An Economic Analysis of Alternative Fertility Control and Associated Management Techniques for Three BLM Wild Horse Herds

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Executive Summary

Contemporary cost projections were computed for several alternative strategies that could be used by BLM to manage three wild horse populations. The alternatives included existing gather and selective removal methods, combined with potential contraceptive applications of varying duration and other potentially useful management techniques. Costs were projected for a 20-year economic life using the Jenkins wild horse population model and cost estimates from BLM that reflect state-by-state per horse removal, adoption, long-term holding, and contraceptive application expenses. Important findings include:

- Application of currently available 2-year contraceptives appear capable of reducing variable operating costs for wild horse populations by about 21% on average.
- Application of 3-year contraceptives, when fully tested and available, may be capable of reducing variable operating costs by about 27% on average.
- Combining contraceptives with modest changes to herd sex ratio (e.g., 55-60% males) can trim existing costs by about 31%.
- All savings are predicted to improve when contraception is applied in conjunction with the proposed removal policy that targets horses age zero to four, instead of zero to five.
- Reductions in herd size result in greater predicted variation in annual operating expenses for each herd, especially below about 200 animals, but are always at least ±20%.
- Because the horse program's variable operating costs only make up about one half of the total program costs (which include fixed and sunk costs), even with aggressive contraceptive management, total program costs could only be reduced by about 17%. This would still save about $7.7 million per year.
- None of the contraceptive options examined eliminated the need for long-term holding facilities over the 20-year period simulated, but the number of horses held may be reduced by about 23% with aggressive contraceptive treatment.
- Cost estimates are most sensitive to adoption age and per day holding costs.
- There are opportunities to improve both the population modeling software and the modeling processes used in assembling Herd Management Area environmental assessments.

Introduction

Managing wild horses (*Equus caballus*) as dictated by the Wild Free-roaming Horse and Burro Act of 1971 (as amended) has proven to be costly. Legislation has restricted options used to manage populations; sanctuary and adoption alternatives have been expensive and less than fully effective (U.S. General Accounting Office 1990; Conover 2002). Herds continue to grow, often at high rates (6 to 25% or more; Eberhardt et al. 1982; Wolfe 1986). Budgetary limitations demand tough decisions on how to best minimize expenditures yet still meet legislated goals to maintain a "thriving natural ecological balance" and preserve existing multiple-use relationships, including rangeland health (U.S. General Accounting Office 1990). Fertility control appears to be one option worth evaluating for cost effectiveness. It is viewed as humane (Reiter et al. 1999), safe and reversible (Kirkpatrick and Turner 2002), and has been shown to successfully complement other methods of population control for wild horses (Garrott 1991; Garrott et al. 1992; Gross 2000; Hobbs et al. 2000).

BLM has maintained a database for state-by-state herd monitoring, census, selective removal, preparation and holding, adoption, compliance check, and other program costs. These new data have been used to compute estimates similar to those from Garrott et al. (1992) for the early 1990s. In this paper, I update cost estimates using 2004 management expenses and currently available contraceptive technology for three specific BLM-managed wild horse populations. The three herds were chosen by BLM based on availability of data suitable for population modeling, and because they represented three different western states, different habitats, and herd sizes that characterize a majority of the managed populations.

Objectives

An economic analysis – with proposal costs weighed against anticipated benefits – is appropriate to examine differences between alternative courses of action where limited funds are invested in the public interest, i.e., is one investment more desirable than another? However, BLM's goal is herd management area reductions to clearly established appropriate management levels (AMLs), not to bring in revenue. This simplifies the objective to one of cost-avoidance. Alternatives explored include: (1) the status quo of selective removal, adoption, and sanctuary; (2) the frequency of gathers and how efficient they are in rounding up animals, (3) status quo plus several alternative contraceptive application scenarios, specifically the duration of the contraceptive agent, and (4) other potential management techniques, such as sex ratio manipulation through age- and sex-specific removal decisions.

It has been argued that contraceptive programs must be tailored for individual herds because small differences in reproductive biology and inherent population growth rates can have large influences on population dynamics (Kirkpatrick and Turner 1986; Garrott 1991), and because herd-specific data vary in quality (Wolfe 1986). In addition, BLM tracks wild horse expenditures on a state-by-state basis for planning purposes because costs differ between states. Therefore this analysis has secondary objectives to examine multiple horse populations and perform appropriate sensitivity analyses to address the range of variability and flexibility inherent in herd management decision-making.

Specific Alternatives Analyzed

To address the issue of cost minimization in setting management guidelines for wild horse populations, several questions emerge as key within the confines of existing or proposed BLM policy guidelines:

- How often should horses be removed and/or treated with contraceptives?
- What sex and age horses are best to remove and/or treat with contraceptives?
- What other findings may be inferred from examination of simulation results (e.g., benefit: cost ratio for gather efficiency, general behavior of the HMA models)?
- Do the answers to the above questions depend strongly on the characteristics of individual herds or their locale?

Potentially, it would be easy to generate so many combinations of treatment alternatives that the results would prove cumbersome and would shift the focus away from valuable generalizations. Therefore, this analysis has concentrated on the following scenarios to help answer the questions posed above:

- Baseline Scenario – Existing "baseline" conditions as reflected in current gather policy (U.S. BLM 2002). This is a regular 4-year gather with age-specific removal rates meant to mimic those shown in Figure 1. Age classes are removed in successive *tiers* as necessary to achieve the designated appropriate management level (AML), with age 0-5 horses removed first, followed by age 10+, and finally by age 6-9 animals.

- Alternative Baseline – Modification of the Baseline Scenario being considered as an update to the existing selective removal policy. Much of the existing selective removal process has yet to be fully institutionalized and may change to something like this scenario, which is the same as Baseline Scenario except Tier 1 includes age classes 0-4, Tier 2 remains 10+, and Tier 3 is 5-9. Contrasting with Figure 1, in the Alternative Baseline Scenario, 70 percent of Tier 3, if removed, are directed to the adoption pool, and 23% of age 4 animals end up in long-term holding.

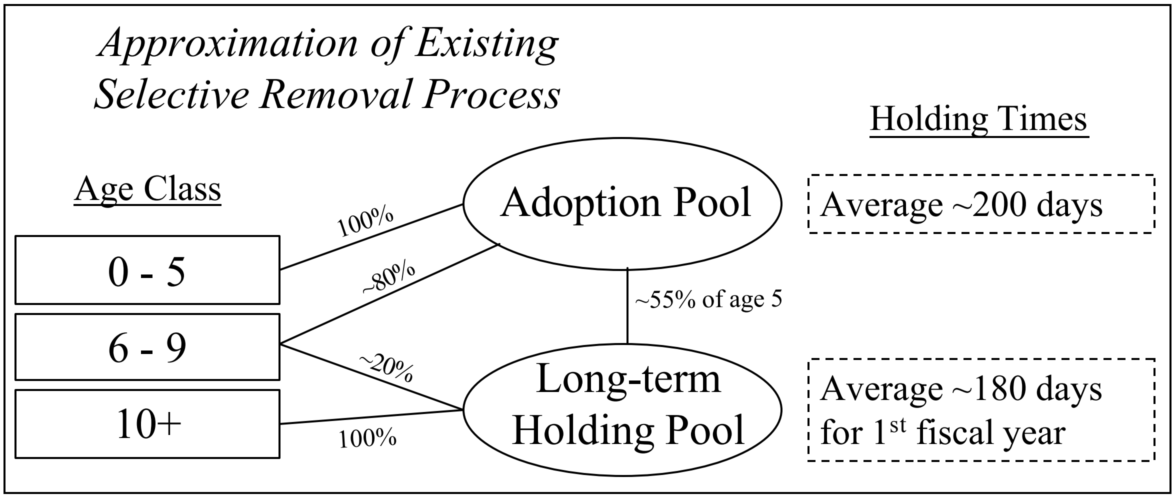

Figure 1. Approximation of existing selective removal policy (Baseline Scenario). Values are taken from Gather Policy & Selective Removal Criteria for Wild Horses, Instructional Memorandum No. 2002-095 (2/13/2002) and information provided by Ron Hall, BLM/NV (9/23/03).

- Gather Frequency Scenario G_i, where *i* represents regular gather interval in years (e.g., 2, 4, 6, or 8 years)

- Contraceptive Scenario C_d, where *d* represents duration of contraceptive in years (e.g., 2, or 3 years), defined more precisely with percent effectiveness in the first and subsequent years as shown in Table 1. Scenario 2-year-a represents values that have been used in some BLM Environmental Assessments. Scenarios 2-year-b and 2-year-c represent a range of values from a recent assessment of one herd, with differences in third year residual efficacy. Contraceptives are assumed to be applied to all mares returned to the range. Note that it is considered to be the case, and the Jenkins model assumes, that if the vaccine does not produce infertility in the first year for a given mare, it would never be effective in subsequent years until retreatment.

Table 1. Annual effectiveness of existing and potential contraceptive treatments. These are gross efficacy rates that are further tempered by age-specific fertility rates in the Jenkins model.

Nominal Duration	Effectiveness Year 1 (%)	Effectiveness Year 2 (%)	Effectiveness Year 3 (%)	Effectiveness Year 4 (%)	Effectiveness Year 5 (%)
2-year-a	80	50	0	0	0
2-year-b[1]	94	82	34	0	0
2-year-c[2]	94	82	68	0	0
3-year[3]	95	85	75	33	0

[1&2] Values taken from draft BLM Instruction Memorandum by Ron Hall (2003; personal communication 2004) reflecting results from the Clan Alpine (NV) HMA. 2-year-b represents a low range estimate and 2-year-c represents a high range estimate.

[3] Hypothetical values liberally extrapolated from 2-year efficacy rates.

- Sex Ratio Scenario S_m, where m represents the long-term sex ratio of males to females resulting from the selective removal process (e.g., 55% male to 45% female). Note that these sex ratios will usually not be given consistently. This is because the sex ratio is generated by long-term changes to sex- and age-class specific removal rates and could not be precisely predicted by specifying population model inputs.

- Gather Efficiency Scenario $E_{\%}$, where *%* represents percentage point change in 'normal' gather efficiency (i.e., if the given gather efficiency were 75%, a –5 would indicate 70% and a +10 would indicate 85%)

- As appropriate, combinations of the above scenarios have been considered. For example, 3-year Contraceptive/Sex ratio-55 would mean the combination of a 3-year contraceptive duration and 55 male:45 female sex ratio. Implicitly, all unspecified parameters would be the same as the baseline case.

Study Areas

The three wild horse populations chosen by BLM for this analysis were the Challis Herd Management Area (HMA) managed out of Challis Idaho, McCullough Peaks HMA near Cody Wyoming, and Little Book Cliffs HMA close to Grand Junction Colorado. As will be seen later, costs and demographics for these three herds capture a large portion of the variability inherent in state-by-state cost differences.

The Challis herd has been managed exclusively by 'gate cut' gathers. Gate cut is not a representative sampling technique because it is dependent on the ease of capture and handling characteristics of corralled horses. Gate cut techniques likely over represents mares, foals, and younger horses in the gathered sample. In 2002, the herd size was estimated at approximately 271 horses with an annual growth rate of about 17%. Foals are included in the AML that is set to 185 animals post-removal. It is estimated that this herd has a foal sex ratio of 58 males:42 females.

