIRST(T+1)+SELLYEAR(T) (37)

Low initial conception rates for heifers and the rancher's desire to maintain only the best replacements for his herd, force the model ranch to cull at least 25% of the possible replacement heifers each year (SELLYEAR(T)). Equation 38 serves to uphold the sale of at least 25% of the replacement heifers in the herd each year.

$$SELLYEAR(T)=G=.25*REPL(T) \quad (38)$$

Using a culling rate (CULL) of at least 15%, Equation 39 conditions the model to sell a minimum number of mature cows (COW(T)+FIRST(T)) during each control period (SELLCOW(T)).

$$SELLCOW(T)=G=(COW(T)+FIRST(T))*CULL \quad (39)$$

Equation 40 transfers the stock of cows (COW(T)) from one decision period (t_n) to the next (t_{n+1}). It equates the number of cows in the herd in the current control period (T) to the amount of surviving cows and first-calf heifers in the herd last period ((COW(T-1)+FIRST(T-1))*(1-DEATH)), less the amount sold during the last period (SELLCOW(T-1)). The death loss of mature cows in the herd is assumed to be 1% (DEATH).

$$COW(T)=E=((COW(T-1)+FIRST(T-1))*(1-DEATH))-SELLCOW(T-1) \quad (40)$$

The model limits the number of first-calf heifers (FIRST(T)) in the herd to less than or equal to 33% in any given year through Equation 41. This condition is employed because research has shown that first-calf heifers tend to have lower calf survival rates and it is assumed that the rancher desires a consistent calf-crop from his herd (Stillings et al. 2003).

$$FIRST(T)=L=.33*(COW(T)+FIRST(T)) \tag{41}$$

Herd size (HERD(T)) is determined by Equation 42, by summing the total number of cows (COW(T)), first-calf heifers (FIRST(T)) and replacement heifers (REPL(T)) present in the herd in each control period (T).

$$HERD(T)=E=COW(T)+FIRST(T)+REPL(T) \tag{42}$$

RESEARCH CONCLUSIONS

Objective Review and Results Analysis

The primary objective of this research is to help ranchers, public agencies and stakeholders recognize the economic tradeoffs that exist at the ranch level when an operator adopts grazing strategies intended to improve the management and ecological condition of a riparian pasture. Three riparian grazing strategies were analyzed using a regionally and temporally specified bio-economic model. Model runs were conducted under various environmental and economic conditions. Comparable runs were conducted for each of the three strategies using analogous states of nature. The resultant net present value (NPV), annual net revenue and the optimal herd size were documented and evaluated.

The economic comparison presented relies upon the total NPV of the ranching operation over the 60-year planning horizon, as well as the long-term equilibrium values of key decision variables, namely the long-run annual net revenue (NR(T)), the terminal value of the herd (TERM), the herd size (HERD(T)) and the herd's annual forage demand (X(L,T)). Income results (NPV, long-run NR(T) and TERM) from the modeling process are presented in Table 17. The data are displayed from left to right in order of grazing management option, rainfall condition and market prices.

Table 17: Modeled income values over the 60-year planning horizon, listed by management option, under various rainfall and price scenarios, using a 7% discount rate.

	States of Nature		Income Value		
Mgt. Option	**Rainfall**	**Prices**	**NPV**	**L-R Annual***	**Term. Value**
Early	Drought	Low	$161,910.83	varies	$15,486.99
		Normal	$475,017.13	$32,913.73	$15,494.63
		High	$929,577.07	$65,308.46	$15,606.16
	Normal	Low	$159,857.51	varies	$15,486.99
		Normal	$490,589.95	$36,048.93	$15,467.87
		High	$981,942.83	$71,718.70	$15,648.53
	Wet	Low	$155,961.10	varies	$15,486.99
		Normal	$506,391.29	$39,517.96	$15,527.50
		High	$1,036,702.58	$78,811.52	$15,651.51
Late	Drought	Low	$165,406.95	varies	$15,486.99
		Normal	$480,470.39	$32,943.10	$15,492.36
		High	$929,827.81	$64,840.40	$15,580.01
	Normal	Low	$164,090.82	varies	$15,486.99
		Normal	$496,463.16	$35,999.70	$15,478.71
		High	$981,083.79	$71,037.94	$15,649.51
	Wet	Low	$160,921.88	varies	$15,486.99
		Normal	$512,706.30	$39,381.77	$15,494.45
		High	$1,035,312.85	$77,895.40	$15,648.84
Late w/H_2O	Drought	Low	$171,893.62	varies	$15,486.99
		Normal	$506,451.24	$34,783.67	$15,492.36
		High	$962,553.86	$67,158.37	$15,650.74
	Normal	Low	$170,577.50	varies	$15,486.99
		Normal	$524,709.25	$38,064.67	$15,478.71
		High	$1,016,553.76	$73,627.32	$15,649.51
	Wet	Low	$167,408.56	varies	$15,486.99
		Normal	$543,388.43	$41,695.16	$15,471.22
		High	$1,073,736.04	$80,785.10	$15,648.84

*At low market prices, long-run annual income never reached equilibrium and continued to vary over the planning horizon.

At the outset of each model run there exists a short adjustment period within which the decision variables deviate from their initial starting values. At the end of the adjustment period the variables stabilize to their long-term equilibrium level. The initial adjustment period in the ranch model occurs over the first four years of the run.

Towards the end of each run a final adjustment of variables occurs. This final adjustment occurs during the last four years of the run to capitalize on the model's ability to over utilize the public riparian forage resource (L5) in year 60 and not incur an economic penalty, thereby maximizing the herd size and profiting on its final sale in year 60 (see explanation and use of Equation 17 together with 22 and 23). An example of these adjustment processes can be seen in raw output data provided in Appendix B.

Under all rainfall and market scenarios tested, late summer grazing of riparian pasture with off-stream water development yields the highest comparable net present value (NPV). Late seasonal grazing produced the second highest comparable NPV except under normal and wet rainfall conditions during high market prices, in which case early seasonal grazing yields a slightly higher NPV. Only small differences exist between comparable NPVs of the early and late seasonal grazing options (0.03 to 3.08%). A clear economic choice between the two strategies does not exist.

Long-run annual net income varies under low market prices for all management options and under all rainfall conditions. When low prices are encountered, a long-run equilibrium does not exist. Facing low prices, the ranch model optimizes the objective by selling off the herd to reduce variable costs. Under low prices, the solution output illustrates a continuing decline in the herd size until midway through the planning horizon, at which point the model elects to grow the herd to capitalize on revenues generated from sale of the operation in the final year. Although the model is finding an optimal solution, long-run annual income equilibrium is not achieved. This "variable" annual income affect at low prices is evident across all three of the management options studied. Table 18 provides an example of annual income variability due to low market prices. Based the summary statistics provided, the model ranch averages an annual loss over the 60-year period and experiences very high annual income variability (e.g., a high standard deviation).

Table 18: An example of variable annual income over 60-year period due to low market prices, using a normal rainfall scenario.

	Annual Income and Statistical Variation		
Mgt. Option	**Average**	**Median**	**Std. Deviation**
Early	$-500.16	$-2662.07	$14060.90
Late	$-316.33	$-2530.33	$14150.82
Late w/H_2O	$-186.29	$-2937.34	$14593.63

Long-run annual net income is highest under late summer grazing with off-stream water development, presumably attributed to higher expected weight gains associated with that management option. In all but one scenario, normal prices under drought conditions, early seasonal grazing offers the second highest long-run annual net income. The apparent differences in NPV and long-run annual net income between the early and late seasonal grazing options result from the initial and ending adjustment periods of the model's decisions variables, the long-run herd size and the terminal value of the herd at the end of the planning horizon.

