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Natural Resource Stewardship and Science

Bison (*Bison bison*) Restoration and Management Options on the South Unit and Adjacent Range Units of Badlands National Park in South Dakota

A Technical Evaluation

Natural Resource Report NPS/BADL/NRR—2014/881

ON THE COVER
Bison bull in the badlands of South Dakota
Photographs by Daniel S. Licht

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Daniel S. Licht

National Park Service
231 East St. Joseph St.
Rapid City, South Dakota 57701

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Executive Summary

The 133,000-acre South Unit of Badlands National Park, located within the Pine Ridge Indian Reservation in western South Dakota, has been proposed for a bison reintroduction. This document evaluates some of the management options and the ecological and economic benefits and impacts of bison restoration.

Three sites, of varying acreage, were evaluated for their capacity to support bison. Using Natural Resources Conservation Service (NRCS) plant productivity data for a normal precipitation year, a forage allocation of 33%, and other assumptions, the three sites could support 854, 3,666, or 5,214 bison (including calves, which comprise about 18% of a herd) (Table Executive Summary 1). Other assumptions result in different estimates. For example, management could stock bison at a rate whereby they consume 15% of plant productivity, or 50%; these changes result in different herd sizes demonstrating the latitude available to management. A 33% allocation is a sensible starting point in part because of the elasticity it provides.

Table Executive Summary 1. Estimated bison herd capacity by site and percent resource allocation.

Site	Acres	Herd Size[1] (33% Allocation)	Drought and Wet-Year Range[1]	Herd Size[1] (15% Allocation)	Herd Size[1] (50% Allocation)
Site A	24,122	854	449 - 1,090	388	1,294
Site B	126,679	5,214	3,034 - 6,652	2,370	7,900
Site C	96,680	3,666	2,034 - 4,675	1,666	5,554

[1] Includes calves.

Forage is just one consideration in establishing a desired herd size. Other factors include the goals and objectives of the reintroduction, the capacity and infrastructure to manage the herd, and legal authorities. For example, National Park Service units in the Great Plains generally stock bison at very low densities, sometimes less than 40% of what the range could support in normal-precipitation years. They do this in part because they have limited funds, personnel, and infrastructure to conduct frequent and/or large culls. Keeping the herd size low is more manageable and provides a buffer should they not be able to cull in subsequent years. Conversely, Custer State Park has the capability to conduct annual culls, the infrastructure to cull large numbers of animals, and a financial motivation for maintaining a large herd. As a result, they can and do support a larger herd then NPS units. An ideal scenario, in terms of maintaining natural processes, conserving bison genetics and biodiversity, and revenue generation, would be one whereby the size of the herd would essentially follow the rain; i.e., in wet periods the herd would be allowed to increase and in dry periods it would be reduced.

The size of the herd directly affects the number of animals that need to be harvested, the potential revenue from sales, and the retention of bison genetic diversity, among other outputs (Table Executive Summary 2). In reality, these numbers will vary between years due to random changes in bison reproduction, survival, changes in bison market prices, and other factors. For example, the average number of animals harvested annually in a herd of 1,000 will be about 180 (assuming a *Yearling + Bull* culling strategy); however, the standard deviation is about 81 animals. Revenue fluctuations could be even greater due to market variations.

Table Executive Summary 2. Estimated years to full population size, annual harvest, average sale revenue, and genetic diversity in 100 years.

Herd Size	Years to Full Population Size[1]	Number Harvested Annually[2]	Average Annual Sale Revenue[2]	Change in Genetic Diversity in 100 Yrs[2]
250	-	45	$78,750	-34.3%
500	1	90	$157,500	-9.0%
854	5	154	$269,010	-6.2%
1,000	6	180	$315,000	-4.8%
2,000	11	360	$630,000	-3.0%
3,666	16	660	$1,154,790	-1.2%
5,214	18	939	$1,642,410	-0.5%

[1] Starting from a herd of 500 comprised of animals age 1-7. [2] Results for a *Yearling + Bull Cull*.

A bison herd grows about 15% annually. A reintroduced bison population would need to be culled to keep the herd at desired population levels. Four plausible culling strategies were identified and evaluated (Table Executive Summary 3). There are tradeoffs between the strategies. For example, a *Yearling + Bull* culling strategy produces the most revenue; however, it has the most un-natural sex and age structure and does poorest in conserving genetic diversity.

Table Executive Summary 3. Estimated bison herd capacity by site and percent resource allocation.

Culling Strategy	Typical Culling Rate[1]	Annual Revenue Per 1,000 Bison	Change in Genetic Diversity[2]	Comments
Yearling Only Annual Cull	70% of Yearlings	$245,000	-2.6%	Easily handled yearlings. Un-natural age structure.
Yearling + Bull Annual Cull	70% of Yearlings and 10% of Adult Bulls	$315,000	-5.2%	Assumes hunting. Un-natural sex-age structure.
All Sex-Age Annual Cull	15% of Each Sex-Age Class Annually	$265,000	-3.5%	Includes calves. Conserves natural sex-age structure.
All Sex-Age Cull Every 4th Year	40% of Each Sex-Age Class Every 4th Year	$255,000	-4.4%	Includes calves. Least costly over the long-term.

1 Actual rates will vary due to stochasticity. 2 Starting rate of 0.60. For a herd of 1,000 over 100 years.

All wildlife reintroductions have inherent uncertainty. Although there is little concern about the viability of a reintroduced bison population to the South Unit, there are other uncertainties. For example, it is uncertain how bison will utilize the habitat. The three sites evaluated in this study contain badlands topography that might be inaccessible or under-utilized by bison, thereby making the forage-based stocking estimates imprecise. To address this uncertainty, a bison reintroduction should be accompanied by a rigorous and scientifically designed adaptive management and monitoring program.

This study provides a scientific evaluation of restoring bison to the South Unit of Badlands National Park and adjacent lands. Ultimately a full environmental assessment that considers all concerns and impacts needs to be conducted before decisions should be made. This report tries to facilitate that process wherever possible by identifying and analyzing numerous scenarios and presenting a range of outputs.

Introduction

Badlands National Park (NP), located in southwestern South Dakota, is comprised of a “North Unit” and a “South Unit.” Bison (*Bison bison*) currently exist in about 64,000 acres of the North Unit; however, they are absent from the South Unit. The 133,300-acre South Unit lies within the Pine Ridge Indian Reservation, with the lands held in trust for the Oglala Sioux Tribe (OST) and managed by Badlands NP. In 2012 the National Park Service (NPS) completed the *South Unit Final General Management Plan/Environmental Impact Statement* (National Park Service 2012). That document recommended the reintroduction of bison to the South Unit.

The prairie ecosystem within and adjacent to the South Unit is a mixture of Northern Great Plains mixed-grass plant community and rugged badlands topography. Prairie vegetation is the result of the interaction of weather, fire, and grazing, the three ecological drivers of the system. The primary native grazer in the biome—and a keystone species of prairie ecosystems (Knapp et al. 1999)—is the bison (**Figure 1**). (See Appendix A for a summary of bison ecology.) Bison have recovered from their nadir at the beginning of the 20^{th} Century, but the species remains one of conservation concern due to harmful management practices, degraded genetics, ecologically ineffective populations, and other concerns (Redford and Fearn 2007, Sanderson et al. 2008, Gates et al. 2010).

The main objective of this study is to evaluate and document the ecologic and economic potential, benefits, and impacts of reintroducing bison to the South Unit. The results presented here are generally given as a range of values from which management can make informed decisions. This report should not be construed as an action plan or decision document. A full analysis of all the ramifications and issues of a reintroduction is necessary and would be conducted through a management plan and associated environmental assessment. That process and those documents would constitute the record of decision.

Figure 1. The establishment of new herds is a high priority in bison conservation.

Study Area

General Setting

The South Unit and adjacent lands lie within the Northern Great Plains biome. Although large portions of the area are comprised of mixed-grass prairie, typical of the biome, the project area is also comprised of large amounts of sparsely-vegetated badlands topography (**Figure 2**). Large portions of the area have a desert-like appearance with scarce water. Summers are hot and dry and winters are cold, although deep snows rarely accumulate.

The study area lies in Shannon County, South Dakota, within the Pine Ridge Indian Reservation. The project area is bounded by BIA Highway 41 to the west, Cuny Table Road on the south, and BIA Highway 27/Bigfoot Trail on the east. Within the project area three sites have been described or proposed by the Midwest Regional Office of the National Park Service for study and evaluation for restoration of bison (**Figure 3**). For purposes of this evaluation they are designated as Sites A (**Figure 4**), B (**Figure 5**), and C (**Figure 6**).