The Little Book Cliffs herd is located about eight miles northeast of Grand Junction, Colorado, on 30,000 acres of public land. Many of these horses are descended from escaped domestic stock, but some may be of Spanish origin. This herd of about 150 horses receives periodic gathers and is already participating in an ongoing contraceptive research trial. All yearlings and 2-year-olds, half of those age 3 to 15, and all mares older than 15 that were captured at the 2002 roundup and returned to the range were primed with contraceptive agent porcine zona pellucida (PZP). Even though the Little Book Cliffs HMA is a herd currently undergoing research, this analysis is using it solely as a proxy for other populations with similar demographics. The simulations that explored this herd's response to contraceptive treatment were not meant to emulate the research protocols currently being applied.

The McCullough Peaks HMA is located about 20 miles east of Cody, Wyoming, covering 110,000 acres of open sagebrush prairie and badlands. The current wild horse population in the McCullough Peaks area is about 400 animals, with the AML set between 70 and 140 animals, not including foals. This herd, too, was chosen by BLM and USGS for additional study pertaining to fertility control, population census techniques, and so forth, but no contraceptives have yet been applied. Unlike the other two herds, McCullough Peaks requires Tier 2 aged horses to be removed to achieve its appropriate management level, and may be required by law to do so.

Methods

The analysis of each herd was completed using five main steps. There was nothing fundamentally difficult about this process except the rather rigorous bookkeeping involved.

Step 1. Organize Jenkins Model Input Data and Parameters for Each HMA

Data representative of each of the three HMAs were compiled and organized in a fashion suitable for the Jenkins wild horse population model (Jenkins 2002). Much of the vital background and operational philosophy for the Jenkins model is given in Appendix A. Suffice it to say that the model attempts to mimic the on-the-ground gather, selective removal, and contraceptive application processes faithfully while including variability in both annual environmental conditions and individual animals. The model requires inputs describing what is known or estimated for survival and reproductive rates, as well as how removals and contraception may be handled. For the Challis HMA, data and modeling parameters were adapted from U.S. BLM Challis Field Office (2002), a task simplified because modeling for this HMA had already been assembled for the Jenkins model and I assumed it to be correct. Existing computer input files (or equivalent) were used for the other two populations, supplemented by information provided by the herd managers. Important demographic parameters and other data on the three herds are provided in Table 2. Note that for two of the herds, Challis and McCullough Peaks, the survival and foaling rates used were borrowed from other better-studied populations assumed to be similar to their counterparts. Complete listings for the baseline data set for the three herds are given in Appendix B.

Table 2. Key demographic elements and other information for the three HMAs considered in this analysis. These values were set to generally mimic an existing or proposed Environmental Assessment (EA) for each HMA.

	Challis	Little Book Cliffs	McCullough Peaks
Cost state	ID	CO	WY
Initial sex ratio (% male)	46	46	46
Sex ratio at birth (% male)	58	50	57
Age 0-9 female survival (geometric mean %)	98	95	95
Age 0-9 male survival (geometric mean %)	93	97	95
Average foaling rate age 2-9 (%)	79	65	71
Gather trigger (# of horses)	253	150	140
Gather efficiency (%)	75	80	90
AML (# of horses)	185	90	100
AML includes foals?	Yes	No	No
AML requires Tier 2 removal	No	No	Yes
Released mares treated for contraceptive alternatives by age	0-1 year: 100% 2-9 year: 50% 10+: 100%	0-4 year: 100% 5-9 year: 75% 10+: 100%	0-4 year: 100% 5-9 year: 75% 10+: 100%

Step 2. Exercise the Jenkins Model for Each Scenario

The Jenkins model was employed for each herd. Each scenario was run as a separate simulation using model input parameters to describe the various management actions that might be taken, contraceptive effectiveness, and so on. Like any model, there are deviations from reality, some addressed in Appendix D. Nonetheless, for this analysis I have assumed that the Jenkins model provides a reasonably accurate portrayal of possible futures important in choosing one cost minimization strategy over another.

Step 3. Estimate Dollar Value for Each Management Cost Component

Dollar values were estimated for each of the main gathering, treating, and selective removal expenditures, along with associated costs related to wild horse management. Most dollar figures were taken from the state-specific costs listed in Table 3. These costs represent FY 2004 values, but are assumed to increase 3% annually regardless of geographic area to parallel the inflation rate BLM uses for planning. Removal costs include all expenses of gathering and transport to adoption or holding facilities, averaged across all removed horses. Preparation and holding costs include freeze branding and required vaccinations. Adoption costs are largely administrative with follow-up compliance checks (site visits to adopted horses).

Table 3. Summary of variable cost estimates for BLM wild horse management across states. Unusually high costs in each column may arise when they are averaged over a small number of horses. Cost estimates were taken from budget planning spreadsheet supplied by Linda Coates-Markle, BLM/MT (4/29/2003) as interpreted by Don Glenn, BLM/DC (6/17/2003) and Lili Thomas, BLM/NV (9/22/2003). NA means not applicable.

Management Office	Removal Cost (/horse)	Prep & Holding Cost (/horse/day)	Adoption Cost (/horse)	Compliance Check (/horse)	Comments
Arizona	$345	$2.80	$318	$50	
California	$211	$3.13	$305	$59	
Colorado	$433	$3.04	$291	$60	Little Book Cliffs
Eastern States	NA	$7.66	$361	$46	
Idaho	$285	$2.10	$396	$18	Challis
Montana	$450	$13.99	$500	$150	
Nevada	$460	$3.11	$510	$66	
New Mexico	$433	$3.15	$362	$81	
Oregon	$360	$3.35	$300	$50	
Utah	$434	$4.72	$367	$50	
Wyoming	$300	$5.21	$760	$70	McCullough Peaks

Costs used in this analysis for multi-year contraceptives are given in Table 4. The range of costs given for the various duration time-release pellets reflects their production method. Higher cost pellets are currently more reliable (and that cost was used in this analysis), but BLM's goal is to reduce the cost to below the lower cost values, on the order of $120 per applied dose. (Note: These cost estimates may not be applicable for herds undergoing research where a variety of protocols may be tried.) Several other potential costs were also considered in the analysis. It was assumed that the minimum gather cost was $10,000. This comes into play only if the number of animals removed times the appropriate per horse removal cost would be below $10,000. A $5,000 per year HMA census flight cost was applied for non-gather years to assess contraceptive treatment effectiveness and routine monitoring per the recommendation of Ron Hall (2003), and was applied only for contraceptive scenarios.

Table 4. Estimated cost range for current 2-year contraceptive materials. Estimates derived from information supplied by Ron Hall (BLM/NV) and Linda Coates-Markle (BLM/MT) 9/23-30/2003.

Component	Cost Range
Primer (PZP and Freunds complete adjuvant)	$21.50
Time release booster doses (PZP and QA-21 adjuvant)	
1-month pellet	$28 – $37
3-month pellet	$31 – $40
12-month pellet	$65 – $95
Application	$20
TOTAL	$165.50 – $213.50

Since some scenarios call for contraceptives of longer duration, I received an estimate for applications having greater longevity. This estimate is given in Table 5 along with the more reliable estimate for the 2-year agent. These are the dollar costs used in this analysis.

Table 5. Estimated per horse costs for existing 2-year and hypothetical 3-year contraceptive materials and application used in this analysis. Cost for the 3-year agent is composed of the total cost of a 2-year agent plus additional 12-month time-release pellets (from Table 2). Estimates derived from Linda Coates-Markle (BLM/MT) 9/30/2003.

Contraceptive Duration	**Estimated Cost per Horse**
2 years	$214
3 years	$309

Step 4. Estimate Dollar Costs from Simulated Scenarios

The results of the Jenkins model simulations were summarized and converted to dollar expenses over a 20-year planning horizon. Twenty years was chosen because it is long enough (five complete 4-year gather cycles) to 1) reduce the uncertainty inherent in estimates of the initial age and sex structure, and 2) reveal most of the effects of variation in sex and age structure that would result over time from the variety of treatment options. Tallying the total expenditures required all cost estimates previously described, including which ages were eligible for adoption and how long adoptable and unadoptable horses are held (see Figure 1). All unadoptable horses (those that have not been successfully placed after three adoption attempts) were assumed to remain in holding facilities for the remainder of their natural life, estimated to be 25 years. In other words, the economic model became its own population model, in a manner of speaking, because it kept track of horses in life-long holding facilities. Results were summarized by software that computed the mean number of horses gathered, removed, and treated by sex and age class for each year of the 20-year simulations, along with average annual costs. In addition, the cost summarization step computed the likely annual variation in costs that would be expected as a result of the variability inherent in the Jenkins model. This step is explained in more detail in Appendix B.

Step 5. Conduct Sensitivity Analysis

The Jenkins simulation model captures environmental and demographic variability, but the uncertainty in cost estimates for the various management options remained to be explored. To accomplish this, a sensitivity analysis was performed for the three populations to see where opportunities for cost cutting might lie and which factors contribute most to the bottom line.

Results

A full suite of results for the Challis HMA are given in Table 6 and shown in the following five figures (2-6). In general, the results confirm that a four-year gather cycle has been a good management decision without contraceptive intervention. Waiting longer between gathers has the potential to significantly increase annual costs because population sizes compound so rapidly (~10-20% annually). Interestingly, Figure 2 shows that there is not much cost difference between a 2- versus a 4-year gather cycle, or between a 6- versus an 8-year cycle, but a large difference between the 4-year and 6-year cycles.

Annual costs are far less sensitive to gather efficiency (Figure 3), at least in the small increments examined here, but are nicely responsive to seemingly modest changes in sex ratio (Figure 4). Removing fewer males and increasing the sex ratio of animals remaining on the range from about 51% to 57% male can dramatically reduce costs.

Contraceptive treatments are shown to be cost effective. Contraceptives alone (Figure 5) can reduce management costs for the Challis herd up to about $15,000 per year. The best estimate of 2-year efficacy (Figure 5, 2c) rivals the results from a 3-year agent. When combined with alterations to herd sex ratio (Figure 6), these treatments appear capable of reducing costs to about 65-70% of baseline.

Interestingly, the Alternative Baseline Scenario alone is not predicted to generate a significant cost savings for the Challis herd. This appears to be because the foaling rate for 5-year olds is so much higher than for 4-year olds, and though this alternative does reduce the total number of horses held in long-term facilities, the population growth rate is slightly higher so the number of horses gathered and removed must also be higher. However, as noted above, combinations of contraceptive treatment and sex ratio manipulation (e.g., 3-year contraceptives/Sex ratio-56% male and Alternative Baseline/3-year contraceptive/Sex ratio-56%) have the potential to reduce average annual costs by about 25-35%. This is an important conclusion.

Table 6. Summary of results for scenarios of the Challis HMA.