The calculated size of the long-run equilibrium herd is dependent upon the amount of forage available. The factors affecting forage availability include variable rainfall conditions, seasonal accessibility of the riparian pasture, utilization ratios between the upland and riparian pasture and the quantity of public rangeland initially available to the ranch. For the purpose of this analysis, the quantity of public rangeland is held constant across all three management options studied. Other factors that determine forage availability, (i.e., rainfall condition, season of use and utilization) are considered under each model run specific to the management option studied. Table 19 lists the equilibrium herd values determined by the ranch model.

Table 19: Composition of the equilibrium herd, listed by management option, under various rainfall and price scenarios, using a 7% discount rate.

	States of Nature		Annual L-R Equilibrium Herd Size		
Mgt. Option	**Rainfall**	**Prices**	**Herd**	**Cows Culled**	**Calves Sold**
Early	Drought	Low	varies	varies	varies
		Normal	364	45	201
		High	364	45	201
	Normal	Low	varies	varies	varies
		Normal	401	50	221
		High	401	50	221
	Wet	Low	varies	varies	varies
		Normal	441	55	244
		High	441	55	244
Late & Late w/H_2O	Drought	Low	varies	varies	varies
		Normal	357	44	197
		High	357	44	197
	Normal	Low	varies	varies	varies
		Normal	392	48	217
		High	392	48	217
	Wet	Low	varies	varies	varies
		Normal	431	53	238
		High	431	53	238

The largest optimal herd exists under the early grazing management option under wet rainfall conditions, most likely the result of lower projected utilization of the riparian forage base and ample forage yields resulting from higher rainfall. Both the late and late with off-stream water development options result in the same herd size under comparable rainfall and price conditions. Thus, the only difference in NPV and annual income between late and late with off-stream water development is the cost of pumping and added revenue from increased cattle performance in the late with off-stream water option. As expected, drought conditions support smaller herd sizes.

The amount of forage utilized by the model ranch is provided in Table 20. All three management options utilize owned and privately leased rangeland to the greatest extent possible, reaching the upper constraint levels of those supply sources under all rainfall and market conditions. The model also maximizes use of available public summer forage based upon the herd's demand, observed utilization ratios and the use limitations associated with the resource. Table 20 also shows the annual amount of hay used (i.e., purchased by the rancher) to sustain the optimal herd over winter. In all scenarios examined, the model chooses to over-utilize the riparian pasture in the final year of operation. This is an economically rational decision, as the penalty for doing so does not result in a cost to the operation given the entire herd is sold later that same year and no riparian forage is needed in year 61. The last column in Table 20 lists the amount of riparian forage consumed over the utilization limit by the herd in year 60. If the rancher is certain he/she will not return the herd to the public forage allotment, the riparian forage resource is used above allowable standards.

Table 20: Forage supply utilized by the equilibrium herd, listed by management option, under various rainfall and price scenarios, using a 7% discount rate.

	States of Nature		Forage Supply Utilized (AUDs)				
Mgt. Option	**Rainfall**	**Prices**	**Owned**	**Public**	**Private**	**Hay**	**Over (yr 60)**
Early	Drought	Low	varies	varies	varies	varies	varies
		Normal	31740	31999	10350	52871	958
		High	31740	31999	10350	52871	958
	Normal	Low	varies	varies	varies	varies	varies
		Normal	31740	39489	10350	58216	1182
		High	31740	39489	10350	58216	1182
	Wet	Low	varies	varies	varies	varies	varies
		Normal	31740	47777	10350	64130	1430
		High	31740	47777	10350	64130	1430
Late & Late w/H_2O	Drought	Low	varies	varies	varies	varies	varies
		Normal	31740	30563	10350	51847	1312
		High	31740	30563	10350	51847	1312
	Normal	Low	varies	varies	varies	varies	varies
		Normal	31740	37718	10350	56952	1620
		High	31740	37718	10350	56952	1620
	Wet	Low	varies	varies	varies	varies	varies
		Normal	31740	45634	10350	62601	1959
		High	31740	45634	10350	62601	1959

Sensitivity analysis was conducted to assess any change in the optimal management choice as a result of varying future returns (i.e., opportunity costs) by using three alternative discount rates. Rates of 3, 7, and 10% were applied to the model to signify low, medium and high discount rates (see Table 11 along with Equation 16). The model was run for each of the three rates under conditions of normal rainfall and average prices. Table 21 reports the findings of the sensitivity analysis by management option and by the discount rate applied.

Table 21: The model's sensitivity to changes in the discount rate, under normal rainfall and average market prices.

	Discount Rate	Comparable Income Values		
Mgt. Option		NPV	L-R Annual	Term. Value
Early	3%	$1,325,306.91	$36,048.93	$359,123.33
	7%	$490,589.95	$36,048.93	$15,467.87
	10%	$338,347.05	$32,861.45	$2,059.25
Late	3%	$1,329,447.62	$35,999.70	$359,145.73
	7%	$496,463.16	$35,999.70	$15,478.71
	10%	$343,745.49	$32,722.43	$2,060.77
Late w/H_2O	3%	$1,386,130.27	$38,064.67	$359,145.73
	7%	$524,709.25	$38,064.67	$15,478.71
	10%	$361,594.03	$34,462.75	$2,060.77

Late seasonal grazing with off-stream water development remains the optimal strategy under each of the discounting scenarios tested. Late seasonal grazing is slightly preferred over early grazing based upon total NPV of the operation. Within comparable rates, similar to income reported in Table 17, early grazing management is valued second in long-run annual income, but only a fraction above that of the late grazing option. The terminal values for the late and late with off-stream water development are the same under equivalent discount rates, as both hold equal herd sizes in the final year of operation. Table 21 shows how discounting affects the present value of future returns. The lower the discount rate used, the higher the economic value of income derived in the future. The calculated NPV and terminal value are inversely related to changes applied to the model's discount rate.

The Lagrangian-multiplier method used to solve the ranch model (see discussion and use of Equations 5 and 6) provides a unique interpretive opportunity of the solution output. Evaluation of the Lagrangian operators employed to resolve the model's over-determined set of equations reveals useful economic information. Analysis of the Lagrangian-multiplier associated with each constraint in the model provides a measure of sensitivity to a unit shift or change in that resource constraint. Under the auspice of optimization theory, the Lagrangian-multiplier can further be interpreted as a benefit-cost ratio for factor inputs. The Lagrangian-Multiplier illustrates how a relaxation of an input constraint would affect the value of the objective function, essentially providing the "shadow price" of the relaxed constraint. For purposes of this analysis, two shadow prices from the solution output are examined and provided in Table 22 and 23.

Table 22: Shadow price of land per AUD under normal rainfall conditions and average market prices.

	Marginal Value by Source (AUDs)		
Mgt. Option	**Owned**	**Privately Leased**	**Public Allotment**
Early	$3.42	$0.51	$8.29
Late	$3.51	$0.61	$8.67
Late w/H_2O	$3.83	$0.92	$9.94

One binding constraint in the ranch model is the amount of land available to the ranching operation. Table 22 shows the shadow prices associated with owned, privately leased and public allotted pasture for each of the three management options examined. Under conditions of normal rainfall and average market conditions, the shadow prices or benefit-cost ratios of public pasture are considerably higher than those associated with owned or leased pasture. The values presented in Table 22 inform the rancher that if the forage from an additional unit of land (AUD) can be obtained for less than what the shadow price indicates, it would benefit (profit) the rancher to invest in the additional unit of land.

Another constraint offering a useful shadow price interpretation is the starting value or initial number of cows in the herd. At the outset, the ranch model is endowed with 255 cows. The equilibrium herd in all scenarios, except those under low market prices, is higher than the initial number of cows allotted. The model does not allow for the purchase of new stock. Consequently, the rancher is constrained by the initial endowment and the reproductive capacity of the herd. The rancher must grow his/her stock as fast a possible until the optimal, or profit-maximizing, herd is reached. Table 23 lists the shadow prices for the initial number of cows in the herd.