Natural Resources

Grass is the predominant vegetation in the area with lesser amounts of forbs. Common plant species in upland prairie, drainages, and badlands topography areas are listed in **Table 1** (see Natural Resources Conservation Service (2014) for scientific names). Almost all of the listed species, and especially the abundant species, have forage value for bison. The abundance and composition of vegetation can change at a site in response to weather, grazing, fire, and other factors. Forage productivity varies greatly from over 2,000 pounds per acre on flat and relatively most sites to very little and even none on the badlands sites. Plant productivity at the sites is described in detail in the Methods and the Results and Discussion sections.

Table 1. List of common plants in prairie and badlands topography.

Upland Prairie (NRCS Code U745)	Badlands Drainage (NRCS code U565)	Badlands Slope (NRCS Code U027)
Needle-and-thread 18%	Little Bluestem 13%	Western Wheatgrass 22%
Little Bluestem 15%	Sideoats Grama 13%	Little Bluestem 22%
Prairie Sandreed 15%	Prairie Sandreed 13%	Sideoats Grama 15%
Western Wheatgrass 10%	Western Wheatgrass 13%	Green Needlegrass 12%
Blue Grama 10%	Thickspike Wheatgrass 10%	Blue Grama 4%
Sand Bluestem 5%	Prairie Cordgrass 5%	Needle-and-thread 3%
Hairy Grama 5%	Needle-and-thread 5%	Sedge 3%
Big Bluestem 5%	Yucca 5%	Hairy Grama 3%
Sedge 5%	Inland Saltgrass 5%	Rocky Mountain Juniper 3%
Sideoats Grama 3%	Switchgrass 5%	Big Bluestem 3%
Switchgrass 3%	Green Needlegrass 5%	Prairie Sandreed 3%
Louisiana Sagewort 1%	Big Bluestem 3%	Rose 1%
Stiff Sunflower 1%	Plains Muhly 3%	Skunkbush Sumac 1%
Fringed Sagewort 1%	Blue Grama 2%	Big Sagebrush 1%
Prairie Coneflower 1%		Broom Snakeweed 1%
Blacksamson Echinacea 1%		Blacksamson Echinacea 1%
Breadroot Scurfpea 1%		Silver Buffaloberry 1

Mule deer (*Odocoileus hemionus*) are found in the project area. Pronghorn antelope (*Antilocapra americana*) are found in flatter terrain away from the badlands topography. Conversely, small bands of bighorn sheep (*Ovis canadensis*) can be found within or near the rugged badlands topography. There are small colonies of black-tailed prairie dogs (*Cynomys ludovicianus*) in grassland areas. Prior to their extirpation, bison were common in the region. They likely increased in abundance, either via immigration or increased survival and recruitment, during wet periods and decreased their presence in dry periods. Severe winters may have been a significant mortality factor. The wolf (*Canis lupus*) and grizzly bear (*Ursus arctos horribilis*) are no longer found in the region, necessitating anthropogenic culling of ungulates.

The badlands topography is notable for several reasons. The rugged topography generally provides sparse forage. The topography could also be a barrier or hindrance to bison movements. This could affect bison foraging patterns, sub-herd structure, dispersal, and other characteristics. It could also affect culling operations, e.g., sub-herds that are closer to culling facilities could be disproportionately culled. That in turn could reduce herd genetic diversity. However, the badlands topography also provides benefits. Site A is designed in part to take advantage of the topography as a natural barrier or fence to contain the bison herd (**Figure 7**).

The study area, i.e., the South Unit of Badlands National Park, has many similarities to the North Unit of the park, and therefore, could have similar management practices and issues in regards to bison. The North Unit, along with Theodore Roosevelt and Wind Cave National Parks, has conserved bison for many decades. All three parks strive to manage for wild bison, natural processes, and natural conditions. Yet all parks at times take a hands-on approach as a surrogate to missing natural processes (e.g., predation) or to meet other park or bison goals. However, all parks struggle with bison management due to insufficient funds and resources. A summary of bison management in Northern Great Plains parks can be found in Appendix B.

Some of the land is currently used for cattle grazing. Cattle have some similarities to bison in terms of grazing impacts; however, the degree of similarity is often a function more of management practices than it is of the species *per se*. Yet there are differences between the two that cannot be replicated regardless of grazing practices (see Appendix C).

Figure 2. South Unit grasslands and topography.

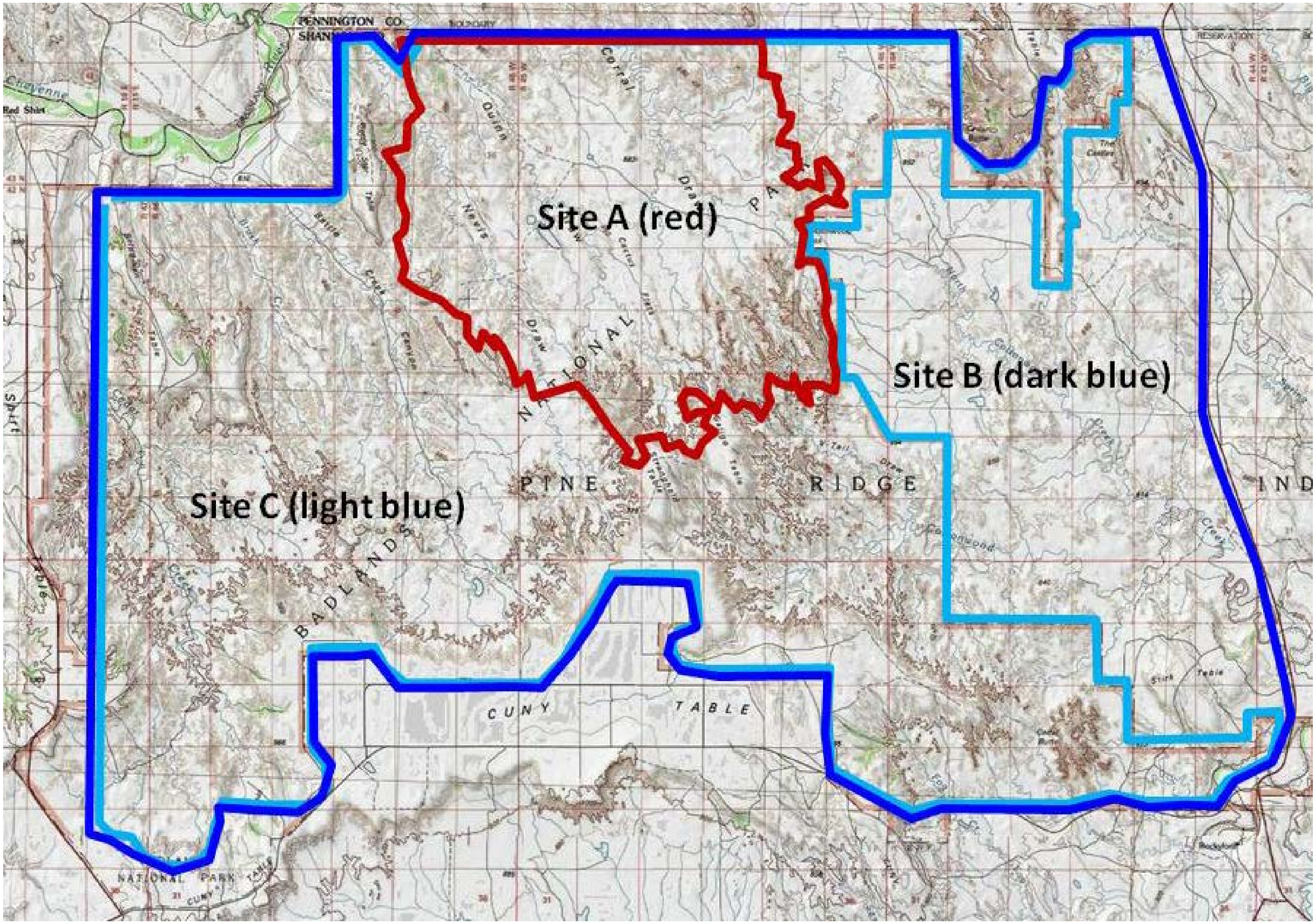

Figure 3. Location of three project sites.