Scenario	Average Annual Cost ($)	Percent of Baseline Cost (%)	Median Annual Growth Rate (%)
Baseline	86677	100.0	19.8
Alternative Baseline	85814	99.0	20.4
2-year contraceptive-a	83095	95.9	17.8
2-year contraceptive-b	75415	87.0	16.1
2-year contraceptive-c	73478	84.7	15.6
3-year contraceptive	72156	83.2	14.9
2-year contraceptive-a/ Sex ratio-56	67442	77.8	12.9
2-year contraceptive-c/ Sex ratio-56	60687	70.0	11.7
3-year contraceptive-a/ Sex ratio-56	59900	77.0	11.0
Alternative Baseline/ 3-year contraceptive/ Sex ratio-56	57136	65.9	11.4
2-year gather cycle	83765	96.6	19.9
6-year gather cycle	145474	167.8	20.8
8-year gather cycle	149745	172.8	20.4
-5% gather efficiency	89899	103.7	19.9
+5% gather efficiency	86667	99.9	20.0
+10% gather efficiency	84178	97.1	20.0
Sex ratio = 53.1% males	83209	96.0	18.1
Sex ratio = 55.1% males	78569	90.7	16.6
Sex ratio = 57.3% males	68619	79.2	14.5

Results for Little Book Cliffs and McCullough Peaks are given in Tables 7 and 8, respectively. I have not repeated the alternatives for gather frequency or efficiency because they provided no additional insight.

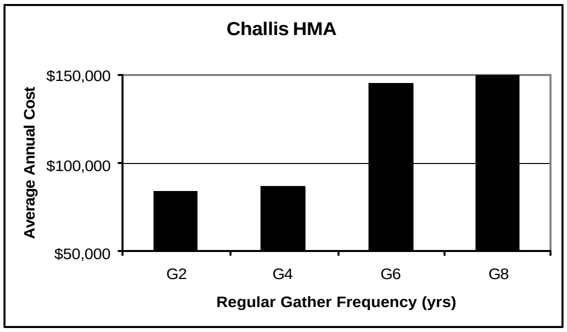

Figure 2. Annualized cost over a 20-year period for four gather frequencies for the Challis HMA (G-2, 4, 6, and 8 years, respectively).

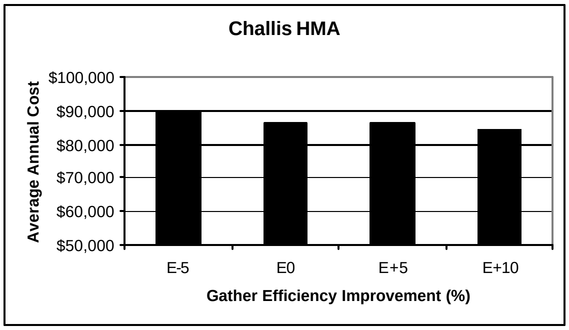

Figure 3. Annualized cost over a 20-year period for four gather efficiencies for the Challis HMA. Challis has an estimated baseline efficiency of 75%, so these scenarios represent 70, 75, 80, and 85% efficiencies, respectively.

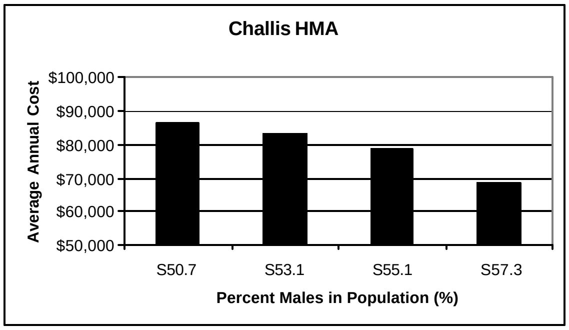

Figure 4. Annualized cost over a 20-year period for four resulting sex ratios for the Challis HMA (S-51, 53, 55, and 57% male, respectively).

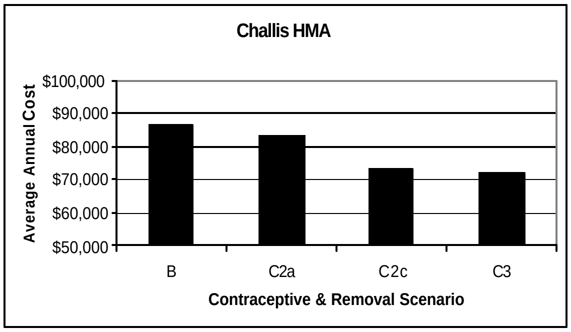

Figure 5. Annualized cost over a 20-year period for three contraceptive scenarios (2a, 2c, and 3-year) compared to the baseline (B) for the Challis HMA.

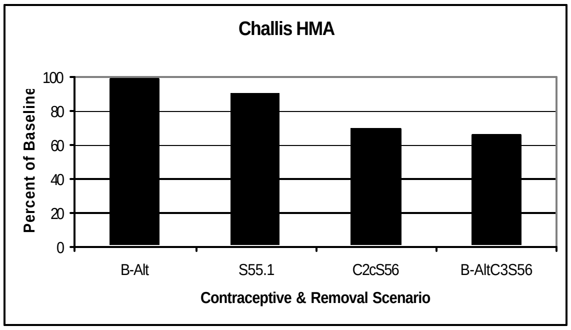

Figure 6. Percent of Baseline cost over a 20-year period for five scenarios: alternative baseline (B-Alt), 55.1% male, 2c with 56% male, and B-Alt with 3-year contraceptive and 55% males, respectively.

Table 7. Summary of results for scenarios of the Little Book Cliffs HMA.

Scenario	Average Annual Cost ($)	Percent of Baseline Cost (%)	Median Annual Growth Rate (%)
Baseline	50766	100.0	12.9
Alternative Baseline	42264	83.3	13.6
2-year contraceptive-a	46230	91.1	9.6
2-year contraceptive-b	46307	91.2	8.1
2-year contraceptive-c	37596	74.1	6.9
3-year contraceptive	36111	71.1	6.2
Sex ratio = 51.8% males	50573	99.6	11.7
Sex ratio = 53.3% males	50469	99.4	10.8
Sex ratio = 55.0% males	46444	91.5	9.4
2-year contraceptive-a/ Sex ratio = 54% males	42181	83.1	8.3
2-year contraceptive-c/ Sex ratio = 53% males	33079	65.2	5.2
3-year contraceptive/ Sex ratio = 53% males	31511	62.1	4.7
Alternative Baseline/ 3-year contraceptive/ Sex ratio = 53% males	28128	55.4	5.1

Table 8. Summary of results for scenarios of the McCullough Peaks HMA.

Scenario	Average Annual Cost ($)	Percent of Baseline Cost (%)	Median Annual Growth Rate (%)
Baseline	168214	100.0	17.5
Alternative Baseline	150836	89.7	17.5
2-year contraceptive-a	151430	90.0	14.1
2-year contraceptive-b	137295	81.6	11.2
2-year contraceptive-c	133562	79.4	10.6
3-year contraceptive	109197	64.9	10.0
Sex ratio = 60% males	157759	93.8	14.5
Sex ratio = 61% males	145534	86.5	12.2
Sex ratio = 63% males	138669	82.4	10.0
2-year contraceptive-a/ Sex ratio = 63% males	130136	77.4	8.4
2-year contraceptive-c/ Sex ratio = 64% males	118241	70.3	6.3
3-year contraceptive/ Sex ratio = 63% males	118497	70.4	5.9
Alternative Baseline/ 3-year contraceptive/ Sex ratio = 62% males	108792	64.7	6.0

Aggregate results were examined to see what other information they provide. Figure 7 shows the relationship between the variability in annual costs and herd population size developed from a variety of scenarios examined. The apparent trend appears to be an L-shaped function of population size; at population sizes below about 200 animals, the variability in annual costs increases dramatically. This is probably an effect engendered by the demographic stochasticity inherent in the Jenkins model, i.e., random events applied to small numbers of animals foster greater variability in the results, with variation in population size translating into variation in expected annual costs. However, the results may simply be an artifact of dealing with three herds, one of which is smaller than the other two.

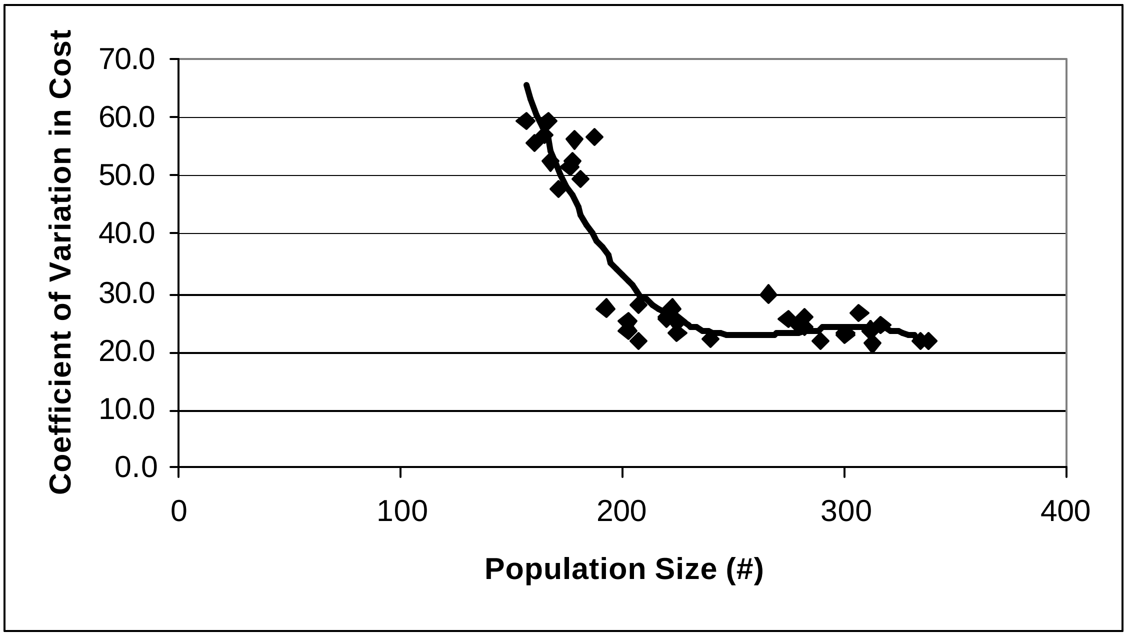

Figure 7. Apparent relationship between the variability in annual costs and herd population size developed from a variety of scenarios for the three populations examined. Trend line is 3rd order polynomial.

Figure 8 shows the relationship between the mean annual growth rate and percent of baseline scenario costs for the three populations combined. As growth rate declines through the application of various management and contraceptive options, the likelihood of reducing costs also declines. The variability (scatter) in results arises from the individual herd demographics and model-induced random variability. However, it seems apparent that when growth rates decline below about 10% annually, there is essentially a guarantee that costs will decline. Between 10 and 20% growth, large variability remains.