Table 23: Shadow price of the initial number of cows in herd under normal rainfall conditions and average market prices.

	Marginal Value
Mgt. Option	**Cow**
Early	$848.64
Late	$855.23
Late w/H_2O	$882.47

The shadow prices in Table 23 show the added value to the objective function if an additional cow were added to the starting herd. The shadow prices provide the rancher the maximum cost he/she should incur for the purchase of an additional cow under each management option. Purchase of an additional cow above the prices given would decrease the expected NPV of the operation.

The water quality affects on Milk Creek of the three management options studied are provided in Table 24. It should be noted that the measured affects on water quality are specific to Milk Creek and are not necessarily germane to other applications of the same management strategy elsewhere. The difference or net-change method used to assess the effect (see earlier discussion under Environmental Measures along with Equations 10 and 11) accounts for spatial and temporal variability of each chosen parameter. In the case of measured E. coli and total coliform, sample values were mathematically logged to address the inherent exponential growth characteristics of bacterium. Stream flow and nitrate+nitrite water quality component values were not assessed during the 1996-97 late season off-stream water treatments and were therefore not available for comparison during those study years.

Table 24: Average net change in water quality parameters of Milk Creek between the early, late and late with off-stream water management options.

	Measured Water Quality Parameter					
Mgt. Option	**Flow** ft^3/sec	**E. coli** mpn/mL	**Total Coliform** mpn/mL	**Total Phosphorous** mg/L	**Ortho Phosphorus** mg/L	**Nitrate + Nitrite** mg/L
Early	-3.4	0.051	0.861	0.037	-0.003	-0.007
Late	-0.3	1.172	0.642	-0.005	-0.004	0.008
Late w/H_2O	n/a*	-0.315	0.817	-0.007	0.003	n/a*

* Parameter not studied under this management option trial.

Late season grazing and late season grazing with off-stream water exhibited the lowest net average change in total coliforms and E. coli respectively. Both the early and late season grazing treatments showed measured declines in ortho phosphorous. Late season grazing demonstrated an overall net decline in the presence of total phosphorous. Interestingly, late season grazing with off-stream water exhibited lower net change in total phosphorus, yet higher differences in ortho phosphorus. The reason for this difference is unknown. Although early season grazing offered the lowest measured net difference in nitrate+nitrite, it is not known how off-stream water treatments affected the parameter, as it was not monitored during those trial periods.

The flow of Milk Creek decreased during the early grazing trial, yet remained fairly constant throughout the late grazing period. It is not know how the change in stream flow influenced the water quality results.

Choosing the optimal grazing strategy to manage solely for water quality would depend upon the parameter of concern. If bacterium concentration was a water-quality limiting factor, a late season grazing treatment would be the preferred management choice on Milk Creek. If phosphorous was a significant concern, the optimal choice would remain the same, a late grazing or late grazing with off-stream water would be the better management choice. The optimal choice is less obvious when managing for nitrate+nitrite as the effect of off-stream water development on this parameter is unknown. Based solely on the results presented, it appears that early season grazing would be preferred over late season if the objective were to reduce the likelihood of nitrate+nitrite from entering the stream. Given the results obtained from the water quality monitoring, it is not clear which management practice would be preferred overall along Milk Creek. The results suggest that the most favorable strategy is the one that best addresses the water-quality limiting factor of highest concern.

A brief summary of cattle distribution indicators assessed during the study is provided in Table 25. The indicators provided are average distance from the stream, forage utilization ratio between riparian and upland forage and streamside fecal counts. The indicators are presented as averages and provide a simple comparative analysis of cattle dispersion within the treatment pastures. The values were derived from empirical data collected by Parsons et al. (2003) during the early and late seasonal trials and Porath et al. (2002) during the off-stream water trials.

Table 25: A comparison of measured cattle distribution indicators between the early, late and late with off-stream water management options, using empirical data from Parsons et al. (2003) and Porath et al. (2002).

	Measured Cattle Distribution Indicators		
Mgt. Option	**Distance from Stream [(a)]**	**Forage Utilization Ratio R/U [(b)]**	**Streamside Fecal Count [(c)]**
Early	161m (528ft)	0.89	33
Late	99m (325ft)	1.45	80
Late w/H_2O	145m (475ft)	0.70	81

(a) Mean estimate, derived from GIS data, (b) Mean estimation across riparian (R) and upland (U) vegetation types, (c) Mean # of pies, within 1m of waters edge.

Cattle foraging the riparian pasture early in the grazing season tended to roam greater distances from the stream compared to cattle that grazed later in the season. Providing off-stream water during late season grazing is more successful at distancing cattle from the stream. Forage utilization estimates did not imitate the distance from stream results. One reason for this may be that Parsons et al. (2003) and Porath et al. (2002) used different methods to assess forage utilization. Porath et al. (2002) randomly located 15 (0.25m^2) plots pre and post-grazing to determine utilization. Parsons et al. (2003) on the other hand, collected an average of 387 post-grazing ocular utilization estimations in each treatment pasture. Based upon Parsons et al. (2003) and Porath et al. (2002) utilization assessments, cattle favored the uplands over the riparian area during both the early and the late with off-stream water treatments. Cattle grazing in pastures with off-stream water showed the greatest preference for upland forage. During late season grazing, cattle favored riparian forage over that of uplands. Streamside fecal counts revealed that cattle spent much less time near the stream during early seasonal grazing compared with both the late and late with off-stream water trials. Fecal count results run counter to monitored changes in chemical water quality parameters yet contradict the measured bacterium levels. The distribution indicators provided depict that early season grazing is most effective at dispersing cattle away from the stream corridor. Greater detail on cattle behavior and distribution results obtained from the study can be found in the works of Parsons et al. (2003) and Porath et al. (2002).

RESULTS SUMMARY

Results from the modeling effort showed a difference in expected economic returns among the three riparian grazing strategies studied. Of the three grazing management strategies studied, late summer grazing of riparian pasture with off-stream water development yielded the highest comparable net present value across all twenty-seven rainfall and market price scenarios considered. Among the scenarios examined, late summer grazing with off-stream water generated profits 3.4 to 5.6% higher than the next best scenario. Although differences in NPV were not substantial, it would be in the rancher's economic interest to graze riparian areas late in the season and provide an off-stream watering source.

Measured differences in NPV between early and late seasonal riparian grazing vary as little as 0.03 to 3.08% among comparable rainfall and market price scenarios. Late seasonal grazing was slightly preferred economically over early grazing in all but two of the twenty-seven runs conducted. Only under conditions of wet or normal rainfall under high market prices does early seasonal grazing yield a higher NPV. Given the slight economic differences between the early or late seasonal grazing strategies, the rancher may wish to elect one over the other or some rotational combination of both based upon management style rather than expected economic yield.

Under low market prices, the ranch model appears to be operating on the margin. When parameterized with low prices, the operation maximizes NPV by selling-off the herd to reduce variable costs associated with each cow in the herd. If low prices are sustained and the model allowed it, the ranching operation would likely cease production and go out of business.

The model demonstrated no sensitivity to changes in the discount rate. Late season grazing with off-stream water remained the optimal management strategy under each of the three discounting scenarios tested. As anticipated, changes to the discount rate inversely affected the present value of future returns for each of the three strategies studied. The resulting changes in NPV did not shift the optimal grazing strategy. Presumably because revenue derived from each of the three management strategies is acquired annually and at a relatively consistent rate throughout the 60-year planning horizon.