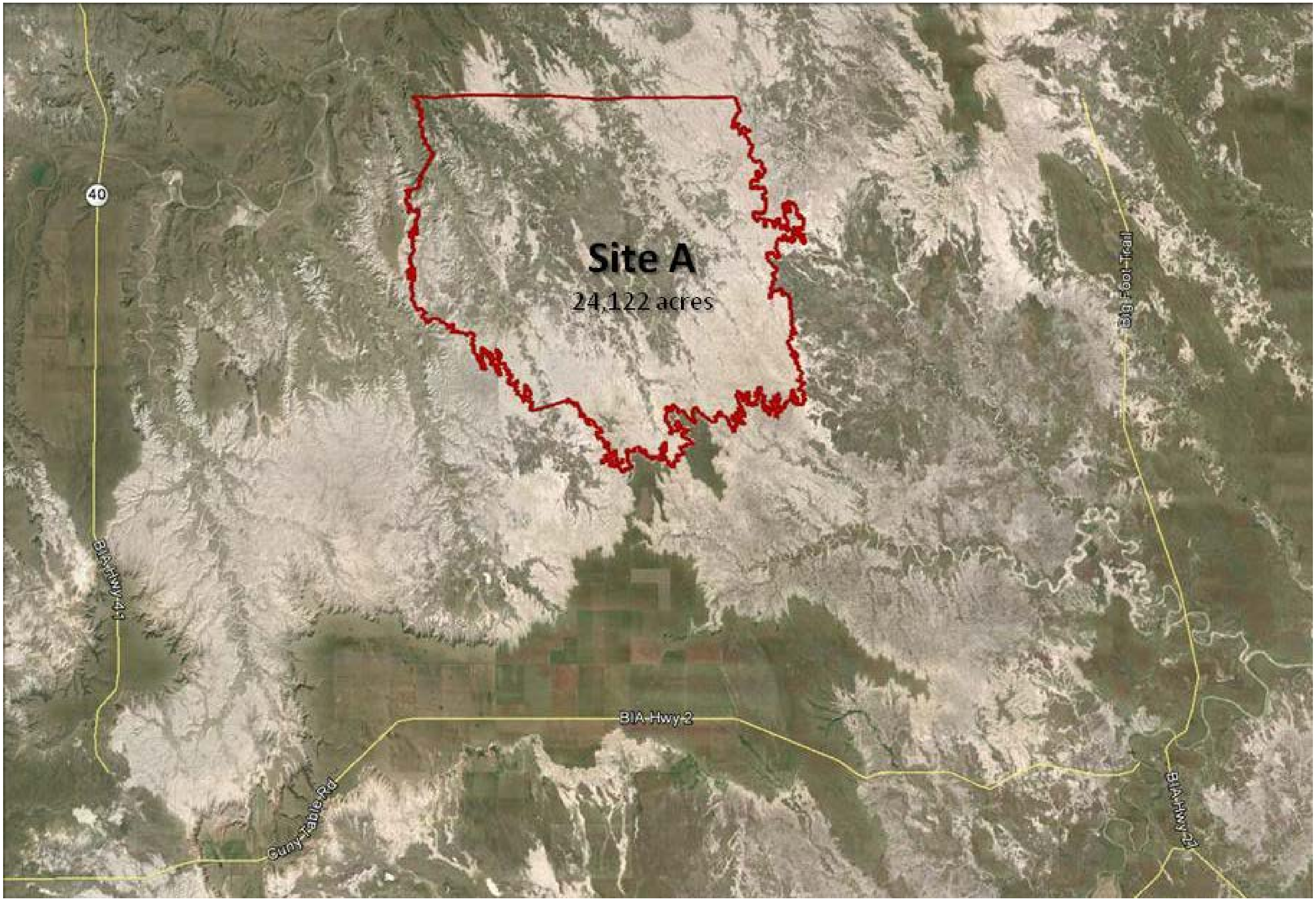

Figure 4. Map and aerial view of Site A.

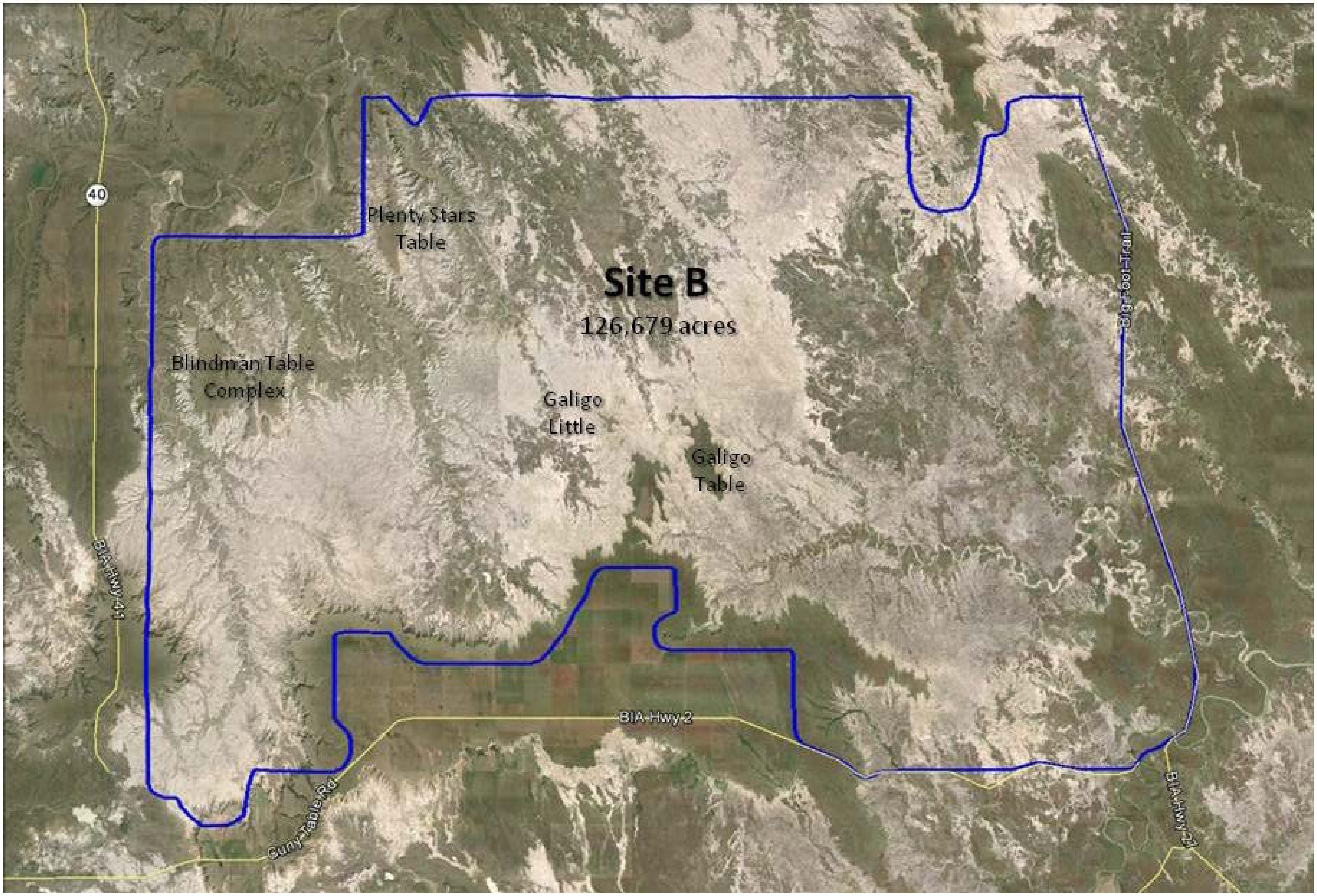

Figure 5. Map and aerial view of Site B.