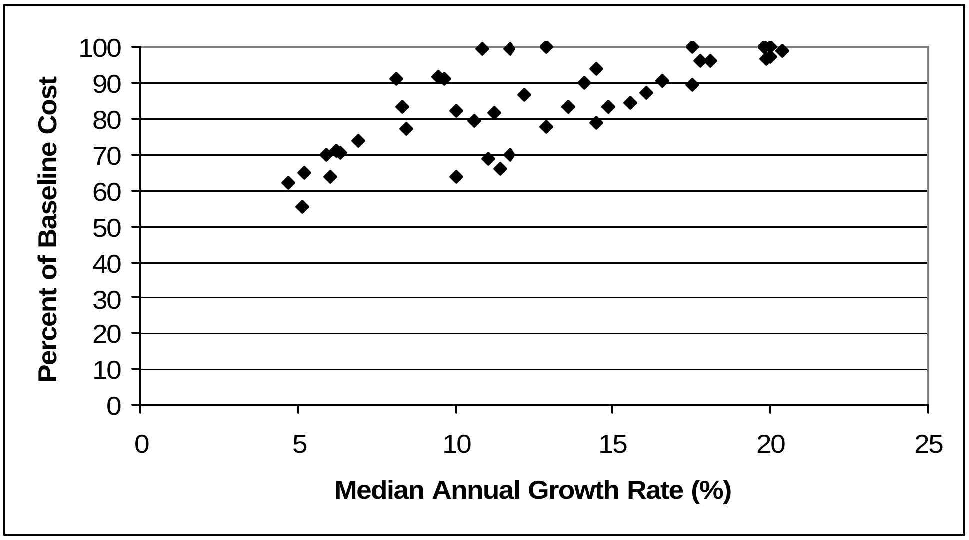

Figure 8. Relationship between mean annual growth rate and percent of the Baseline Scenario costs developed across all three populations examined.

Sensitivity Analysis for Cost Components and Related Factors

A basic sensitivity analysis was completed for the various elements that contribute to the cost estimates. This analysis tests how sensitive bottom line costs are to small changes in each of the contributing factors. The chart below (Figure 9) was generated by changing each cost and management factor ±10% and taking the ratio of the resulting cost fluctuation to the base cost of the 2-year Contraceptive Scenario-b for the Challis herd. Age class values were incremented up and down one age class – the minimum possible. (Because these age increments more closely represent a 20% change, their results have been divided by two to more closely reflect their relative impact.)

The results unsurprisingly indicate that the maximum age usually considered mostly adoptable (5 years) is the single largest influence on total costs. In other words, if this age were really four or six instead of five, there would be a large change in costs. Adoption age is followed by the average per day holding cost (*$/Unadoptable/day* = $5.21). Then comes a group of factors that have roughly equal sensitivity: the percent of age 5 horses that are adoptable (very much related to the maximum adoptable age), the number of days that horses are held prior to adoption (200 days), and the costs of adoption themselves. Costs related to contraceptives, treatment and off-year censuses, contribute little to the sensitivity, indicating that their cost is trivial compared with other management expenses. Four parameters have little or no effect: minimum gather cost, the maximum possible age of adoptable horses (10 years), the percentage of horses between age 5 and 10 (called *% of mid-ages* in Figure 9) that are adoptable (20%), and days unadoptable horses are held during their first year of removal (180 days). The two parameters dealing with age classes (*max age adoptable* and *% of mid-ages*) made no difference because none of these older aged animals needed to be removed to achieve the stated AMLs for the Challis herd.

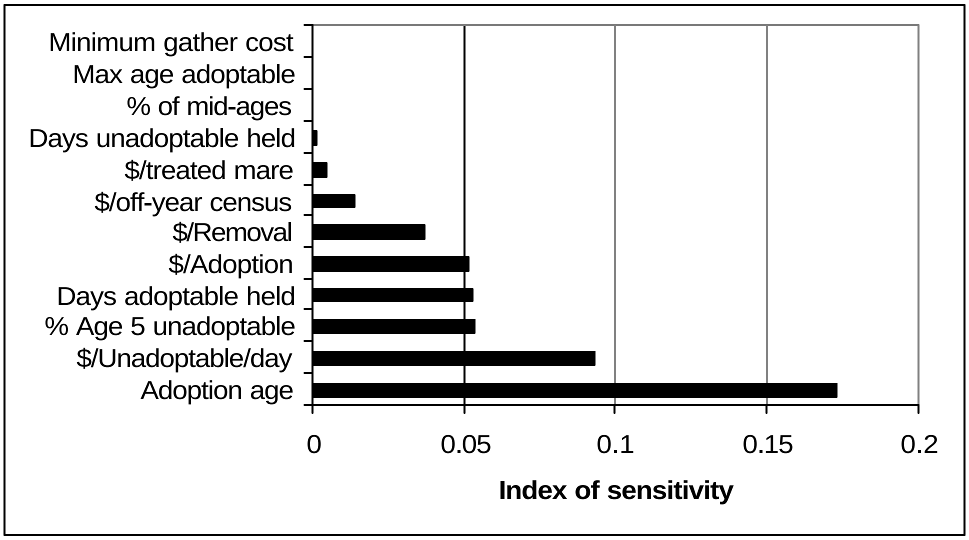

Figure 9. First order sensitivity analysis for management costs and other attributes for the Challis herd relative to the 2-year Contraceptive Scenario-b. The impact of adoption age has been divided by a factor of two to better represent its true relationship with the other factors.

Results of this form of sensitivity analysis for the other two herds were similar, but with some important differences. The holding cost (*$/Unadoptable/day)* was more important than the adoption age for the McCullough Peaks herd. This may not be surprising considering the high holding costs for this HMA given in Table 3. Likewise, the costs associated with adoption were somewhat less important for the Little Book Cliffs herd than the other two, again reflecting this herd's favorable adoption-related expenses.

Conclusions and Discussion

If all economists were laid end to end, they would not reach a conclusion.
– George Bernard Shaw

Results of this analysis have shown that when contraceptives are added to the gather-removal program, they are more cost effective than current or anticipated removal strategies that have no contraceptive component. When averaged over the variable costs anticipated with a regular 4-year gather (Figure 10), and depending on the herd and the aggressiveness of treatment, cost savings could range from 4 to 46%, averaging approximately 25%.

Populations controlled solely by gathers decline dramatically with each gather but increase rapidly between gathers. In contrast, populations controlled by contraceptives in conjunction with removals increase less rapidly. If sex ratio is also managed to increase males, even greater stability can result. Regardless of the management option, program costs always parallel population growth (Figure 10), agreeing with the findings of Gross (2000) and Garrott et al. (1992).

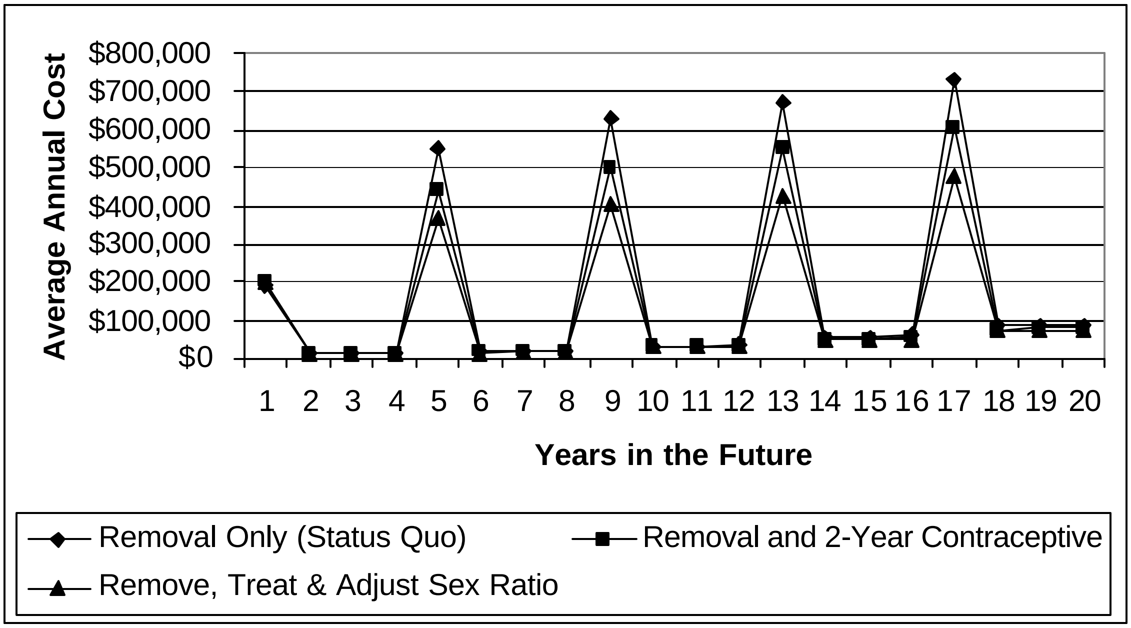

Figure 10. Example illustrating how periodic management expenses grow due to population growth, annual cost inflation, and holding of sanctuary horses for three possible scenarios.

A 4-year gather frequency appeared to be quite well matched with the demographic effects (and dollar costs) associated with 2-year contraceptive agents. However, if a viable 4-year agent becomes available, it would be wise to revisit the issue of gather frequency as it seems plausible that increasing the interval to five or more years may have economic benefits.

Comparison with Findings of Others

Garrott et al. (1992) explored the impacts of alternative contraceptive management on wild horses in the early 1990s. They separated costs for wild horse management into three basic components: contract gather costs, contraceptive purchase and per mare application (including manufacture, implantation drugs and supplies, and veterinary services), and removal costs. They assumed all contraceptive applications would be associated with gathering as opposed to aerial darting for safety and logistic reasons. Adoption placement costs (including transportation, brand inspection, vaccinations and disease testing, branding, wrangler fees, age determination, administration, facility maintenance, and per day feeding) were more difficult to estimate. They broke costs down by age of horse since some age classes were considered adoptable while others were considered unadoptable, each having their own per horse cost. Like this analysis, Garrott et al. (1992) simulated a variety of different herds, and considered more contraceptive alternatives than examined here. Their results were comparable, indicating that most variable program expenses are not related to contraceptive treatment per se, but rather remain associated with adoption program costs.

Others have pointed out that the cost-efficiency of contraceptive treatment for a species as long lived and with as high a reproductive rate as wild horses is extremely dependent on herd-specific demographics and management constraints (Garrott 1991; Hobbs et al. 2000), and that contraception must be used in conjunction with an ongoing removal program (Gross 2000). This example confirms that the current 22-month contraceptive agent within a 4-year gather cycle (2-year Contraceptive Scenario-c) can make an important difference in variable costs associated with management when gather efficiencies are typical (e.g., only 80%) and natural rates of increase are relatively high (Garrott 1995). However, when combined with modest changes to the demographic structure of the population, such as altering the sex ratio to only a slight male bias, contraceptives may offer the possibility of far more substantive cost reductions.

It should be noted, however, that none of the contraceptive options considered in this analysis eliminate the need for long-term holding facilities. Collectively, the number of additional horses added to long-term holding is reduced by 23% over the simulated 20-year period with aggressive contraceptive treatment, yet only one of the three HMAs examined (McCullough Peaks) actually showed a decreasing number of horses added through the 20 years. The other two populations continued to increase the horses added to holding through time, albeit at rates 18-36% below the baseline scenario.

Putting the Results in Perspective

This analysis has explored methods of reducing costs through a combination of contraceptive and other potential management techniques. However, costs tabulated in the Results section should be considered *variable* costs because they arise from the variation in herd population dynamics and management strategy. In other words, the dollar values presented thus far are comparative variable costs that will accrue due to <u>impending</u> management decisions.