Water quality monitoring results did not clearly favor one management option over another and remain inconclusive. The optimal strategy varies depending upon the water-quality limiting factor of highest concern. Overall, late season grazing and late season grazing with off-stream water are preferred over early season grazing due to lower net changes in bacterium and phosphorous concentrations. Early season grazing offers better control of nitrate+nitrite then late season grazing, but the affect of late season grazing with off-stream water is not known for comparison.

Cattle distribution indicators including, average distance from stream and streamside fecal counts, point toward early season grazing as the most effective strategy at dispersing cattle away from the stream corridor and farthest from the riparian area. Forage utilization results were less conclusive and may not be comparable because methods of assessment varied between the 1996-97 off-stream water study and the 1998-99 season of use study (Parsons et al. 2003 and Porath et al. 2002).

APPLICABILITY, FUTURE RESEARCH AND COMMENTS

This thesis utilizes basic production relationships and reasonable complexity to develop a simplified but useful characterization of a cattle ranching operation. The research is unique in that it uses a GAMS (General Algebraic Modeling System) approach to assess cattle grazing economics at the ranch level. The modeling process attempts to mimic expected market and natural environmental conditions where possible. Acceptance of the model requires recognition of its simplifying assumptions and inherent limitations. The results should be viewed as a case study with some level of constructive uncertainty.

The ranching model presented can be improved by incorporating additional complexity. One recognized improvement would be to allow for variable production expenses over the course of a single year. This could be achieved by increasing the model's decision periods from an annual to a monthly basis. Recurring costs and revenues could then be limited to traditional months of the year, more accurately depicting familiar cash flow patterns experienced by the ranching industry. Another possible improvement would be modifying the model to randomly select varying states of nature based upon their probability or cyclical nature.

The water-quality monitoring results presented can also be improved. The analysis would benefit greatly by understanding historical background levels of the parameters monitored and by contrasting those known levels against measured changes or differences due to alternative grazing management strategies. Additional sampling would further improve the monitoring results. Increasing sample frequency and collecting additional samples within similar channel substrates identified in each of the treated pastures would support the water quality analysis and strengthen the results presented.

No single grazing management system has consistently restored degraded riparian habitat (Leonard et al. 1997). Given the relatively small economic difference between the three grazing strategies studied, a rancher may find it difficult to choose one over the other. A combined use or annual rotation of the management options presented may be an appropriate application considering diverse management styles and unique land constraints facing each rancher.

Successful riparian grazing management plans are by necessity site-specific (Chew 1991, Mosley et al. 1997). A grazing system that works well along one stream-course may be inappropriate along neighboring streams only miles away. Although this research provides ranchers and land managers with useful economic information, the study results are specific to the research site and may be limited in their applicability across diverse social and ecological landscapes. Understanding and recognizing the limitations inherent in this study will assist and improve future research conducted elsewhere on riparian grazing management systems.

Under growing public concern and legal obligation, resource managers are faced with the difficult task of developing and implementing management practices that satisfy the requirements of diverse and often competing interests affecting the use of public lands. The protection of societal interests, such as soil conservation, water quality and other factors of resource sustainability, is possibly the most complicated issue facing public policy makers. The results from this research bring to light economic information that will help public resource managers propose more socially acceptable rangeland policy that is attentive to the economic viability of Northwestern ranching operations.

The most important water-quality protection measures can also be some of the most important practices to preserve the long-term viability of the grazing land resource. Managing grazing lands for sustainable yield of forage and livestock can also achieve optimum water pollution control (Ohlenbusch et al. 1995). The costs of poor grazing management, particularly in highly visible riparian pastures, include not only lost production and profits, but also increased public resentment and legal liability. Conversely, proper grazing management can defuse public criticism and render it meaningless (Chew 1991).

Good management critically depends on constructive feedback, which continually assesses its success (Hodgson and Illius 1996). Judicious management of riparian areas necessitates an ecosystem perspective that evaluates current grazing practices in context with other land uses on an ecological as well as economic basis. The results expressed in this study are based solely upon expected economic returns exclusive to the ranching unit. The private economic benefits presented here ignore perceived public benefits often associated with management intensive riparian grazing systems, such as enhanced wildlife and fisheries habitat and improved water quality.