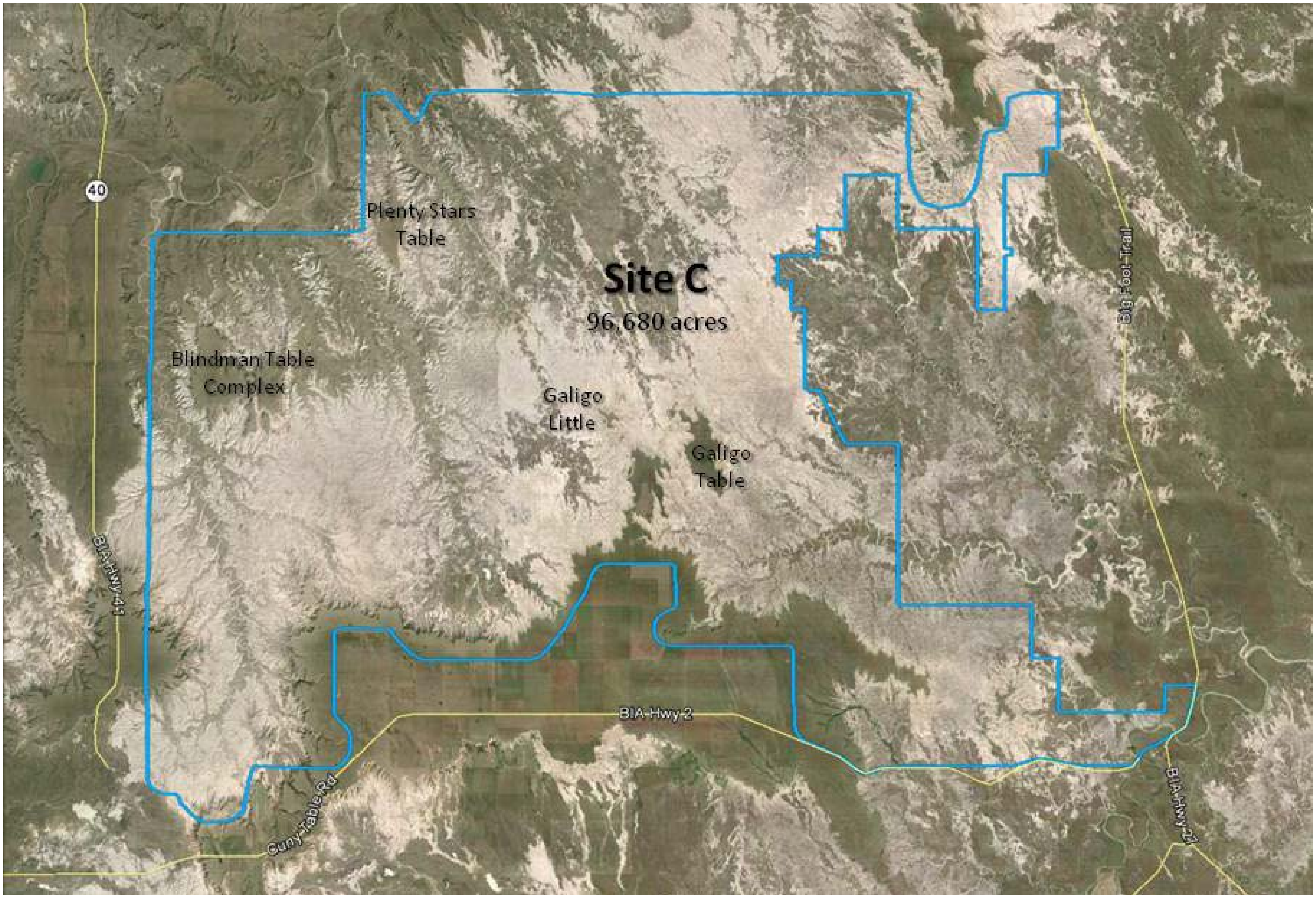

Figure 6. Map and aerial view of Site C.

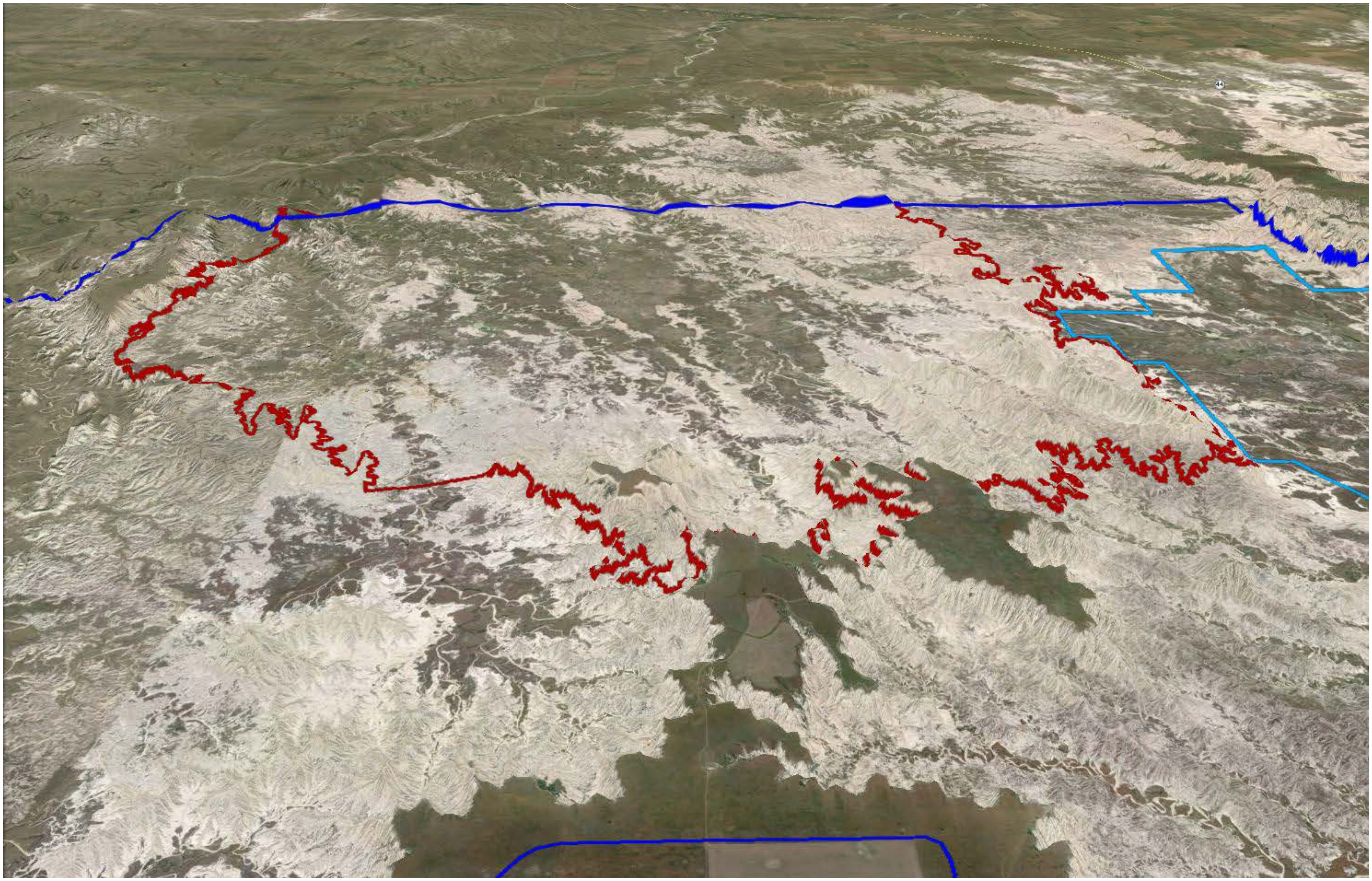

Figure 7. Exaggerated 3D view of badlands topography and boundary of Sites A, B, and C.

Methods

Forage Utilization

Perhaps the most important piece of information needed to evaluate bison restoration to a site is to determine how many bison the land should or could support. Ultimately, there are numerous "right" answers for this and they depend on goals, priorities, policy, legal authorities, logistical constraints, and other considerations. Goals can include specific objectives for forage consumption, bison genetics, revenue, visitor experience, and a myriad of other outputs.

The typical way to establish a desired population level for large ungulates—and especially for grazers such as bison—is to determine a stocking density based on annual forage productivity at the site. Based on that productivity, and assumptions about herbivore consumption rates and other variables, the number of animals a site could support based on energetic needs can be determined. All NPS units in the Northern Great Plains use some form of a plant productivity model as a primary factor in establishing bison population goals. This method is the same as what some cattle ranchers use and is the method strongly promoted by the U.S.D.A. Natural Resources Conservation Service (Natural Resources Conservation Service 2003).

The analysis in this report uses U.S.D.A. Natural Resources Conservations Service (NRCS) data, specifically, values from the agency's Web Soil Survey (WSS) website (Natural Resources Conservation Service 2014) to determine plant productivity at the site. The website uses the same values in the agency's long-established Field Office Technical Guides, but in a digital format with geographic information system (GIS) capabilities. The digital delivery has many benefits including that it is updated more quickly. NRCS last visited the South Unit in 2011.

Each of the three sites was delineated as an *Area of Interest* (AOI). For each AOI annual productivity was provided by map unit. I used the weighted average aggregation method, the higher value was used for tie breaking, and null values were interpreted as having zero productivity. WSS output is expressed as annual dry weight production per acre, in unfavorable (dry), normal, and favorable (wet) years. Calculating annual forage productivity for a site was a matter of summing the per-acre productivity values by the number of acres in the AOI. I assumed that bison could access all areas within the AOI; however, due to the steep badlands topography some areas may be inaccessible to bison. I discuss this possibility in the Results and Discussion sections. I also assumed all productivity was suitable forage for bison; although there are some plants that do not provide forage their biomass is negligible (**Table 1**).

The next step was to determine how much forage the grazer of interest consumes. To expedite that step ranchers often use the concept of an *Animal Unit* (AU) with an AU defined as a 1,000 lb beef cow nursing a young calf. Such a cow-calf pair is generally assumed to need 26 pounds of oven-dry matter forage daily, or 30 pounds of air-dry forage. The amount of forage required by one AU for one month is called an *Animal Unit Month* (AUM). Hence, for a cow-calf pair the AUM would require 912 pounds of air-dried forage (1 AU x 30 lbs forage daily x 30.4 days in an average month). The AUM approach is especially useful for managing sites where the available vegetation changes dramatically between seasons and/or where only short-term grazing is desired (e.g., for livestock grazing in alpine areas). However, there are problems with applying the AU approach to bison. For example, authors have provided a disparate range of animal unit "equivalents" to convert cattle AUs to bison AUs. Bragg et al. (2002) reported that a bison AU should be 1.25 of a cow-calf AU whereas Miller (2002) used 0.9 and Holechek (1988) used 1.8. Furthermore, some researchers have questioned whether the standard assumptions for a cattle cow-calf pair are still appropriate due to increases in cattle weights over the past several decades (Uresk 2010). I did not use the AU approach.