BLM also incurs certain *fixed* costs associated with the wild horse program that include all overhead (Washington and regional offices, many HMA monitoring costs, holding facility maintenance, etc.). The fixed costs could be assumed to continue more or less unchanged regardless of the specific gather and selective removal process, with the knowledge that some of these fixed costs, like annual monitoring, aerial censusing, and new or revised AML establishment, are subject to annual budgetary constraints. Portions of the fixed costs are 'sunk' costs that support the 20,000 wild horses currently residing in holding facilities. Like all fixed costs, these sunk costs have been ignored so far in this analysis because their presence (obligation) is the result of <u>past</u> decisions. Table 9 presents a summary of nationwide costs, both fixed and variable, for BLM's wild horse program.

As one can see, the variable costs represent slightly less than half (46%) of the aggregate costs. Results presented above have indicated that it might be reasonable to expect about a 38% annual decrease in variable costs if the most aggressive management methods were to be implemented. If these savings accrue solely to the variable side of the ledger, and if fixed/sunk costs remain the largest component of the overall wild horse program, even if variable costs were reduced by 38%, aggregate program costs would likely decrease by only 17%. Though it is probably best to couch the results of this analysis in relative terms, assuming that 17% is approximately correct for all herds combined, this would amount to about a $7.7 million annual savings in variable program costs in 2004 dollars. Significant changes to gather and selective removal procedures could alter the fixed cost structure (specifically labor and facility costs) such as completely closing an existing facility, further reducing costs. Sunk costs would be expected to decline through time if the number of unadoptable horses declines. These potential changes to overall program costs have not been considered in this analysis.

Table 9. Summary of nationwide fixed and variable cost estimates for BLM's wild horse program for FY2004. Cost estimates were summarized from budget planning spreadsheet supplied by Linda Coates-Markle, BLM/MT (4/29/2003) as interpreted by Don Glenn, BLM/DC (6/17/2003) and Lili Thomas, BLM/NV (9/22/2003).

Cost Type	Factor	Expense	Total	Percent
Fixed				
	Annual Monitoring	$219,912		
	Annual Censusing	$369,590		
	AML Establishment	$56,635		
	Labor	$8,862,197		
	Non-unit cost	$3,513,962		
	Long Term Holding Facilities	$6,387,500		
	=====================	=========		
	Total Fixed Costs	$23,801,893		54%
Variable				
	Selective Removal	$5,331,471		
	Prep & Holding	$12,046,381		
	Adoption	$2,713,550		
	Compliance Checks	$279,150		
	==============	=========		
	Total Variable Costs	$20,370,552		46%
			=========	=====
Fixed + Variable			$44,172,445	100%

Uncertainty Inherent in Results

It is important to try to describe each of several major forms of uncertainty inherent in this analysis. *First* data quality for individual herd status (age and sex composition, fertility and survival rates, etc.) can vary widely. We must acknowledge that these horse populations are difficult and expensive to monitor, and our estimates of initial conditions and the various vital parameters are inaccurate (or indeed borrowed from other, better studied populations), but we must start with the information as best as it is currently understood. Fortunately, these data may be improved through time.

Second is forecasting. Population births and deaths are subject to the whims of animal and range conditions, predation, and other poorly understood population regulation mechanisms. In essence, the nature of the Jenkins population model used in this analysis automatically accounts for much of the uncertainty in initial conditions and lack of predictability of forecasts. As we have seen, this variability, as reflected in the coefficient of variation of annual costs, appears to be in the neighborhood of 20-30% annually for each HMA simulated. It may take many years to improve our estimates of this forecast uncertainty.

Third, there is uncertainty in the BLM-derived estimates of expenses for each of the several cost components: gathering, selective removal, adoption, holding, contraceptive treatment, and population censusing. Costs vary through time and the vagaries of local conditions. The cost summarization software automatically accounts for the uncertainty passed to it from the population model, but does not automatically incorporate uncertainty in the cost estimates, though this has been addressed to some degree through sensitivity analysis. Further, since this cost analysis has focused on variable program expenses, overhead costs have been treated as fixed costs and, along with 'sunk' costs (those costs originating from past decisions) such as the existing sanctuary inventory, have been summarized only to put the variable costs in perspective. There are obvious uncertainties in fixed costs that hinge on the practical life of all physical facilities (e.g., adoption corrals, fencing, etc.) and it is reasonable to assume that the 20-year time frame used in this analysis is long enough that new contraceptive techniques or agents may be available that change the complexion of the results presented here.

There is a bright side to some of this uncertainty. The computed coefficients of variation for costs are meant to be relevant for single populations. When considering the variation in costs that might arise program-wide, it is reasonable to assume that the overall variance would be reduced. This is largely because gather schedules would presumably be staggered, but also because some populations would be increasing while others would be decreasing, with the 'average' expected to be less erratic, much like the behavior of a 'balanced' portfolio. One should never discount region-wide oscillations that might be due to widespread drought or other climatic oscillations (El Nino) that may provide broadly favorable or unfavorable habitat conditions over large geographic areas like the Intermountain West. On average though, variable program costs would not be expected to fluctuate more than about ±20% across all herds at the same time.

Research and Management Recommendations for BLM's Consideration

Sex Ratio Manipulation

Many of the environmental assessments that I reviewed, as well as some additional published literature (Berger 1986), have recommended maintaining populations with 'natural' sex ratios that tend toward females, e.g., 40 males:60 females (e.g., U.S. BLM Worland Field Office 2000). Since sex ratio measured in the field results from the combined effects of sex ratio at birth and relative male:female survival and removal rates that vary from herd to herd, I believe that it may be problematic to characterize a 'natural' sex ratio, especially for a feral species undergoing active management.

In any event, this analysis has assumed no *a priori* constraint on the sex ratio resulting from any given management plan, and even though examining how changes to each HMA's sex ratio influenced cost was not the primary goal of this analysis, simulations revealed that only modest changes in herd sex structure could rival cost savings inherent in available contraceptive application techniques. When both contraceptives and sex ratio manipulation were combined, cost savings could be even more significant. Herds that have small groups of bachelor males that are difficult to gather may lend themselves easily to this paradigm, while other herds that have many small harems may prove more difficult and costly to manage favoring males. Further, there may be potential genetic concerns regarding sex ratios that favor males. Nonetheless, any implicit or explicit BLM policy recommending sex ratios inclined toward females should be reexamined in light of the results presented here.

Balancing Range Conditions with Population Size

The 20-year simulations used in this analysis often showed that any given management strategy might take several years to achieve relatively stable demographic characteristics for each herd. For example, Figure 11 is taken from one Jenkins model simulation for McCullough Peaks. This plot illustrates that the population size approaches stability after a few gather cycles. Recall that McCullough Peaks was simulated by removing animals from only Tiers 1 and 2. It may have reached its AML more quickly if Tier Three animals had also been immediately removed. However, the apparent delay in population reduction has management implications. One might be tempted to adjust the management strategy after only one or two gather cycles if the population did not appear to be responding (or management costs declining) as fast as considered desirable. Although removal decisions must always be made aided by good data and concrete management objectives, the results shown here also argue for patience in population management for these long-lived animals. In particular, a management option that removes only age 0-4 horses without any other age classes removed may result in a somewhat higher number of horses on the range initially, yet produce a satisfactory reduction over the long term. If the range is capable of sustaining a larger number of horses for several years, this more patient strategy could significantly help reduce long-term management and holding costs.

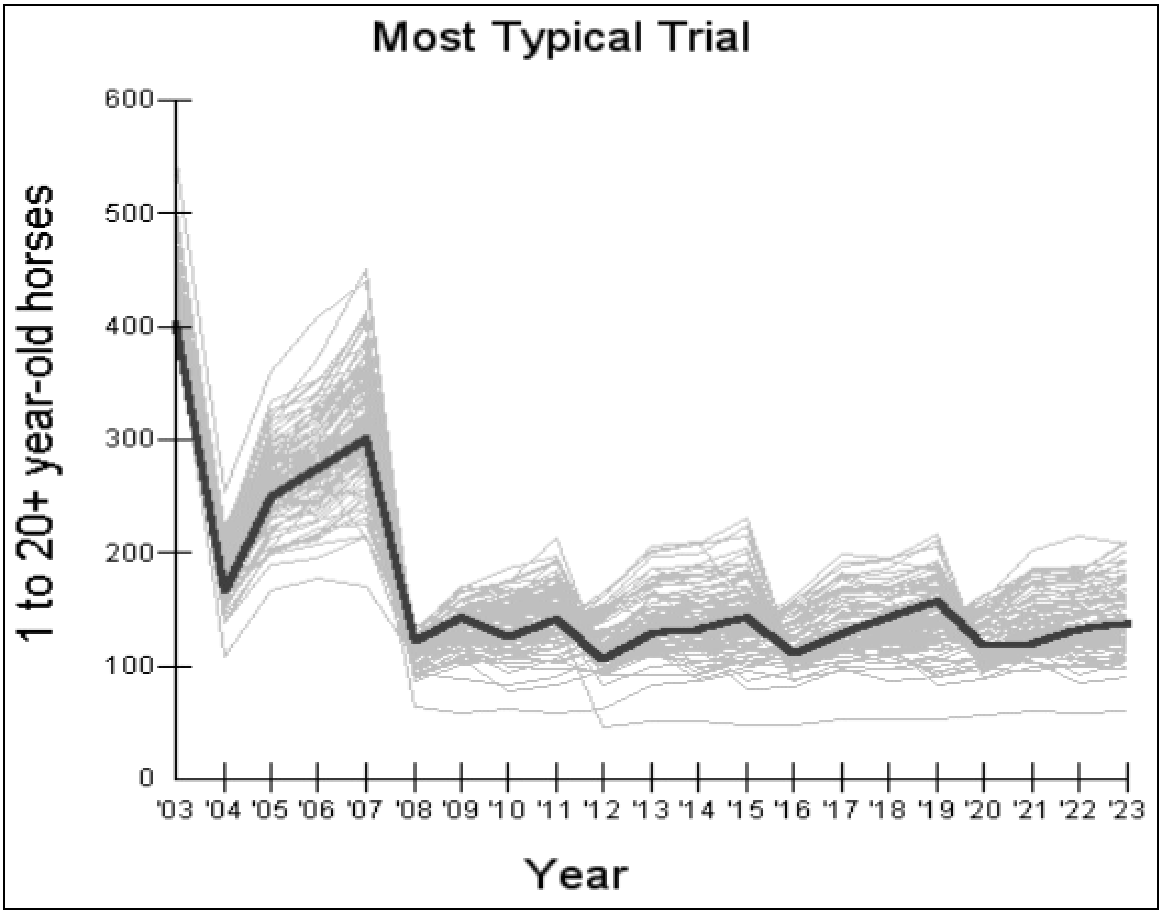

Figure 11. Example Jenkins model output for the McCullough Peaks HMA showing the total after-gather population size (minus foals since foals are not included in this AML) through a 20-year simulation. The light lines trace the 100 individual simulation trials and the heavy line traces the "most typical" result.