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APPENDICES

APPENDIX A: MODEL CODE

Three unique models were utilized for this thesis, one for each of the management options compared. Although parameterized differently, the structure of all three models is identical. The example provided below is for the early seasonal grazing option, "Early Grazing Option." Parameter values for the other two management options (i.e. models) are presented in parentheses for reference.

```
*Early Grazing Option
*Model: Average Prices, Normal Rainfall Conditions, 7% Interest Rate
*Jeff Sharp
*Dept. of Agriculture and Resource Economics, Oregon Sate Univ.
*Revision 02/18/03

$offsymxref offsymlist

****Set Section*****************************************************
Set T  Time Periods
/1*60/

L  Forage Supplier
/L1  Owned Spring and Fall Range
L2   Public Lease
L3   Private Lease
L4   Winter Hay
L5   Over Utilize Public Lease/

G  Forage Location
/G1  Riparian Zone
G2   Riparian Upland
G3   Upland1
G4   Upland2/

AS Cattle Age and Sex Sold
/AS1 Cow
AS2 Yearling Heifer
```

```
AS3 Heifer Calf
AS4 Bull Calf/

****Data Section*****************************************************
Scalar
 CLF      Calving % (conception birth rate and death loss) /.884/
 LEASELMT  Limit of AUD from private lease (AUDs)        /10350/
 OWNLMT    Limit of AUD on owned rangeland (AUDs)         /31740/
 CULL      Cull Cow Rate                        /.15/
 DEATH     Cow Death Rate                         /.01/
 COWCST    Variable cost per cow per month less forage cost /17.19/
*Following is altered to reflect variable discounting
 DELTA     Discount Rate                        /.07/
*Following is altered to reflect management option employed
 PCST      Annual water development pump maint cost        /0/;
*(Late /0/)
*(Late w/H2O /438.40/)

*****Discounting****************************************************
Scalar
 DISC     Discount;
 DISC = 1/(1+DELTA);
Display DISC;
Parameter RHO(T) Discount Factor;
 RHO(T) = DISC**(ORD(T));

Parameter CP(T) Control period;
 CP(T)=ORD(T)$(ORD(T) GT 1);

*****Three States of Nature*******************************************
Scalar
 Precp   Median Precipitation of crop year      /12.59/

****Drought
*  Rain                       /10.43/;
****Normal
  Rain                        /12.59/;
****Wet
*   Rain                       /14.98/;

*****Market Parameters***********************************************

*****Cattle Weights*****
Parameter
```

```
WT(AS) Selling weights (100's lbs) by management
*Following is altered to reflect management option employed
/AS1  10.74
AS2  8.00
AS3  6.15
AS4  6.92/
*(Late /AS1  10.78, AS2  8.00, AS3  6.18, AS4  6.95/;)
*(Late w/H2O /AS1  10.95, AS2  8.00, AS3  6.32, AS4  7.04/;)

*****Cattle prices per 100wt*****
Scalar
**Low prices
*MKTCOW   /31.00/
*MKTCALFF  /69.36/
*MKTCALFM  /78.31/;
**Average prices
MKTCOW   /44.43/
MKTCALFF  /86.26/
MKTCALFM  /96.93/;
**High prices
*MKTCOW   /57.85/
*MKTCALFF  /103.16/
*MKTCALFM  /115.54/;

*****Cost and Field Data**********************************************
Parameter
 C(L) Cost of forage per AUD by supplier
 / L1  .0910
   L2  .1870
   L3  .2976
   L4  .8644
   L5  .0000/

 YIELD(G) Normal yield dry lbs forage per acre on pub lease (Sneva and Hyder
index)
 /G1  1158.8
  G2  722.5
  G3  722.5
  G4  722.5/;

Parameter Utilstd(G) Utilization standard on Public Lease (USFS allotments)
/G1  .35
 G2  .50
 G3  .50
```

```
 G4  .50/;

Scalar
*Following is altered to reflect management option employed
Riputil Utilization Ratios on riparian area by management     /.32/
*(Late /.51/)
*(Late w/H2O /.35/)
*Following is altered to reflect management option employed
Uputil  Utilization Ratios on upland area by management      /.36/;
*(Late /.35/)
*(Late w/H2O /.50/)

Parameter GLA(G) Percent forage Growth (from GLA) avail by mgt option
*Following is altered to reflect management option employed
/G1  .73
 G2  .73
 G3 1.00
 G4 1.00/;
*(Late /G1  1.00, G2  1.00, G3   .73, G4  1.00/;)
*(Late w/H2O /G1  1.00, G2  1.00, G3   .73, G4  1.00/;)

Parameter
  Acre(G) 3% Riparian zone in summer pastures
 /G1  87
  G2  568
  G3  1118
  G4  1118/;

****Variable Section****************************************************

Variables
  Z              Objective function Total Gross Margin
  SELLCALFF(T)    Number of heifer calves sold in each year
  SELLCALFM(T)    Number of steer calves sold  in each year
  SELLCOW(T)      Number of cows culled in each year
  SELLYEAR(T)     Number of yearling heifers culled
  COW(T)          Mature cows in herd each year
  HERD(T)         Herd size each year
  REPL(T)         Number of calves in herd for replacement
  FIRST(T)        First calf heifers in each year
  TERM            Terminal Value
  NR(T)           Yearly gross margin
  VARCST(T)       Total variable costs per year by management
  INCOME(T)       Income for each year by management
```

```
 X(L,T)          AUDs of forage consumed by herd by source
 SUMFOR(G,T)     Lbs of forage on public lease
 OVERUSE(T)      AUDs of forage utilize above public limit
 OVER(G,T)       Over utilization rate on public lease;

Positive Variable
SELLCALFF,SELLCALFM,SELLCOW,SELLYEAR,COW,HERD,
           REPL,FIRST,X,SUMFOR,OVERUSE,OVER;

****Equation Section**************************************************

Equations
 Profit        Objective Function Maximize total gross margin
 Inc(T)        Income Equation
 Vari(T)       Variable Costs
 Resource(T)   Resource Constraints on Ranch
 SDForage(T)   Forage S_D
 Summer(G,T)   Summer forage from public lease
 Overfor(T)    AUDs public lease forage used above util lmts
 Ratio(T)      Fixed ratio between riparian and upland utilization
 Overlmt(T)    Over utilization lmt of pub lease is set at .75
 Own(T)        Land constraint
 Permit(T)     AUDs available on Permitted land
 Private(T)    Limit to amount of leased AUDs
 Winter(T)     Feeding hay constraint
 Overgrz(T)    Number of AUDs over grazed on pub lease (L5)
 TermV         Terminal value Of ranching operation in yr 60
 Net(T)        Gross margin
 Initial1      Initial number of mature cows
 Initial2      Initial number of first calf cows
 Initial3      Initial number of replacement cows
 FCalves(T)    Female calf crop by management in year t
 MCalves(T)    Male calf crop by management in year t
 Yearling(T)   Yearling decision by management in year t
 Cowsell(T)    Mature cow culling rate by management in year t
 Herds(T)      Number of cows
 Oldcow(T)     First year heifers are less than a third of herd
 Year(T)       Cull part of the yearlings
 Herd1         Herd size;

Profit..       Z=E=Sum(T,NR(T)*RHO(T))+TERM;
Inc(T)..       INCOME(T)=E=

(((SELLCOW(T)*WT('AS1'))+(SELLYEAR(T)*WT('AS2')))*MKTCOW)+
```

```
            ((SELLCALFF(T)*WT('AS3'))*MKTCALFF)+
            ((SELLCALFM(T)*WT('AS4'))*MKTCALFM);
Vari(T)..     VARCST(T)=E=
            (12*(COWCST*(COW(T)+FIRST(T))))+Sum(L,X(L,T)*C(L));

*Terminal value of ranch in Yr 60 (NR infanitly Disc - NR Disc over 60yr)
TermV..       TERM=E=((COW('60')+FIRST('60')-SELLCOW('60'))*181.42)
            *((1/DELTA)-((1/DELTA)-((1/DELTA)*(1/((1+DELTA)**60)))));
Net(T)..      NR(T)=E=(INCOME(T)-VARCST(T)-PCST);
Resource(T).. HERD(T)=L=500;

****Forage Equations*************************************************
*AUDs of forage available in Summer pastures at time of grazing
Summer(G,T).. SUMFOR(G,T)=E=((((((((rain/precp)*111)-10.6)/100)
                  *YIELD(G))*ACRE(G))*GLA(G))
                  *(UTILSTD(G)-2*OVER('G1',T-1)))/25;

Overfor(T).. OVERUSE(T)=E=((((((((rain/precp)*111)-10.6)/100)
                  *YIELD('G1'))*ACRE('G1'))*GLA('G1'))
                  *OVER('G1',T))/25;

*A fixed utilization ratio exists between riparian and upland forage
*depending upon the management choice (calc from field util estimations)
Ratio(T)..    OVER('G1',T)*UPUTIL=E=
          OVER('G2',T)*RIPUTIL;

*Utilization is limited on the riparian area to %75
Overlmt(T)..  OVER('G1',T)+UTILSTD('G1')=L=.75;

*There must be enough forage to support herd all year (D-S=L=0)
SDForage(T).. (365*(Cow(T)+FIRST(T)+.75*REPL(T)))-SUM(L,X(L,T))=L=0;
Own(T)..      X('L1',T)=L=OWNLMT;
Permit(T)..   X('L2',T)=E=SUM(G,SUMFOR(G,T));
Private(T)..  X('L3',T)=L=LEASELMT;
*There must be enough Hay to sustain herd through Winter (D-S=L=0)
Winter(T)..   X('L4',T)=G=(152*(COW(T)+FIRST(T)+.75*REPL(T)));
Overgrz(T)..  X('L5',T)=E=OVERUSE(T);

****Initial Values
Initial1..    COW('1')=E=255;
Initial2..    FIRST('1')=E=45;
Initial3..    REPL('1')=E=60;

****Marketing Decision Equations
```

```
FCalves(T)..   (COW(T)+FIRST(T))*CLF*.5=E=SELLCALFF(T)+REPL(T+1);
MCalves(T)..   (COW(T)+FIRST(T))*CLF*.5=E=SELLCALFM(T);
Yearling(T)..  REPL(T)=E=FIRST(T+1)+SELLYEAR(T);
Cowsell(T)..   SELLCOW(T)=G=(COW(T)+FIRST(T))*CULL;
Herds(T)$(CP(T) GT 1)..
          COW(T)=E=((COW(T-1)+FIRST(T-1))*(1-DEATH))
               -SELLCOW(T-1);
*The use of the operator $ in identifier above conditions the equation to be true only
*when the control period (T) is greater than (GT) one (1)
Oldcow(T)..    FIRST(T)=L=.33*(COW(T)+FIRST(T));
Year(T)..      SELLYEAR(T)=G=.25*REPL(T);
Herd1(T)..     HERD(T)=E=COW(T)+FIRST(T)+REPL(T);

Model Grazeopt /all/;
*Selects # of equations printed in list file
option limrow = 3;
*Selects # of columes to print showing how vars enter equations
option limcol = 0;
*Selects to enable printing of marginal values
option solprint = off;
*Selects solver as minos5
option nlp=minos5;
Solve Grazeopt Using nlp Maximizing Z;

Parameter
Report Solution Summary;
Report(T,"Herd Size") = HERD.L(T);
Report(T,"Number of Cows in Herd") = COW.L(T);
Report(T,"First Calf Heifers in Herd") = FIRST.L(T);
Report(T,"Replacement Calves in Herd") = REPL.L(T);
Report(T,"Cows Culled") = SELLCOW.L(T);
Report(T,"Calves Sold") = SELLCALFF.L(T)+SELLCALFM.L(T);
Report(T,"Yearlings Culled") = SELLYEAR.L(T);
Report(T,"Annual Gross Margin") = NR.L(T);

Display Report;
Display X.L, Z.L, TERM.L, OVER.L, OVERUSE.L;
```