A somewhat similar approach, but one that directly and precisely accounts for differing body mass of the animals, is to multiply animal weight(s) by a constant forage intake to estimate the amount of forage consumed by the animal(s). Miller (2002) presented forage intakes of 2.1 to 2.8% of a bison's body mass in summer and 1.4 to 1.8% in winter. Feist (2000) reported bison dry matter intake rates of 2.2 to 3.0% in summer and 1.4 to 1.8% in winter. Westfall et al. (1993) used 1.7% of body weight for yearlings and adults, and 3.1% for calves for a forage allocation model at Theodore Roosevelt National Park. A widely used constant that is often applied across ungulate species, sexes, ages, reproductive status, season, forage quality, and other variables is 2.667%. I used the intake rate of 2.667%, but frame the results with lower (2.0%) and higher (3.0%) intake rates as well. Once a herbivore intake rate is established, the next step is to determine the weight of an animal or average weight within a herd.

Bison weights can vary greatly between sites and years and are likely dependent on a variety of factors such as range condition. Badlands NP routinely rounds up its North Unit bison and weighs animals during the process. The average weight of cows ≥ 2.5 years is 1,057 lbs while the average weight of males ≥ 2.5 is 1,573 lbs, assuming the herd has a natural age distribution (Licht et al., in prep). The average weight of female yearlings and calves is 723 and 363 lbs, respectively, while male yearlings and calves weigh 785 and 378 lbs, respectively. Assuming a normal sex and age structure (Millspaugh et al. 2005) the average fall weight of all Badlands NP North Unit bison (including calves) is 1,057 lbs (Licht et al., in prep). However, the October weights are likely when the adult animals are at their heaviest; late winter/early spring bison weights can be 10% less (Feist 2000, Miller 2002) or around 950 lbs. Therefore, I used 1,000 lbs as the typical bison weight for purposes of determining a carrying capacity.

Once the area of interest is delineated, annual plant productivity is calculated, a forage intake rate is established, and an average animal weight determined, the next step is to identify how much of the available forage should be allocated for consumption by herbivores. It is widely accepted that plants need to retain 40-60 percent of their leaf material to conduct photosynthesis and to produce carbohydrates and other products. In other words, plants need to retain about 50% of their annual productivity to sustain themselves. As a result, many land managers use a "*take half, leave half*" rule (Pratt and Rasmussen 2001). However, some managers allocate less than 50% to ungulates so as to meet other range goals (e.g., habitat requirements for a particular bird species), because of management constraints, or for other reasons. Some managers also assume that insects, trampling, hail, and other factors will consume/reduce some of the productivity. The amount managers allocate to this "waste" varies greatly, ranging from zero to 25%. This "waste" likely varies greatly between sites and years and is therefore difficult to predict. In summary, there is no single right value for forage allocation; anywhere within the 15-50% range is sustainable and probably within natural variation. With this in mind, I used a 33% forage allocation to bison for my primary analysis, but framed the results using a lower (15%) and higher (50%) allocation. (Although deer, pronghorn, bighorn sheep, and prairie dogs are present in the project area, and would also consume forage, I assumed the amount was negligible and did not explicitly include them in calculations.)

Ideally, once an ungulate stocking density is established, and animals are introduced to the pasture, future population targets would be refined based on vegetation monitoring and adaptive management principles (Natural Resources Conservation Service 2003). For example, if plant structure is found to be changing to unacceptable levels, or floral composition is changing in undesired ways, then the targeted herd size should be adjusted. There are several easy and quick methods that can be used to monitor plant productivity and structure (Natural Resources Conservation Service 2003, Herrick 2005, Uresk and Mergen 2012) and they should be considered as part of a bison restoration program.

Modeling Demographics and Culling Strategies

In the absence of predators bison herds can grow exponentially at a rate of 14-20%. The South Unit does not support wolves or bears (*Ursus* sp.)—natural predators of bison—so the herd would quickly exceed the site's carrying capacity. Hence, anthropogenic control of the bison population is needed. While there are many ways to control population growth, some are unlikely to be implemented so they will not be evaluated here (e.g., reproductive control, reintroducing predators). At national parks in the Great Plains the accepted and widely-used method of keeping a herd within the site's carrying capacity is to periodically round up the bison and remove surplus animals via live transfer out of the park.

Within the framework of a bison roundup program there are a myriad of variations that could be used. For example, bison could be rounded up every year or every fourth year. The removal (cull) could target only yearlings or be proportional across all age classes. Ultimately, the selection of a culling strategy is dependent on herd objectives (e.g., desired growth rate, sex and age composition, genetic diversity), logistical considerations (e.g., available personnel and infrastructure), preferences of the recipients of bison (e.g., what sex and age classes they want), and other factors. Weather, fire, and other stochastic variables also come into play as they affect range conditions. All these considerations make it unrealistic to expect rigorous adherence to a fixed long-term strategy. Nonetheless, modeling various plausible culling scenarios helps decision-makers evaluate the feasibility of bison restoration, the benefits of such restoration, and to plan for long-term management.

For purposes of analyzing herd demographics, culling strategies, and genetic diversity I used the program VORTEX (Lacy 2000, Lacy et al. 2014, Lacy and Pollak 2014). Although VORTEX is often viewed as a program for modeling extinction probabilities, it can also be used for modeling populations where extinction is not a concern. The program allows for modeling herd demographics, harvest scenarios, genetic outputs, and other variables relevant to a proposed restoration of bison to the South Unit.

To parameterize the model I used a variety of sources. For fecundity rates I used the values from the Millspaugh et al. (2005) model. The rates in that model were derived from Badlands NP roundup data. Specifically, for 2-year olds I used the fecundity rate of 0.05, for 3-year olds 0.54, for 4-year olds 0.71, and for 5 to 10-year olds I used a rate that averaged 0.80. For older animals the rate declined steadily from 0.65 for 11-year olds to 0.01 for 17-year olds. These rates are comparable to the rates reported by Pyne et al. (2010) and Berger and Cunningham (1994) for the Badlands NP herd.

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Table 2. Survival rates from Badlands NP data and values used in model.

Parameter	Pyne et al. (2010)[1]	Millspaugh et al. (2005)	Value Used in Models
Survival			
Female			
Calf	0.96	0.98	0.97
Yearling	0.94	0.98	0.96
3 to 9	0.94	0.99	0.97
10	0.94	0.99	0.96
11	0.94	0.98	0.96
12	0.94	0.95	0.95
13	0.94	0.94	0.94
14	0.94	0.92	0.93
15	0.89	0.86	0.87
16	0.89	0.74	0.74
17	0.89	0.56	0.56
18	0.89	0.33	0.33
19	0.89	0.12	0.12
20	0.89	0.07	0.07
21	0.89	0.00	0.00
Male			
Calf	0.94	0.98	0.96
Yearling	0.93	0.99	0.96
3 to 9	0.80	0.99	0.90
10	0.80	0.98	0.89
11	0.80	0.98	0.89
12	0.80	0.97	0.88
13	0.80	0.90	0.85
14	0.80	0.79	0.80
15	0.80	0.63	0.63
16	0.80	0.35	0.35
17	0.80	0.14	0.14
18	0.80	0.08	0.08
19	0.80	0.00	0.00

[1] Pyne et al. (2010) reported results in age classes of 0.5, 1.5, 2.5-14.5, and ≥ 15.5 for females and 0.5, 1.5, 2.5-9.5, and ≥ 10.5 for males.

To parameterize the survival rates in the model I generally used the midpoint of the rates (**Table 2**) from Millspaugh et al. (2005) and Pyne et al. (2010), both of which used the Badlands NP bison roundup database but used different analytical methods and assumptions. The values from the two studies had the greatest disparity in the mature male class. For stochastic simulations I assumed a standard deviation of 5 for all rates. Using those fecundity and survival values, the growth rate for my model was about 15% annually. The is below the 17% growth achieved when using the Millspaugh et al. (2005) survival rates, but above the 11% from the Pyne et al. (2010) survival rates.

I assumed a starting population of 500 animals and that the animals would come from Badlands NP North Unit in a single year. (Should animals come over multiple, but closely spaced years, and approximate the sex-age composition described below, the outputs in this study would still be relevant.) I assumed the composition of the transferred animals would be biased toward young animals and females, in part because they are more readily captured in the park roundups.

I used the Badlands NP 2009 North Unit roundup data and assumed that approximately 90% of each cohort would be transferred to a site in the South Unit. Specifically, the starting values for the VORTEX simulations in this study were 75, 75, 40, 35, 25, 20, and 15 females ages 1-7, respectively, and 75, 75, 30, 20, 10, and 5 males, ages 1-6, respectively.