Population Modeling Software Improvements

Though modeling each wild horse herd with the Jenkins model is established BLM policy (U.S. BLM 2002), not all herds currently have such models. Even if the models have been assembled for a specific herd, these models may not necessarily reflect established selective removal guidelines, but instead be tailored toward previous removal practices. This analysis was not intended to be a critical assessment of the existing HMA models, but simply used what was available for the three herds examined here.

I have mentioned several areas where the Jenkins model might be improved to more faithfully represent the specific gather, selective removal, and contraceptive practices currently being used or contemplated as management decisions are fine-tuned (see Appendix D). I must admit that I do not have a good feel for whether modifications would significantly change the relative standing of the various scenarios examined here. My assumption is that simulation results would indeed differ, but that these differences would not actually change decisions based on those results, the ultimate form of sensitivity analysis. Nonetheless, it will be worthwhile to continually monitor where the model deviates from reality and test or upgrade it in response to perceived problems or improved data quality from research results.

Tom Hobbs and colleagues at Colorado State University are developing another individual-based modeling package. This software will contain a mathematical routine that will have the capability to suggest an 'optimum' gather, selective removal, and contraceptive management program for various herds, something that this current cost analysis addressed only in a limited trial-and-error manner. When fully developed, the new software could be applied side-by-side with the Jenkins model to identify areas where each product might be improved.

Population Modeling Process Improvements

Results given in this analysis have seconded the findings of Garrott (1991) and Kirkpatrick and Turner (1986) that specific contraceptive prescriptions can depend strongly on individual herd population dynamics. Drawing on a large experience in big game population modeling in the West, I believe there will be a need to have one or more 'experts' to consistently apply whatever population model is used to evaluate HMA environmental assessments. Data gathering for each herd can be unique with subtle data quality issues. Modeling software, though ostensibly easy to use once you are familiar with their nuances, can produce very different results depending on exactly how the model structure is interpreted and applied for each herd. Though it will always be a good idea to have the herd managers closely involved in population modeling, such modeling will never be a day-to-day activity for them. These individuals often move from position to position, and applying the software will often receive only minimal attention. Filtering the HMA models through a specialist could 1) provide a level of quality control that may be necessary both in making cost effective long-term management decisions that can more easily respond to changing management directives, and 2) stand up to increasing scrutiny in our ever more sophisticated and litigious society. BLM should consider hiring an individual who can uniformly apply the appropriate population modeling software across the various herds, and assist and advise all of the herd managers in the uniform application of techniques. Further, it might be wise to encourage publication of modeling results in peer-reviewed journals to provide a solid foundation for scientific credibility.

Revised Cost Accounting

Because of the way BLM has tabulated removal costs, the base cost of gathering is averaged across all horses removed. Any management activity, like contraceptives, that results in an overall reduction of the number of horses that need to be removed to achieve the stated AML would likely end up with a higher cost per animal removed because all relatively invariant gather costs would be averaged across fewer horses. If, for example, gathering were used solely for a contraceptive treatment so effective that no horses were ever removed, the cost of the gather would not be accountable with BLM's current cost estimation procedure, at least as I have interpreted it. This is the reason why I included an estimate of the minimum gather cost. Fortunately, sensitivity analysis has indicated that this is not likely to dramatically influence the results for many populations. Nonetheless, BLM may wish to partition total gather costs into two categories, one that would represent the base cost for a gather (to get the crew and equipment in place, construct fences and traps, permits, supplies, etc.) and specific per horse removal costs for marking, any veterinary services, and transport. This would support a cost accounting that more easily scales downward to reduced removal levels, a desirable target for the horse program.

Acknowledgements

This report could not have happened had it not been for many helping hands. Linda Coates-Markle (BLM) and Francis Singer (USGS) helped define the objectives, establish useful contacts, supplied interesting insights, and reviewed progress. Don Glenn, Ron Hall, and Lili Thomas (BLM) coached me on the details of BLM's cost estimates and how their existing processes worked. Tricia Hatle (BLM) and Linda Zeigenfuss (USGS), with help from Jim Dollerschell (BLM) and Gerald Thygerson (BLM retired), supplied Jenkins' HMA models or equivalent for the McCullough Peaks and Little Book Cliffs populations. Linda Zeigenfuss also helped tirelessly with numerous other data gathering and related activities. Stephen Jenkins (U. Nevada Reno) was generous with his time in coaching me in the use of his population modeling software, WinEquus. Jason Ransom supplied background information on two of the herds examined. Linda Zeigenfuss, Steve Jenkins, Francis Singer, Linda Coates-Markle and Al Kane (USDA) all provided excellent comments on the first draft of this document. Finally, I must acknowledge that this report would have been unnecessary if we had been able to devise a successful abstinence program for wild horses.

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Appendix A. Using the Jenkins' WinEquus Software

General Description

A description of the Jenkins modeling software taken from selected portions of the WinEquus 'Help file' (Copyright 2002 by Jenkins and Veech, Version 1.4, April 2002 – used with permission) follows:

Overview

This is a population model for feral horses, designed to help you evaluate various management plans that might be considered for a particular area. The model uses data on average survival probabilities and foaling rates of horses to project population growth for up to 20 years. The model accounts for year-to-year variation in these demographic parameters by using a randomization process to select survival probabilities and foaling rates for each age class from a distribution of values based on these averages. This aspect of population dynamics is called environmental stochasticity, and reflects the fact that future environmental conditions that may affect horse populations can't be known in advance. Therefore each trial with the model will give a different pattern of population growth. Some trials may include mostly 'good' years, when the population grows rapidly; other trials may include a series of several 'bad' years in succession. The stochastic approach to population modeling uses repeated trials to project a range of possible population trajectories over a period of years, which is more realistic than predicting a single specific trajectory.

The model incorporates both selective removal and fertility treatment as management strategies. A simulation may include no management, selective removal, fertility treatment, or both removal and fertility treatment. You can specify many different options for these management strategies such as the schedule of gathers for removal or fertility treatment, the threshold population size which triggers a gather, the target population size following a removal, the ages and sexes of horses to be removed, and the effectiveness of fertility treatment.

To run the program, you must supply an initial age distribution (or have the program calculate one for you), annual survival probabilities for each age-sex class of horses, foaling rates for each age class of females, and the sex ratio at birth. Sample data are available for all of these parameters. You must also specify basic management options.

Population Data: Age-Sex Distribution

An important point about the initial age-sex distribution is that it is NOT necessarily the starting population for each of the trials in a simulation. This is because the program assumes that the initial age-sex distribution supplied on this form or calculated from a population size that you enter is not an exact and complete count of the population. For example, if you enter an initial population size of 100 based on an aerial survey, this is really an estimate of the population, not a census. Furthermore, it is likely to be an underestimate, because some horse will be missed in the survey. Therefore, the program uses an average sighting probability of about 90% (Garrott et al. 1991) to "scale-up" the initial population estimate to a starting population size for use in each trial. This is done by a random process, so the starting population sizes are different for all trials.

Contraceptive Efficacy

A set of parameters on the management options form called Percent Effectiveness of Fertility Control interacts with the contraception parameters to determine the actual reduction in reproduction in the population. For example, if effectiveness for the first year = 80% and 50% of released mares of each age class are treated, then only 40% of released mares in the population (80% x 50%) are actually infertile for the first year.

Contraceptive Parameters

Because of the way immunocontraceptives work (Turner et al. 1997), sterility in the first year really means that an effectively treated female will not produce a foal in the second foaling season after being treated. Mating in horses typically follows fairly soon after foaling. If gathers for treatment occur following mating, as the model assumes, then the female may already be pregnant and the immunocontraceptive won't cause her to abort the foal she is carrying. Instead, it will prevent fertilization during the mating season after this foal is born the following spring or summer, so will prevent foaling the spring or summer after that.

It may seem contradictory to remove 100% of 0 to 5 year-old horses [as an example] and at the same time treat 100% of 0 to 5 year-old mares. But remember that the contraception parameters are percentages of *released* mares to be treated. If the gather stops when the population has been reduced to the target level, then under these conditions no treated 0 to 5 year-old mares will be released. But it may be desirable to continue the gather after the population has been reduced to the target level, and treat and release extra females that are brought in. If your choice … is to continue the gather to treat females, and the removal and contraception parameters are as stated in the beginning of this paragraph, then until the target is reached all 0 to 5 year-old females (as well as males) will be removed as they are brought in. The gather will continue after the target is reached, and additional 0 to 5 year-old females gathered will be treated and released.

Environmental Stochasticity

For any natural population, mortality and reproduction vary from year to year due to unpredictable variation in weather and other environmental factors. This model mimics such *environmental stochasticity* by using a random process to increase or decrease survival probabilities and foaling rates from average values for each year of a simulation trial. Each trial uses a different sequence of random values, so gives different results for population growth. Looking at the range of final population sizes in many such trials will give you an indication of the range of possible outcomes of population growth in an uncertain environment.

How variable are annual survival probabilities and foaling rates for wild horses? The longest study reporting such data was done at Pryor Mountain, Montana by Garrott and Taylor (1990). Based on 11 years of data at this site, survival probability of foals and adults combined was greater than 98% in 6 years, between 90 and 98% in 3 years, 87% in 1 year, and only 49% in 1 year of severe winter weather. These values clearly aren't normally distributed, but can be approximated by a logistic distribution. This pattern of low mortality in most years but markedly higher mortality in occasional years of bad weather was also reported by Berger (1986) for a site in northwestern Nevada. Therefore, environmental stochasticity in this model is simulated by drawing random values from logistic distributions.

Because year-to-year variation in weather is likely to affect foals and adults similarly, this model makes foal and adult survival perfectly correlated. This means that when survival probability of foals is high, so is survival probability of adults, and vice versa. By contrast, you may adjust the correlation between survival probabilities and foaling rates to any value between -1 and +1. The default correlation is 0 based on the Pryor Mountain data and the assumption that most mortality occurs in winter and winter weather is not highly correlated with foaling-season weather.

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WinEquus produces a variety of tables and graphs of simulation results. For this economic analysis, the WinEquus simulation results were saved to a text file that was subsequently read by a special-purpose program (see Appendix C) to calculate expected economic costs (and their variability) over a 20-year period.

Setting Jenkins Model Simulations for Economic Analysis

Following the lead of U.S. BLM Challis Field Office (2002) and the values or settings the Jenkins' WinEquus model uses by default if no other choice is made, the following 'switches' were used in all HMA model simulations. All other management switches or options varied depending on the specifics of each alternative evaluated and have been described in the main text.

- Simulations were run for 20 years (producing 21 years of simulation output) with 100 trials each (100 trials is the default)

- Gathering for removal occurred at regular 4-year intervals

- When fertility control was used:
  - Gathers for fertility control occurred regardless of population size
  - Gathers continued after removals to treat additional females to be released (default if the above condition is true). Note, however, that the percentage of females actually treated by age class depends on other model input.