APPENDIX B: SOLUTION OUTPUT

Three unique models were utilized for this thesis, one for each of the management options compared. Although parameterized differently, the structure of all three models is identical. The example provided below is the solution output for the early seasonal grazing option, "Early Grazing Option." The output first illustrates how calculations are performed using the coded equations, the exogenous variables and the parameters, secondly the output provides the value of the endogenous or state variables of the model.

```
----    49 PARAMETER DISC          =      0.935 Discount

---- PROFIT    =E=  Objective Function Maximize total gross margin

PROFIT..  Z - TERM - 0.9346*NR(1)
    - 0.8734*NR(2) - 0.8163*NR(3) - 0.7629*NR(4) - 0.713*NR(5)
    - 0.6663*NR(6) - 0.6227*NR(7) - 0.582*NR(8) - 0.5439*NR(9)
    - 0.5083*NR(10) - 0.4751*NR(11) - 0.444*NR(12) - 0.415*NR(13)
    - 0.3878*NR(14) - 0.3624*NR(15) - 0.3387*NR(16) - 0.3166*NR(17)
    - 0.2959*NR(18) - 0.2765*NR(19) - 0.2584*NR(20) - 0.2415*NR(21)
    - 0.2257*NR(22) - 0.2109*NR(23) - 0.1971*NR(24) - 0.1842*NR(25)
    - 0.1722*NR(26) - 0.1609*NR(27) - 0.1504*NR(28) - 0.1406*NR(29)
    - 0.1314*NR(30) - 0.1228*NR(31) - 0.1147*NR(32) - 0.1072*NR(33)
    - 0.1002*NR(34) - 0.0937*NR(35) - 0.0875*NR(36) - 0.0818*NR(37)
    - 0.0765*NR(38) - 0.0715*NR(39) - 0.0668*NR(40) - 0.0624*NR(41)
    - 0.0583*NR(42) - 0.0545*NR(43) - 0.0509*NR(44) - 0.0476*NR(45)
    - 0.0445*NR(46) - 0.0416*NR(47) - 0.0389*NR(48) - 0.0363*NR(49)
    - 0.0339*NR(50) - 0.0317*NR(51) - 0.0297*NR(52) - 0.0277*NR(53)
    - 0.0259*NR(54) - 0.0242*NR(55) - 0.0226*NR(56) - 0.0211*NR(57)
    - 0.0198*NR(58) - 0.0185*NR(59) - 0.0173*NR(60) =E= 0 ; (LHS = 0)

---- INC       =E=  Income Equation

INC(1)..  - 530.499*SELLCALFF(1) - 670.7556*SELLCALFM(1) -
477.1782*SELLCOW(1)
    - 355.44*SELLYEAR(1) + INCOME(1) =E= 0 ; (LHS = 0)
INC(2)..  - 530.499*SELLCALFF(2) - 670.7556*SELLCALFM(2) -
477.1782*SELLCOW(2)
```

```
    - 355.44*SELLYEAR(2) + INCOME(2) =E= 0 ; (LHS = 0)
INC(3)..  - 530.499*SELLCALFF(3) - 670.7556*SELLCALFM(3) -
477.1782*SELLCOW(3)
    - 355.44*SELLYEAR(3) + INCOME(3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- VARI        =E=  Variable Costs

VARI(1)..  - 206.28*COW(1) - 206.28*FIRST(1) + VARCST(1) - 0.091*X(L1,1)
    - 0.187*X(L2,1) - 0.2976*X(L3,1) - 0.8644*X(L4,1) =E= 0 ; (LHS = 0)
VARI(2)..  - 206.28*COW(2) - 206.28*FIRST(2) + VARCST(2) - 0.091*X(L1,2)
    - 0.187*X(L2,2) - 0.2976*X(L3,2) - 0.8644*X(L4,2) =E= 0 ; (LHS = 0)
VARI(3)..  - 206.28*COW(3) - 206.28*FIRST(3) + VARCST(3) - 0.091*X(L1,3)
    - 0.187*X(L2,3) - 0.2976*X(L3,3) - 0.8644*X(L4,3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- RESOURCE    =L=  Resource Constraints on Ranch

RESOURCE(1)..  HERD(1) =L= 500 ; (LHS = 0)
RESOURCE(2)..  HERD(2) =L= 500 ; (LHS = 0)
RESOURCE(3)..  HERD(3) =L= 500 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- SDFORAGE    =L=  Forage S_D

SDFORAGE(1)..  365*COW(1) + 273.75*REPL(1) + 365*FIRST(1) - X(L1,1) -
X(L2,1) - X(L3,1) - X(L4,1) - X(L5,1) =L= 0 ; (LHS = 0)
SDFORAGE(2)..  365*COW(2) + 273.75*REPL(2) + 365*FIRST(2) - X(L1,2) -
X(L2,2) - X(L3,2) - X(L4,2) - X(L5,2) =L= 0 ; (LHS = 0)
SDFORAGE(3)..  365*COW(3) + 273.75*REPL(3) + 365*FIRST(3) - X(L1,3) -
X(L2,3) - X(L3,3) - X(L4,3) - X(L5,3) =L= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- SUMMER      =E=  Summer forage from public lease

SUMMER(G1,1)..  SUMFOR(G1,1) =E= 1034.4568 ;
    (LHS = 0, INFES = 1034.4568 ***)
SUMMER(G1,2)..  SUMFOR(G1,2) + 5911.1816*OVER(G1,1) =E= 1034.4568 ;
    (LHS = 0, INFES = 1034.4568 ***)
SUMMER(G1,3)..  SUMFOR(G1,3) + 5911.1816*OVER(G1,2) =E= 1034.4568 ;
    (LHS = 0, INFES = 1034.4568 ***)
REMAINING 237 ENTRIES SKIPPED

---- OVERFOR     =E=  AUDs public lease forage used above util lmts
```

OVERFOR(1).. OVERUSE(1) - 2955.5908*OVER(G1,1) =E= 0 ; (LHS = 0)
OVERFOR(2).. OVERUSE(2) - 2955.5908*OVER(G1,2) =E= 0 ; (LHS = 0)
OVERFOR(3).. OVERUSE(3) - 2955.5908*OVER(G1,3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- RATIO =E= Fixed ratio between riparian and upland utilization

RATIO(1).. 0.36*OVER(G1,1) - 0.32*OVER(G2,1) =E= 0 ; (LHS = 0)
RATIO(2).. 0.36*OVER(G1,2) - 0.32*OVER(G2,2) =E= 0 ; (LHS = 0)
RATIO(3).. 0.36*OVER(G1,3) - 0.32*OVER(G2,3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- OVERLMT =L= Over utilization lmt of pub lease is set at .75

OVERLMT(1).. OVER(G1,1) =L= 0.4 ; (LHS = 0)
OVERLMT(2).. OVER(G1,2) =L= 0.4 ; (LHS = 0)
OVERLMT(3).. OVER(G1,3) =L= 0.4 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- OWN =L= Land constraint