I modeled a range herd sizes, specifically, 100, 250, 500, 854, 1000, 2000, 3666, 5214, 7500, and 10,000 animals. The values of 854, 3666, and 5214 are the mid-point values identified in the stocking rate calculations for the 3 sites. The other modeled carrying capacities result in a range of outputs that can aid the decision-making process. For example, if the desired goal was 1,500 animals the genetic diversity, revenue generated, herd composition, and other considerations could be interpolated from the results presented in this document. I did not use a carrying capacity truncation in the model as I assumed the herd would not reach a point where substantial density-dependent impairment to recruitment or survival would occur.

Relevant VORTEX input parameters are listed below.

Reproduction

Reproductive System: Polygynous
Age of first offspring for females: 3 (but see age-specific fecundity discussion)
Maximum age female reproduction: 17 (but see age-specific fecundity discussion)
Age of first offspring for males: 3 (but see discussion of the genetic methods)
Maximum age male reproduction: 17 (but see discussion of the genetic methods)
Maximum lifespan: 21
Maximum number of broods per year: 1
Maximum number of young per litter: 1
Sex ratio of young: 50:50
Density Dependent Reproduction: off
Percent Adult Females Breeding: see discussion
Environmental Variation (EV) in % Breeding: 5
% Males in Breeding Pool: variable by age and dominance status

Mortality

See **Table 2**

Other Variables

Iterations: 10
Years: 25 or 100
Inbreeding depression: off except for inbreeding depression simulations
Lethal equivalents: zero except for inbreeding simulations then 1.57, 3.14 and 6.29
Percent due to recessive lethals: 50
Environmental Concordance of Reproduction and Survival: on
Catastrophes: 0
Carrying Capacity: variable from 100 to 10,000
Starting Population: 500
Harvest: variable, see culling strategies

I designed four plausible culling strategies.

Strategy #1. *Cull Yearlings Annually.* This strategy removed enough yearlings at a 50:50 sex ratio to get the herd back down to the desired population level (e.g., 1,000 animals). Assuming a 15% annual growth this strategy would remove about 70% of the yearlings annually; however, random fluctuations in survival and reproduction would cause annual variation. It's even possible that in some years the pre-harvest herd size may be less than the target population (due to severe mortality and poor reproduction) and no cull would be necessary. An annual removal of yearlings is typical of many private and some public herds (e.g., until recently it was used by Wind Cave National Park).

Strategy #2. *Cull Yearlings Annually Plus 10% of Adult Males.* Similar to strategy #1 this scenario removed enough yearlings, at a 50:50 sex ratio, to reduce the herd to the desired population level (e.g., 1,000 animals). However, in addition to the yearling cull, this scenario annually removed 10% of the adult males (i.e., age 3.5 and older). The removal of 10% of the adult males reduced the post-harvest population below the desired goal by a slight amount. As a result, this scenario meant a greater likelihood that culls might not be necessary in the subsequent years.

Strategy #3. *Cull All Age-Sex Classes Annually.* This strategy annually removed enough animals from each age/sex class to get the population back to the desired level (e.g., 1,000 animals). The modeled rate of removal was equal across all cohorts. Assuming a population with a 15% annual growth, this means that approximately 15% of each age and sex class was removed every year. However, random fluctuations in survival and reproduction would cause annual variation in the number of animals removed. It's even possible that in some years the pre-harvest herd size may be less than the target population (due to severe mortality and poor reproduction) and no cull would be necessary. Similar approaches are used in some state and private herds, although some operators exclude the calf cohort. However, removal of adult bulls may require a method in addition to roundups, such as hunting.

Strategy #4. *Cull All Age-Sex Class Every 4th Year.* This strategy culled the herd every fourth year, assuming the herd size was above the population goal in that year. Unlike the other strategies that reduced the herd to the population goal (or slightly below in Strategy #2), this strategy culled the herd at a rate that resulted in a post-cull population that was .75 of the long-term goal for the herd. This approach provided a buffer for 4 years of growth before the next roundup. In the long-term the population average was near the goal for the herd, but with more variability around that goal. In culling years each cohort was culled at an equal rate. On average, about 40% of the cohort was removed, but this varied due to fluctuations in survival and reproduction. This strategy somewhat mimics the current situation in National Park Service units in the Great Plains whereby they do not have adequate funding for annual or more periodic culls. However, the removal of adult bulls at a rate comparable to the other cohorts may require hunting or other culling methods in addition to roundups.

I modeled each culling strategy across 10 different herd sizes, three of which where the mid-points identified in the forage utilization analysis, i.e., 854, 3666, and 5214 animals. The range of modeled herd sizes allows the reader to infer and interpolate for any herd size between 100 and 10,000.

Modeling Revenue Generation

The potential generation of revenue from a South Unit bison herd could be an important determinant in future management decisions. Although National Park Service units do not typically sell bison, there is a possibility that there may be special provisions for a herd in the South Unit, managed by the NPS and the OST. Therefore, I modeled the sale value of harvested bison for the three sites under the four culling strategies. It is important to note that I did not model the various non-consumptive values of bison such as ecotourism revenue, visitor experience, willingness-to-pay values, or cultural benefits as they are beyond the scope of this study. Furthermore, some bison, such as mature bulls, may be removed via trophy hunts; the revenue generated from the sale of permits for such hunts might differ from the live-animal values. However, due to uncertainty about the prevalence of hunts and the permit fees assessed for such hunts I did not model hunt-related revenue.

Ranch Advisory Partners (2013) used per-pound bison values in a study for the Oglala Sioux Tribe. Those values, apparently live-animal values, are presented in **Table 3**. Custer State Park in South Dakota conducts an annual roundup and sells surplus animals via an auction. Live-animal values for their 2013 roundup are also listed in the table. However, bison values can change dramatically and have since 2013. I used the weighted-average bison carcass values from the September 11, 2014 publication of the U.S. Department of Agriculture Monthly Bison Report (U. S. Department of Agriculture 2014). The report provides values in hot carcass hundredweights (also known as *centum weight*, often abbreviated as *cwt*). I assumed that hot carcass weights for bison are .55 of the live weight (Saskatchewan Ministry of Agriculture 1998). Because the USDA Monthly Bison Report does not include calf values I extrapolated the per-pound yearling values to calves of the same sex. The values used in this report to generate economic revenue of the herd are expressed per live animal (**Table 3**).

Table 3. Bison per-animal sale value.

	Average Fall Weights from Badlands NP	Ranch Advisory Partners (2013) per lb value	Custer State Park 2013 sale price per animal[2]	U. S. Department of Agriculture (2014) hundredweight (cwt)	Per Live-animal Value Used in Model (lbs * 0.55 / 100 * cwt)
Females					
Calves	365	$1.90	$1230	na	$780
Yearlings	725	$1.50	$1198	$389.93	$1550
Adults (2.5+)[1]	1050	$1.05	$1853	$290.13	$1680
Males					
Calves	380	$2.10	$997	na	$840
Yearlings	785	$2.10	$1533	$402.37	$1740
Adults (2.5+)[1]	1575	$1.80	Na	$322.74	$2800

[1] Age classes weighted by proportion of normal herd structure. [2] Calf prices midpoint between light and heavy calves. Cow price includes only “mature bred cows.”

Bison sale values do change dramatically over time hence the values presented here may not be appropriate in the future; however, the math is straightforward and the demographic data here can easily be used to model varying price rates.

Modeling Genetics

Conservation of bison genetics has become an important consideration in bison management (Dratch and Gogan 2008, Sanderson et al. 2008, U. S. Department of the Interior 2008) and therefore should be an important consideration in setting bison population goals for the sites. VORTEX (Lacy and Pollak 2014) can model bison genetic diversity and the associated impacts of inbreeding depression. I modeled bison genetic diversity under various herd sizes, culling strategies, and assumptions regarding genetic inputs. By default VORTEX assigns founder animals unique alleles (i.e., an infinite allele model) and then tracks individuals over time to calculate expected and observed heterozygosity, allele retention, and lethal alleles. When inbreeding depression is enabled the model simulates assumed impacts of inbreeding by reducing reproduction and juvenile survival based on the presence of lethal alleles. VORTEX has been used by others to model temporal changes in bison genetic diversity and theoretical inbreeding impacts to small bison herds (Halbert et al. 2004, Halbert and Derr 2008).

For purposes of modeling bison genetic diversity I parameterized the model with the 26 loci and allele frequencies used by Halbert and Derr (2008), values that they derived from the Badlands NP North Unit herd. This seeding essentially started the modeled reintroduced herds with a genetic diversity of 0.60. Male bison reproductive success is not equal among all males, with prime age adults and dominant males having substantially more success (Berger and Cunningham 1994). To mimic this I used a curvilinear function in the model so that >90% of the males age 8-12 were in the breeding pool with declining rates of inclusion outside that age range so that only 30% of the males ages 4 and 16 were in the pool (Berger and Cunningham 1994). To model dominance I randomly assigned 10% of the founder males and 10% of all newborn males as dominant, a status they kept through their life. A founder herd from the North Unit of Badlands NP would likely consist of a large number of inbred animals. To mimic this I parameterized the model with an inbreeding rate (i.e., mean relationship between individuals) of 0.4. I derived this rate from a VORTEX simulation I ran of the 50-year old Badlands NP North Unit bison herd.