- Scaling factors for annual variation:
  - survival probabilities = 1.00 (default)
  - foaling rates = 1.00 (default)

- Correlation between annual variation in survival probabilities and foaling rates = 0.00 (default)

- Initial population size is inexact but smoothed (default)

- Foal survival is not density dependent (default)

- Minimum age of sanctuary-bound horses: Not applicable (default)

The general procedure for each HMA model would be to 1) load the three relevant input files [initial sex and age structure, survival probabilities by sex and age class, and foaling rates by mare age class along with sex ratio of foals] making any change to the total estimated population size as necessary; 2) define each management option that consists of six parts: selective removal rates by sex and age class, contraceptive options, the 'gather when population exceeds' trigger, the 'reduce population to' level, whether or not foals are included in the AML, and percent of the population that can be gathered; 3) run the simulation model for 20 years using 100 trials each; 4) examine the simulation results to make sure that AML was achieved; 5) save the results to a uniquely named text file designating each scenario; 6) record the median growth rate associated with that simulation; and 7) proceed to the cost estimation program.

Appendix B. Listings of Jenkins Model Parameters for the Three HMAs Analyzed

The following three tables present the basic parameters used in Jenkins' model simulations. Note, however, that the values in the columns titled "Initial Base Population" for males and females are actually randomly sampled values that assume that the user-specified model inputs are approximately 90% of the 'true' value. In addition, the log files incorrectly report that gathers do not continue after removals to treat additional females (Steve Jenkins, personal communication). This error has been corrected in these three tables.

```
 Age       Initial Base           Survival       Foaling    Percentages for    Percentages for
Class      Population         Probabilities      Rates        Removals       Fertility Treatment
        Females     Males   Females     Males             Females     Males
------------------------------------------------------------------------------------------------
foal         25        25     0.919     0.877      0.00      100%      100%      100%
1            12        10     0.996     0.950      0.00      100%      100%      100%
2            32        36     0.994     0.949      0.52      100%      100%       50%
3            16        16     0.993     0.947      0.67      100%      100%       50%
4            16        11     0.990     0.945      0.76      100%      100%       50%
5             9        10     0.988     0.942      0.89      100%      100%       50%
6            11         7     0.985     0.939      0.76        0%        0%       50%
7            10         5     0.981     0.936      0.90        0%        0%       50%
8             8         5     0.976     0.931      0.88        0%        0%       50%
9             3         5     0.971     0.926      0.91        0%        0%       50%
10-14        12        11     0.947     0.903      0.81        0%        0%      100%
15-19         9         4     0.870     0.830      0.82        0%        0%      100%
20+           3         2     0.591     0.564      0.75        0%        0%      100%

Sex ratio at birth:  58% males
Scaling factors for annual variation:  survival probabilities = 1.00, foaling rates = 1.00
Correlation between annual variation in survival probabilities and foaling rates = 0.00

Management by removals and fertility control
Starting year is 2003
Gathering occurs at regular interval of 4 years
Initial gather year is 2003
Gathers for fertility treatment occur regardless of population size.
Gathers continue after removals to treat additional females.
Threshold population size for gathers is 253.
Target population size following removals is 185.
Foals are included in AML.
Percent of population that can be gathered = 75%.
Percent effectiveness of fertility control:  year 1 is  80%, year 2 is  50%, year 3 is  0%, year 4
is  0%, year 5 is  0%.
```

Table B.1. Challis Jenkins model log file for 2-year Contraceptive Scenario-a. Survival and foaling rates were borrowed from the Garfield Flat herd for BLM's modeling.

```
Age       Initial Base           Survival       Foaling    Percentages for    Percentages for
Class      Population         Probabilities      Rates       Removals       Fertility Treatment
        Females     Males   Females     Males             Females     Males
------------------------------------------------------------------------------------------------
foal         11        11     0.919     0.936      0.00      100%      100%      100%
1            13        13     0.983     0.962      0.00      100%      100%      100%
2             7         9     0.935     0.948      0.04      100%      100%      100%
3             5         5     1.000     0.963      0.59      100%      100%      100%
4             6         8     0.968     0.957      0.58      100%      100%      100%
5             4         6     0.976     0.971      0.75      100%      100%       75%
6             4         4     0.985     0.962      0.83        0%        0%       75%
7             3         5     0.938     0.979      0.74        0%        0%       75%
8             3         3     0.879     1.000      0.81        0%        0%       75%
9             2         5     0.944     1.000      0.82        0%        0%       75%
10-14         8         9     0.970     0.983      0.64        0%        0%      100%
15-19         2         3     0.980     0.001      0.74        0%        0%      100%
20+           1         1     0.794     0.001      0.00        0%        0%      100%

Sex ratio at birth:  50% males
Scaling factors for annual variation:  survival probabilities = 1.00, foaling rates = 1.00
Correlation between annual variation in survival probabilities and foaling rates = 0.00

Management by removals and fertility control
Starting year is 2003
Gathering occurs at regular interval of 4 years
Initial gather year is 2003
Gathers for fertility treatment occur regardless of population size.
Gathers continue after removals to treat additional females.
Threshold population size for gathers is 150.
Target population size following removals is 90.
Foals are excluded from AML.
Percent of population that can be gathered = 80%.
Percent effectiveness of fertility control:  year 1 is  80%, year 2 is  50%, year 3 is  0%, year 4
is  0%, year 5 is  0%.
```

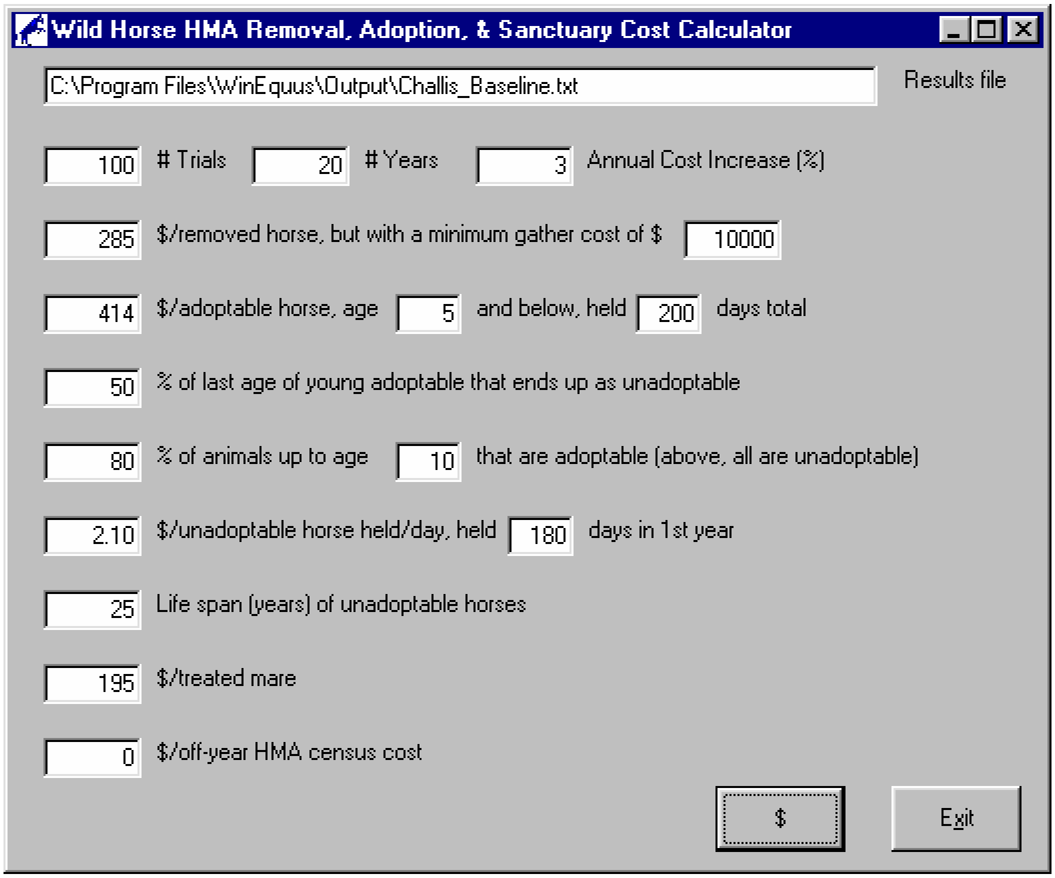
Table B.2. Little Book Cliffs Jenkins model log file for 2-year Contraceptive Scenario-a. Survival and foaling data were not borrowed from any other herd.

```
 Age       Initial Base           Survival       Foaling    Percentages for    Percentages for
Class      Population         Probabilities      Rates        Removals       Fertility Treatment
        Females     Males   Females     Males             Females     Males
------------------------------------------------------------------------------------------------
foal         20         5     0.917     0.917      0.00      100%      100%      100%
1            12         3     0.969     0.969      0.00      100%      100%      100%
2             8         8     0.951     0.951      0.35      100%      100%      100%
3             8         3     0.951     0.951      0.40      100%      100%      100%
4            10         5     0.951     0.951      0.65      100%      100%      100%
5            12         2     0.951     0.951      0.75      100%      100%       75%
6            33         5     0.951     0.951      0.85        0%        0%       75%
7            33        11     0.951     0.951      0.90        0%        0%       75%
8            30        12     0.951     0.951      0.90        0%        0%       75%
9            31        20     0.951     0.951      0.90        0%        0%       75%
10-14        29        54     0.951     0.951      0.85        0%        0%      100%
15-19        19        49     0.951     0.951      0.70        0%        0%      100%
20+          11        39     0.951     0.951      0.70        0%        0%      100%

Sex ratio at birth:  57% males
Scaling factors for annual variation:  survival probabilities = 1.00, foaling rates = 1.00
Correlation between annual variation in survival probabilities and foaling rates = 0.00

Management by removals and fertility control
Starting year is 2003
Gathering occurs at regular interval of 4 years
Initial gather year is 2003
Gathers for fertility treatment occur regardless of population size.
Gathers continue after removals to treat additional females.
Threshold population size for gathers is 140.
Target population size following removals is 100.
Foals are excluded from AML.
Percent of population that can be gathered = 90%.
Percent effectiveness of fertility control:  year 1 is  80%, year 2 is  50%, year 3 is  0%, year 4
is  0%, year 5 is  0%.
```

Table B.3. McCullough Peaks Jenkins model log file for 2-year Contraceptive Scenario-a. Survival and foaling rates applied by BLM were borrowed from the Granite Range herd.

Appendix C. Program to Estimate Economic Costs from WinEquus Simulation Results

As mentioned in Appendix A, the Jenkins model was used to simulate the individual populations' alternative futures and the simulation results were written to a text file. A Microsoft VisualBasic program was constructed to read these results and calculate average yearly costs as well as overall average costs for a 20-year period. User-specified input to this program (Figure C.1) includes cost estimates for the individual components of the variable costs for each state.



C:\Program Files\WinEquus\Output\Challis_Baseline.txt Results file

100 # Trials 20 # Years 3 Annual Cost Increase (%)

285 $/removed horse, but with a minimum gather cost of $ 10000

414 $/adoptable horse, age 5 and below, held 200 days total

50 % of last age of young adoptable that ends up as unadoptable

80 % of animals up to age 10 that are adoptable (above, all are unadoptable)

2.10 $/unadoptable horse held/day, held 180 days in 1st year

25 Life span (years) of unadoptable horses

195 $/treated mare

0 $/off-year HMA census cost

Figure C.1. Input costs and parameters for companion program to estimate costs of each specific simulation run with the Jenkins modeling software.