OWN(1).. X(L1,1) =L= 31740 ; (LHS = 0)
OWN(2).. X(L1,2) =L= 31740 ; (LHS = 0)
OWN(3).. X(L1,3) =L= 31740 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- PERMIT =E= AUDs available on Permitted land

PERMIT(1).. X(L2,1) - SUMFOR(G1,1) - SUMFOR(G2,1) - SUMFOR(G3,1)
- SUMFOR(G4,1) =E= 0 ; (LHS = 0)
PERMIT(2).. X(L2,2) - SUMFOR(G1,2) - SUMFOR(G2,2) - SUMFOR(G3,2)
- SUMFOR(G4,2) =E= 0 ; (LHS = 0)
PERMIT(3).. X(L2,3) - SUMFOR(G1,3) - SUMFOR(G2,3) - SUMFOR(G3,3)
- SUMFOR(G4,3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- PRIVATE =L= Limit to amount of leased AUDs

PRIVATE(1).. X(L3,1) =L= 10350 ; (LHS = 0)
PRIVATE(2).. X(L3,2) =L= 10350 ; (LHS = 0)
PRIVATE(3).. X(L3,3) =L= 10350 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- WINTER =G= Feeding hay constraint

WINTER(1).. - 152*COW(1) - 114*REPL(1) - 152*FIRST(1) + X(L4,1) =G= 0 ; (LHS = 0)
WINTER(2).. - 152*COW(2) - 114*REPL(2) - 152*FIRST(2) + X(L4,2) =G= 0 ; (LHS = 0)
WINTER(3).. - 152*COW(3) - 114*REPL(3) - 152*FIRST(3) + X(L4,3) =G= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- OVERGRZ =E= Number of AUDs over grazed on pub lease (L5)

OVERGRZ(1).. X(L5,1) - OVERUSE(1) =E= 0 ; (LHS = 0)
OVERGRZ(2).. X(L5,2) - OVERUSE(2) =E= 0 ; (LHS = 0)
OVERGRZ(3).. X(L5,3) - OVERUSE(3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- TERMV =E= Terminal value Of ranching operation in yr 60

TERMV.. 44.726*SELLCOW(60) - 44.726*COW(60) - 44.726*FIRST(60) + TERM =E= 0 ; (LHS = 0)

---- NET =E= Gross margin

NET(1).. NR(1) + VARCST(1) - INCOME(1) =E= 0 ; (LHS = 0)
NET(2).. NR(2) + VARCST(2) - INCOME(2) =E= 0 ; (LHS = 0)
NET(3).. NR(3) + VARCST(3) - INCOME(3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- INITIAL1 =E= Initial number of mature cows

INITIAL1.. COW(1) =E= 255 ; (LHS = 0, INFES = 255 ***)

---- INITIAL2 =E= Initial number of first calf cows

INITIAL2.. FIRST(1) =E= 45 ; (LHS = 0, INFES = 45 ***)

---- INITIAL3 =E= Initial number of replacement cows

INITIAL3.. REPL(1) =E= 60 ; (LHS = 0, INFES = 60 ***)

---- FCALVES =E= Female calf crop by management in year t

FCALVES(1).. - SELLCALFF(1) + 0.442*COW(1) - REPL(2) + 0.442*FIRST(1) =E= 0 ; (LHS = 0)
FCALVES(2).. - SELLCALFF(2) + 0.442*COW(2) - REPL(3) + 0.442*FIRST(2) =E= 0 ; (LHS = 0)
FCALVES(3).. - SELLCALFF(3) + 0.442*COW(3) - REPL(4) + 0.442*FIRST(3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- MCALVES =E= Male calf crop by management in year t

MCALVES(1).. - SELLCALFM(1) + 0.442*COW(1) + 0.442*FIRST(1) =E= 0 ; (LHS = 0)
MCALVES(2).. - SELLCALFM(2) + 0.442*COW(2) + 0.442*FIRST(2) =E= 0 ; (LHS = 0)
MCALVES(3).. - SELLCALFM(3) + 0.442*COW(3) + 0.442*FIRST(3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- YEARLING =E= Yearling decision by management in year t

YEARLING(1).. - SELLYEAR(1) + REPL(1) - FIRST(2) =E= 0 ; (LHS = 0)
YEARLING(2).. - SELLYEAR(2) + REPL(2) - FIRST(3) =E= 0 ; (LHS = 0)
YEARLING(3).. - SELLYEAR(3) + REPL(3) - FIRST(4) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- COWSELL =G= Mature cow culling rate by management in year t

COWSELL(1).. SELLCOW(1) - 0.15*COW(1) - 0.15*FIRST(1) =G= 0 ; (LHS = 0)
COWSELL(2).. SELLCOW(2) - 0.15*COW(2) - 0.15*FIRST(2) =G= 0 ; (LHS = 0)
COWSELL(3).. SELLCOW(3) - 0.15*COW(3) - 0.15*FIRST(3) =G= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- HERDS =E= Number of cows

HERDS(2).. SELLCOW(1) - 0.99*COW(1) + COW(2) - 0.99*FIRST(1) =E= 0 ; (LHS = 0)
HERDS(3).. SELLCOW(2) - 0.99*COW(2) + COW(3) - 0.99*FIRST(2) =E= 0 ; (LHS = 0)
HERDS(4).. SELLCOW(3) - 0.99*COW(3) + COW(4) - 0.99*FIRST(3) =E= 0 ; (LHS = 0)
REMAINING 56 ENTRIES SKIPPED

---- OLDCOW =L= First year heifers are less than a third of herd

```
OLDCOW(1)..  - 0.33*COW(1) + 0.67*FIRST(1) =L= 0 ; (LHS = 0)
OLDCOW(2)..  - 0.33*COW(2) + 0.67*FIRST(2) =L= 0 ; (LHS = 0)
OLDCOW(3)..  - 0.33*COW(3) + 0.67*FIRST(3) =L= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- YEAR      =G=  Cull part of the yearlings

YEAR(1)..  SELLYEAR(1) - 0.25*REPL(1) =G= 0 ; (LHS = 0)
YEAR(2)..  SELLYEAR(2) - 0.25*REPL(2) =G= 0 ; (LHS = 0)
YEAR(3)..  SELLYEAR(3) - 0.25*REPL(3) =G= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

---- HERD1     =E=  Herd size

HERD1(1)..  - COW(1) + HERD(1) - REPL(1) - FIRST(1) =E= 0 ; (LHS = 0)
HERD1(2)..  - COW(2) + HERD(2) - REPL(2) - FIRST(2) =E= 0 ; (LHS = 0)
HERD1(3)..  - COW(3) + HERD(3) - REPL(3) - FIRST(3) =E= 0 ; (LHS = 0)
REMAINING 57 ENTRIES SKIPPED

Model Statistics    SOLVE GRAZEOPT USING NLP FROM LINE 256

MODEL STATISTICS

BLOCKS OF EQUATIONS     27    SINGLE EQUATIONS     1504
BLOCKS OF VARIABLES     17    SINGLE VARIABLES     1382
NON ZERO ELEMENTS     4559    NON LINEAR N-Z          0
DERIVATIVE POOL          3    CONSTANT POOL           0
CODE LENGTH              1

GENERATION TIME    =    0.160 SECONDS   1.4 Mb    WIN-18-100

EXECUTION TIME     =    0.440 SECONDS   1.4 Mb    WIN-18-100

          S O L V E     S U M M A R Y

   MODEL   GRAZEOPT          OBJECTIVE  Z
   TYPE    NLP               DIRECTION  MAXIMIZE
   SOLVER  MINOS5            FROM LINE  256

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE        490589.9479

 RESOURCE USAGE, LIMIT        2.250     1000.000
```

ITERATION COUNT, LIMIT 734 10000
EVALUATION ERRORS 0 0

MINOS5 Sep 30, 1999 WIN.M5.18.3 105.035.037.WAT GAMS/MINOS 5.4

B. A. Murtagh, University of New South Wales and P. E. Gill, W. Murray, M. A. Saunders and M. H. Wright, Systems Optimization Laboratory, Stanford University.