The genetic results are presented for the four different culling strategies and across the 10 modeled herd sizes. This provides a range of outputs, allowing managers and decision-makers to make inferences about how various herd sizes and culling practices affect the retention of genetic diversity over time.

Inbreeding depression is defined as the decline in survival and recruitment that occurs when a population is strongly inbred (Lacy et al. 2014). I modeled the theoretical impacts of inbreeding depression on herd demographics, but to do this I assumed a culling rate that was constant across all years. I used a fixed culling rate for this analysis because the varying population-dependent culling strategies used for other analyses tended to mask the theoretical impacts of inbreeding on herd demographics. It is important to stress that inbreeding depression was not incorporated into other simulations, e.g., the model outputs for revenue generation. Although inbreeding depression is a real phenomenon, and appears to affect the small isolated Texas State Bison herd (Halbert et al. 2004), and may be affecting some NPS herds (Licht, unpub. data), I felt that is was too speculative and too uncertain to include in long-term projections for herd demographics and revenue for this report.

Result and Discussion

Forage Stocking Rate

Estimates for the number of bison that each of the three sites could support based on energetic (i.e., forage) needs are presented in detail below. These estimates are based on NRCS plant production data for the soil types within the three sites (Natural Resources Conservation Service 2014). However, a bison restoration program should be accompanied by a vegetation monitoring program. The planning estimates reported here include assumptions that may turn out to be wrong. For example, the estimates assume bison have access to all areas within the three sites; that may not be the case. If monitoring determines that bison are not accessing some areas at a normal rate then stocking rate adjustments might be needed. The simulations in this report generally assume a starting herd of 500 animals, an amount that is smaller than what the three sites can support under most assumptions, thereby providing a period of time in which bison movements and habitat can be monitored as the herd grows to the target population size.

Site A

Site A contains relatively few areas of high forage productivity, with the best areas being associated with drainages (**Figure 12**). The 24,122 acres in Site A is projected to produce 25.2 million pounds of forage in a normal year. Assuming that all of the forage is accessible to bison, a mean bison weight of 1,000 lbs, a daily forage intake rate of 2.67% of body mass, and 33% of the sites forage allocated to bison, Site A could support 854 bison, including calves, or a bison per 28 acres. In a dry year the park could support 449 bison and in a wet year 1,090. Different objectives (e.g., the amount of forage allocated to bison) and different assumptions (e.g., intake rates) result in different carrying capacities (**Table 4**).

Table 4. Modeled bison carrying capacity (includes calves) for Site A.

Forage Production Allocated to Bison	Forage Intake as Percent of Body Mass	Range Condition		
		Dry Year Carrying Capacity	Normal Year Carrying Capacity	Wet Year Carrying Capacity
15%	0.0300	182	346	441
	0.0267	204	388	496
	0.0200	272	518	662
33%	0.0300	400	760	970
	0.0267	449	854	1090
	0.0200	599	1140	1456
50%	0.0300	605	1152	1470
	0.0267	680	1294	1652
	0.0200	908	1728	2205

Figure 12 shows five classes of plant productivity within Site A. The red areas are typically associated with badlands type topography whereas the yellow, green, and blue polygons are associated with flatter and relatively moister (at least temporarily) soils. **Table 5** shows the respective area, plant productivity, and number of bison supported by each of the five classes. Compared to Sites B and C, Site A has a lower percentage of area in high productivity and a high amount of area in poor productivity.

Table 5. Modeled normal-year productivity by range category within Site A.

Color on Figure 12	Acres in Site	Percent of Site	Productivity Per Acre lbs.	Total Productivity million lbs.	Bison*
Red	8735	36.2	<= 481	3.71	126
Yellow	4864	20.2	>481 and <=1160	5.31	180
Green	7273	30.2	>1160 and <=1581	10.34	350
Light Blue	3194	13.2	>1581 and <=1850	5.73	194
Dark Blue	56	0.2	>1850	0.12	4
Total	*24122*	*100*		*25.21*	*854*

* The number of bison assumes a 33% forage allocation, a 2.67% intake rate, and a 1,000 lb bison (includes calves).

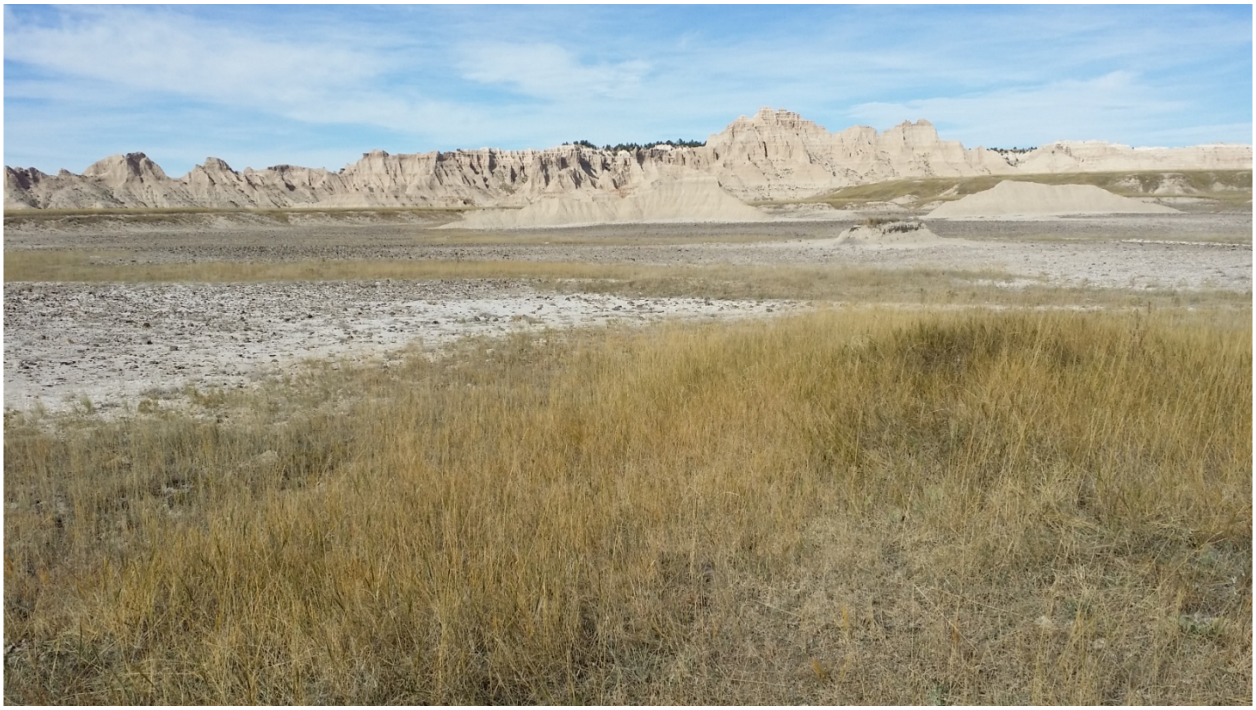

Figure 8. A fair productivity (yellow category) soil type.

Site A contains a 29 acre table about a mile the west of the Galigo Table (the latter is outside of Site A), referred to as Galigo Little (**Table 8**). This unnamed table is most likely inaccessible to bison as all the sides are steep and it is well within a large expanse of rugged badlands topography. The table has only enough normal year forage for about 2 bison.

Differing culling strategies would affect herd composition and theoretically, the number of bison a site could support. For example, an annual cull of yearlings and 10% of the bulls results in a herd that only weighs about 0.91 of a herd with a normal age and sex structure. For Site A that could increase the stocking rate from 854 to 934 animals, assuming the altered sex-age structure was maintained. I do not adjust my outputs for such a scenario, but it would not be unreasonable if management adjusted stocking rates based on herd composition.

Site B

Site B has relatively more areas with high plant productivity compared to Site A; however, it also contains substantial amounts of area with fair and poor productivity (**Figure 13**). The high productivity areas tend to be on the periphery of the site and on the elevated tables. The 126,679 acres in Site B can produce 153.9 million pounds of forage in a normal year. Assuming bison have access to all of the site, and a mean bison weight of 1,000 lbs, a daily forage intake rate of 2.67% of body mass, and 33% of the forage allocated to bison, Site B could support 5,214 bison, including calves, or a bison to 24 acres. In a dry year the site could support 3,034 bison and in a wet year 6,652 bison. Different objectives (e.g., the amount of forage allocated to bison) and different assumptions (e.g., intake rates) result in different carrying capacities (**Table 6**).

Table 6. Modeled bison carrying capacity (includes calves) for Site B.