The number of *trials* and number of *years* are set to match the Jenkins model set-up. The number of trials and number of years captures both the variability inherent in stochastic simulation model and any population adjustments in age and sex structure that occur over about one horse life span. The *annual cost increase* adjusts all future expenditures for the rate of inflation. The *$/removed horse* reflects the cost of gathering and removal averaged across all removed horses. *Minimum gather cost* is just what it says, i.e., even if the number of gathered horses is small, there would be a minimum cost just to have a gather. The *$/adoptable horse* reflects the combined cost of adoption and compliance checks (Table 3). All horses up to the first age listed are assumed to be adoptable, except for the *% of last age of young adoptable that ends up as unadoptable*. In other words, a certain percentage of the oldest age class of adoptable animals (50% of age 5 animals in the above figure) is considered unadoptable. Adoptable animals are held for the first number of *days* listed prior to adoption. A *% of animals up to age* xx are also considered adoptable. Unadoptable animals accrue a cost of *$/unadoptable horse held/day*, are held *days in 1st year*, and 365 days thereafter through their *life span*. Note that adoptable horses also accrue the same holding cost for the days they are held prior to adoption. Contraceptive application is reflected in the *$/treated mare* cost estimate. *$/off-year HMA census cost* reflects any additional costs involved with a contraceptive program in non-gather years (typically years 2 through 4), such as flight costs to assess treatment effectiveness and perform other routine monitoring (Hall 2003). This last item would be zero except for scenarios involving contraceptive treatment.

The program reads the simulation results, averaging the costs for each year over the number of trials for which the software was run, and then summarizes the results across all simulation years. The output from this program looks like that shown in Table C.1.

```
 C:\Program Files\WinEquus\Output\Challis_C2a.prn  11/21/2003  3:06:40 PM
 Trials = 100   Years = 20   Inflation % = 3
 $/Removed horse = 285 , with minimum gather cost = 10000
 $/Adoption = 414 up to age 5 and held 200 days
 55 % of last 'fully' adoptable age diverted to unadoptable
 80 % of ages up to 10 that are adoptable
 $/Unadoptable/Day = 2.1 held 180 days the 1st year
 Life span (yrs) = 25       $/Treated mare = 214
 $/Off-year census = 5000 (Include for treatment scenarios only!)

Year     Expense    ±_CV  PopSize SexRat | Gather Treat Remove Adopt UnAdopt | Held  Die
-----------------------------------------------------------------------------------------
   1    $137,325   15.6%      305  0.467 |    218    29    120   114       6 |    6    0
   2      $9,934   11.3%      238  0.478 |      0     0      0     0       0 |    6    0
   3     $10,232   11.3%      269  0.488 |      0     0      0     0       0 |    6    0
   4     $10,539   11.3%      318  0.497 |      0     0      0     0       0 |    6    0
   5    $256,159   19.3%      390  0.508 |    278    19    197   194       3 |    9    0
   6     $14,202   12.5%      242  0.487 |      0     0      0     0       0 |    9    0
   7     $14,629   12.5%      264  0.492 |      0     0      0     0       0 |    9    0
   8     $15,067   12.5%      316  0.505 |      0     0      0     0       0 |    9    0
   9    $276,073   26.4%      377  0.509 |    267    20    187   181       5 |   15    0
  10     $21,295   13.2%      239  0.487 |      0     0      0     0       0 |   15    0
  11     $21,934   13.2%      260  0.493 |      0     0      0     0       0 |   15    0
  12     $22,592   13.2%      301  0.505 |      0     0      0     0       0 |   15    0
  13    $300,125   27.8%      364  0.514 |    262    25    176   170       6 |   21    0
  14     $30,463   13.2%      233  0.500 |      0     0      0     0       0 |   21    0
  15     $31,377   13.2%      255  0.508 |      0     0      0     0       0 |   21    0
  16     $32,318   13.2%      299  0.519 |      0     0      0     0       0 |   21    0
  17    $330,713   26.3%      354  0.526 |    255    22    168   163       5 |   26    0
  18     $41,064   12.4%      228  0.512 |      0     0      0     0       0 |   26    0
  19     $42,296   12.4%      248  0.517 |      0     0      0     0       0 |   26    0
  20     $43,565   12.4%      291  0.526 |      0     0      0     0       0 |   26    0
-----------------------------------------------------------------------------------------
Mean     $83,095   21.6%      290  0.502 |    256    23    169   164       5 |   15    0

           71.0% for Adoptions
           19.2% for Holdings
            9.8% for Treatment
```

Table C.1. Example output from cost estimator program for Challis 2-year Contraceptive Scenario-a.

The economic model output contains the name of the Jenkins model simulation results file and echoes the input values used. *Expenses* are inflation-adjusted values and *CV* is the coefficient of variation, i.e., the percent that expenses might be expected to vary annually given the variability reflected in the stochastic population model. The CV value is calculated as one standard deviation from the mean value for the year divided by that mean value. The remaining values listed (population size, sex ratio, number gathered, number treated, number removed, number adopted, number unadoptable, number held, and number dying) also represent annual averages, rounded to the nearest animal. The *mean* values listed near the bottom are averages across the number of years, except for those associated solely with gathering (population size, sex ratio, number gathered, number treated, number removed, number adopted, number unadoptable), which are averaged across the number of gathers. Finally, the program provides the percentage of the mean annual expense attributable to the total cost of adoptions, long-term holding, and contraceptive treatment.

Scanning the values listed in Table C.1 above, one can usually see how the population is adjusting through time to the management strategy implemented in the population modeling software. It is also a useful way to assess whether the selective removal rates specified in the Jenkins model have been effective in reaching the specified herd-specific AML – if foals are included in the AML.

Appendix D. Caveats to this Analysis

In conducting any sort of analysis that pretends to forecast the future, there are numerous caveats that should be mentioned. It is the author's considered opinion that none of the items listed below should be regarded as truly significant in interpreting the main conclusions of this analysis; they merely serve to document and inform any subsequent analysis, and point to opportunities for additional research.

Practical ecological and management problems such as preservation and regulation of wild horse populations can be addressed with quantitative tools such as models. A model is nothing more than a mathematical caricature of the real world. Models can be excellent tools for developing a better understanding of the way things work and the expected effects of certain management interventions, but they typically do not -- indeed cannot -- fully capture all the possible variability inherent in the system under study. Models are therefore compromises between available data and complete understanding (Akcakaya et al. 1997).

There are several particular areas where the Jenkins model may not fully capture biological processes or current management practices. One deviation from reality is the model's view that horses gathered and removed approximate a sample of the population. As one reviewer pointed out, gathers are not likely to be a random sample, but instead probably over represent mares, foals, and younger horses due to their relative 'gatherability'. Small, scattered groups of bachelor males are likely underrepresented in the gather because they can be elusive. The full ramifications of this *lack* of bias in the model are unknown and need further work. Another limitation deals with the application of specified sex- and age-specific removal 'rates'. This is a two-pronged issue. Removal rates can be set too low to actually achieve the target AML and, because of the model's implementation, it can be difficult to tell whether or not the AML has actually been achieved under all conditions simulated, especially if foals are not included in the AML. Related to this, the current selective removal policy's three-tiered age removal guidelines can be difficult to emulate with the existing Jenkins software because the specified removal rates are applied as if the animals are being run through a random removal process. That is, each animal is handled in a random order and either removed or returned to the field. The software does not, as an example, first remove all Tier One animals, followed by Tier Two and then Three only as necessary. One can approximate the three-tiered policy using a trial-and-error approach, but this can be tedious and cannot be changed during a multi-year simulation period. Fortunately, if the software can reach AML solely by removing Tier 1 animals – as seemed to be the case for two of populations studied here, all is well. In the case of McCullough Peaks, Tier Two removals were needed, and even then it took several years to truly achieve its AML (see previous Figure 11). Herds with significant numbers of older aged animals might pose additional modeling problems. Finally, there is a small lack of fidelity in the Jenkins model's representation of age classes. The last three age classes in the software are aggregates (10-14, 15-19, and 20+). I assumed that unadoptable horses in these age categories were 12, 17, and 22 years old, respectively, when calculating how long they would remain in long-term holding.

Because of randomness inherent in Jenkins model simulations, running exactly the same scenario a second time is guaranteed to produce slightly different results. Changing a parameter and re-running the software will also produce different results both because of chance phenomena in the model and the parameter change itself. This has implications when interpreting the results, occasionally making it difficult to unilaterally assign effects to causes, especially when counter-intuitive or questionable predictions arise from small input changes. This phenomenon could perhaps be minimized if more simulation trials were used, but it also mimics difficulties with real-world experiments.

It would be prudent to address whether the three populations examined here are truly representative of horse herds larger than those simulated. It is my opinion that the estimates of relative cost savings of contraceptive alternatives are not likely to change much for larger herds. I say this because these dynamics are fundamentally governed by the relative ratio of survival and foaling rates that, in combination with removal strategy, controls the effective population growth rate. However, I have not actually tried to confirm these conclusions by simulating larger populations.

Additional caveats to this analysis include: (1) I have not accounted for any potential compensatory reproductive stimulus after a contraceptive has worn off (Garrott and Taylor 1990) or any increase in longevity of treated mares (Garrott et al. 1991). (2) This analysis did not consider any effects on genetic integrity, cumulative risks to population persistence, or herd social/behavioral effects. It was assumed that these considerations were already reflected in the establishment of each herd's AML. However, the particular method of achieving an AML (such as using fertility control) can influence the minimum projected population size, an important factor in ensuring genetic integrity. (3) This analysis did not factor in any density dependent survival or reproduction because it was assumed that each population's AML was well below estimates of range carrying capacity. (4) There are some inaccuracies inherent in the cost-accounting model when percentages are applied to a small number of removed animals, such as to divide an age class into adoptable or unadoptable animals. (5) There are other small deviations from reality inherent in the cost accounting model. In the existing baseline situation (as depicted in Figure 1), slightly more males than females are moved from the adoption pool to the long-term holding pool due to difficulty of handling or other problems that tend to make these males more unadoptable (see Godfrey and Lawson 1986). (6) This analysis was not intended to cover other generalities of managing populations with contraceptives such as those provided by Garrott and Siniff (1992), Gross (2000) or Hobbs et al. (2000).

Economic analysis is not a substitute for judgment. Judgment will continue to play a role in assessing values, uncertainties, and elements that do not lend themselves to quantification. Economic analysis is but one component of the whole decision making process. Economic analysis assumes rational behavior, which can be both a strength and a weakness. There are likely to be many other intangibles: socio-political acceptability (Boyles 1986; Berger 1986; Berger 1991), legality, income-distributional effects, and potential environmental aspects. I have not done a full-blown *net benefit to society* analysis. For example, I have not considered costs of decreased grazing by domestic livestock and wildlife on horse range, potential increased siltation of streams if horse populations were higher, maintenance of fences and other improvements, nor the 'subsidy' that may be received by some individuals participating in the adoption program (Godfrey 1979). In addition, I have not included the costs of research into contraceptive application and follow-up, a necessary component of any large-scale undertaking.