EXIT -- OPTIMAL SOLUTION FOUND

**** REPORT SUMMARY : 0 NONOPT
0 INFEASIBLE
0 UNBOUNDED
0 ERRORS

---- 269 PARAMETER REPORT Solution Summary

	Herd Size	Number of~	First Cal~	Replaceme~	Cows Cull~	Calves So~
1	360.000	255.000	45.000	60.000	45.000	150.531
2	411.669	252.000	45.000	114.669	44.550	199.188
3	398.842	249.480	86.002	63.360	50.322	224.997
4	400.894	281.805	47.520	71.569	49.399	220.867
5	400.566	276.633	53.677	70.256	49.546	221.528
6	400.618	277.460	52.692	70.466	49.523	221.422
7	400.610	277.328	52.850	70.432	49.527	221.439
8	400.611	277.349	52.824	70.438	49.526	221.436
9	400.611	277.346	52.828	70.437	49.526	221.437
10	400.611	277.346	52.828	70.437	49.526	221.437
11	400.611	277.346	52.828	70.437	49.526	221.437
12	400.611	277.346	52.828	70.437	49.526	221.437
13	400.611	277.346	52.828	70.437	49.526	221.437
14	400.611	277.346	52.828	70.437	49.526	221.437
15	400.611	277.346	52.828	70.437	49.526	221.437
16	400.611	277.346	52.828	70.437	49.526	221.437
17	400.611	277.346	52.828	70.437	49.526	221.437
18	400.611	277.346	52.828	70.437	49.526	221.437
19	400.611	277.346	52.828	70.437	49.526	221.437
20	400.611	277.346	52.828	70.437	49.526	221.437
21	400.611	277.346	52.828	70.437	49.526	221.437
22	400.611	277.346	52.828	70.437	49.526	221.437
23	400.611	277.346	52.828	70.437	49.526	221.437
24	400.611	277.346	52.828	70.437	49.526	221.437
25	400.611	277.346	52.828	70.437	49.526	221.437
26	400.611	277.346	52.828	70.437	49.526	221.437

27	400.611	277.346	52.828	70.437	49.526	221.437
28	400.611	277.346	52.828	70.437	49.526	221.437
29	400.611	277.346	52.828	70.437	49.526	221.437
30	400.611	277.346	52.828	70.437	49.526	221.437
31	400.611	277.346	52.828	70.437	49.526	221.437
32	400.611	277.346	52.828	70.437	49.526	221.437
33	400.611	277.346	52.828	70.437	49.526	221.437
34	400.611	277.346	52.828	70.437	49.526	221.437
35	400.611	277.346	52.828	70.437	49.526	221.437
36	400.611	277.346	52.828	70.437	49.526	221.437
37	400.611	277.346	52.828	70.437	49.526	221.437
38	400.611	277.346	52.828	70.437	49.526	221.437
39	400.611	277.346	52.828	70.437	49.526	221.437
40	400.611	277.346	52.828	70.437	49.526	221.437
41	400.611	277.346	52.828	70.437	49.526	221.437
42	400.611	277.346	52.828	70.437	49.526	221.437
43	400.611	277.346	52.828	70.437	49.526	221.437
44	400.611	277.346	52.828	70.437	49.526	221.437
45	400.611	277.346	52.828	70.437	49.526	221.437
46	400.611	277.346	52.828	70.437	49.526	221.437
47	400.611	277.346	52.828	70.437	49.526	221.437
48	400.611	277.346	52.828	70.437	49.526	221.437
49	400.611	277.346	52.828	70.437	49.526	221.437
50	400.611	277.346	52.828	70.437	49.526	221.437
51	400.611	277.346	52.828	70.437	49.526	221.437
52	400.611	277.346	52.828	70.437	49.526	221.437
53	400.611	277.346	52.828	70.437	49.526	221.437
54	400.611	277.346	52.828	70.437	49.526	221.437
55	400.611	277.346	52.828	70.437	49.526	221.437
56	400.611	277.346	52.828	70.437	49.526	221.437
57	400.611	277.346	52.828	70.437	49.526	189.585
58	432.463	277.346	52.828	102.289	49.526	145.937
59	500.000	277.346	76.717	145.937	53.109	312.992
60	406.866	297.413	109.453		61.030	359.669

+	Yearlings~	Annual Gr~
1	15.000	7101.801
2	28.667	30588.533
3	15.840	36922.588
4	17.892	35909.139
5	17.564	36071.291
6	17.617	36045.347
7	17.608	36049.498
8	17.609	36048.834

9	17.609	36048.940
10	17.609	36048.923
11	17.609	36048.926
12	17.609	36048.925
13	17.609	36048.925
14	17.609	36048.925
15	17.609	36048.925
16	17.609	36048.925
17	17.609	36048.925
18	17.609	36048.925
19	17.609	36048.925
20	17.609	36048.925
21	17.609	36048.925
22	17.609	36048.925
23	17.609	36048.925
24	17.609	36048.925
25	17.609	36048.925
26	17.609	36048.925
27	17.609	36048.925
28	17.609	36048.925
29	17.609	36048.925
30	17.609	36048.925
31	17.609	36048.925
32	17.609	36048.925
33	17.609	36048.925
34	17.609	36048.925
35	17.609	36048.925
36	17.609	36048.925
37	17.609	36048.925
38	17.609	36048.925
39	17.609	36048.925
40	17.609	36048.925
41	17.609	36048.925
42	17.609	36048.925
43	17.609	36048.925
44	17.609	36048.925
45	17.609	36048.925
46	17.609	36048.925
47	17.609	36048.925
48	17.609	36048.925
49	17.609	36048.925
50	17.609	36048.925
51	17.609	36048.925
52	17.609	36048.925

53	17.609	36048.925
54	17.609	36048.925
55	17.609	36048.925
56	17.609	36048.925
57	17.609	19151.488
58	25.572	-8710.396
59	36.484	64188.109
60		91038.625

---- 270 VARIABLE X.L AUDs of forage consumed by herd by source

	1	2	3	4	5	6
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	2255.588	10350.000	10350.000	10350.000	10350.000	10350.000
L4	52440.000	58216.294	58216.294	58216.294	58216.294	58216.294

+	7	8	9	10	11	12
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	13	14	15	16	17	18
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	19	20	21	22	23	24
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	25	26	27	28	29	30
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	31	32	33	34	35	36
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000

L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	37	38	39	40	41	42
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	43	44	45	46	47	48
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	49	50	51	52	53	54
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	58216.294	58216.294	58216.294

+	55	56	57	58	59	60
L1	31740.000	31740.000	31740.000	31740.000	31740.000	31740.000
L2	39489.412	39489.412	39489.412	39489.412	39489.412	39489.412
L3	10350.000	10350.000	10350.000	10350.000	10350.000	10350.000
L4	58216.294	58216.294	58216.294	66935.770	87603.842	65744.323
L5				1182.236		

---- 270 VARIABLE Z.L = 490589.948 Objective function
Total Gross Margin

VARIABLE TERM.L = 15467.867 Terminal Value

---- 270 VARIABLE OVER.L Over utilization rate on public lease

	60
G1	0.400
G2	0.450

---- 270 VARIABLE OVERUSE.L AUDs of forage utilize above public limit

60 1182.236

EXECUTION TIME = 0.060 SECONDS 1.4 Mb WIN-18-100