Forage Production Allocated to Bison	Forage Intake as Percent of Body Mass	Range Condition		
		Dry Year Carrying Capacity	Normal Year Carrying Capacity	Wet Year Carrying Capacity
15%	0.0300	1227	2109	2691
	0.0267	1379	2370	3024
	0.0200	1841	3164	4036
33%	0.0300	2700	4641	5920
	0.0267	3034	5214	6652
	0.0200	4050	6961	8880
50%	0.0300	4091	7031	8970
	0.0267	4597	7900	10078
	0.0200	6137	10547	13455

Figure 13 shows five categories of plant productivity within Site B. The red areas are typically associated with badlands type topography whereas the yellow, green, and blue polygons are associated with flatter and relatively moister (at least temporarily) soils. **Table 7** shows the respective area, plant productivity, and number of bison supported for each of the five classes. Site B contains the most high productivity land on both a total area and a percentage basis.

Table 7. Modeled normal-year productivity by range category within Site B.

Color on **Figure** 13	Acres in Site	Percent of Site	Productivity Per Acre lbs.	Total Productivity million lbs.	Bison*
Red	33117	26.1	<= 481	13.82	468
Yellow	42161	33.3	>481 and <=1295	49.66	1682
Green	22496	17.8	>1295 and <=1608	32.74	1109
Light Blue	16046	12.7	>1608 and <=1920	28.82	976
Dark Blue	12823	10.1	>1920	28.95	980
Total	126643	100		153.99	5215

* The number of bison assumes a 33% forage allocation, a 2.67% intake rate, and a 1,000 lb bison (includes calves).

Figure 9. A grazed good productivity (dark blue category) soil type.

Site B contains several plateaus or tables (**Figure 5**, **Table 8**). The Galigo Table, Galigo Little, and the two small southernmost tables in the Blindman Complex (referred to as Blindman South and Blindman Little in **Table 8**) show no evidence of cattle or vehicle use and may be inaccessible to bison, whereas the other tables show evidence of cattle use and should be accessible to bison. Although the number of bison these areas could support is not great, they nevertheless should be monitored for bison use and if bison are not utilizing the areas at a normal rate then management may want to revise the carrying capacity estimates.

Table 8. Plateaus in Site B and their productivity.

Plateau Name	Acres	Percent of Site Area	Normal Year Productivity	Percent of Site Productivity	Bison*
Galigo Table	411	0.32	818447	0.53	28
Galigo Little	29	0.02	49685	0.05	2
Plenty Star Table	303	0.24	569011	0.37	19
Blindman Table	687	0.54	1406905	0.91	48
Blindman East	276	0.22	586855	0.38	20
Blindman South	53	0.04	112859	0.07	4
Blindman Little	18	0.01	39460	0.03	1
Total	*1777*	*1.39*	*3583222*	*2.34*	*122*

* The number of bison assumes a 33% forage allocation, a 2.67% intake rate, and a 1,000 lb bison (includes calves).

Differing culling strategies would affect herd composition and theoretically, the number of bison a site could support. For example, an annual cull of yearlings and 10% of the large bulls results in a herd that only weighs about 0.91 of a herd with a normal age and sex structure. For Site B that could increase the stocking rate from 5,214 to 5,704 animals, assuming the altered sex-age structure was maintained. I do not adjust my outputs for such a scenario, but it would not be unreasonable if management adjusted stocking rates based on herd composition.

Site C

Site C has some areas with high productivity, but also has substantial areas of fair to poor productivity (**Figure 14**). The 96,680 acres in site C could produce 108.3 million pounds of forage in a normal year. Assuming bison have access to all of the site, a mean bison weight of 1,000 lbs, a daily forage intake rate of 2.67% of body mass, and 33% of the forage allocated to bison, Site C could support 3,666 bison, including calves, or a bison to 26 acres. In a dry year the site could support 2,034 bison and in a wet year 4,675. Different objectives (e.g., the amount of forage allocated to bison) and different assumptions (e.g., intake rates) result in different carrying capacities (**Table 9**).

Table 9. Modeled bison carrying capacity (includes calves) for Site C.

Forage Production Allocated to Bison	Forage Intake as Percent of Body Mass	Range Condition		
		Dry Year Carrying Capacity	Normal Year Carrying Capacity	Wet Year Carrying Capacity
15%	0.0300	823	1483	1891
	0.0267	925	1666	2125
	0.0200	1234	2224	2837
33%	0.0300	1811	3262	4161
	0.0267	2034	3666	4675
	0.0200	2716	4894	6241
50%	0.0300	2743	4943	6304
	0.0267	3082	5554	7083
	0.0200	4115	7415	9456

Figure 14 shows five classes of plant productivity within Site C. The red areas are typically associated with badlands type topography whereas the yellow, green, and blue polygons are associated with flatter and relatively moister (at least temporarily) soils. **Table 10** shows the respective area, plant productivity, and number of bison supported for each of the five classes.

Site C contains several plateaus or tables (**Figure 6**, **Table 11**). The Galigo Table, Galigo Little, and the two small tables in the Blindman Complex (referred to as Blindman South and Blindman Little in **Table 11**) show no evidence of cattle or vehicle use and may be inaccessible to bison. The other tables show evidence of cattle use and therefore it is reasonable to assume that bison would use the sites as well. Although these tables do not support a lot of bison, the areas should be monitored for bison use and if bison are not utilizing the areas at a normal rate then management may want to revise the carrying capacity estimates.

Table 10. Modeled normal-year productivity by range category within Site C.

Color on Figure 14	Acres in Site	Percent of Site	Productivity Per Acre lbs.	Total Productivity million lbs.	Bison*
Red	31893	33.0	<= 481	13.36	452
Yellow	29720	30.7	>481 and <=1295	34.85	1180
Green	17850	18.5	>1296 and <=1655	26.71	905
Light Blue	12230	12.7	>1655 and <=2010	22.51	762
Dark Blue	4928	5.1	>2010	10.82	366
Total	*96621*	*100*		*108.25*	*3665*

* The number of bison assumes a 33% forage allocation, a 2.67% intake rate, and a 1,000 lb bison (includes calves).

Figure 10. An ungrazed moderate productivity (green category) soil type.

Differing culling strategies could change herd composition and theoretically, the number of bison a site could support. For example, an annual cull of yearlings and 10% of the large bulls results in a herd that only weighs about 0.91 of a herd with a normal age and sex structure. For Site C that could increase the stocking rate from 3,666 to 4,101 animals, assuming the altered sex-age structure was maintained. I do not adjust my outputs for such a scenario, but it would not be unreasonable if management adjusted stocking rates based on herd composition.

Table 11. Plateaus in Site C and their productivity.

Plateau Name	Acres	Percent of Site Area	Normal Year Productivity	Percent of Site Productivity	Bison*
Galigo Table	411	0.43	818447	0.76	28
Galigo Little	29	0.02	49685	0.05	2
Plenty Star Table	303	0.31	569011	0.53	19
Blindman Table	687	0.71	1406905	1.30	48
Blindman East	276	0.29	586855	0.54	20
Blindman South	53	0.05	112859	0.10	4
Blindman Little	18	0.02	39460	0.04	1
Total	*1777*	*1.83*	*3583222*	*3.32*	*122*

* The number of bison assumes a 33% forage allocation, a 2.67% intake rate, and a 1,000 lb bison (includes calves).

Comparison to Other Estimates and Stocking Rates

There are many "correct" stocking rates for a bison herd. Ultimately, the selection of a stocking rate depends on goals, priorities, logistics, assumptions, and legal authorities, as well as plant productivity and other factors. That is one reason why this report provides a range of values for stocking rates as well as other outputs. In this section I compare and contrast the estimates here with known stocking rates in the region and other estimates for the project area.

Badlands National Park North Unit

Badlands NP has about 64,000 acres available to bison in the North Unit. Similar to the three sites analyzed in this report, much of that land consists of rugged badlands topography with poor plant productivity. The park generally tries to support about 700 bison in the unit (Pyne et al. 2010), although the herd may currently be closer to 1,500 (Eddie Childers, pers. comm.). A roundup in September 2014 indicated the 1,500 or so animals were healthy and heavy (Brian Kenner, pers. comm.). The 700-animal target level is based on drought conditions, i.e., an unfavorable year using NRCS terminology. The park's bison management plan indicates the normal-year forage carrying capacity for the herd is 1,500-1,800 adult animals (Badlands National Park 2003), and Raekeke and Cole (1969) suggested the park could support about three times the 700-animal goal. The latter densities are comparable to the normal-year densities in this report. The reason for managing the herd at drought levels at all times, regardless of moisture conditions, is in large part because of logistical constraints. For example, the park does not have reliable funding to round up and dispose of surplus bison so roundups cannot be assured in all years. Keeping the population low, i.e., about 40% of what the range could support, provides a buffer for several years of growth before the next roundup. Furthermore, the infrastructure at the park does not allow for roundup of large numbers of bison in a safe manner, hence smaller roundups are preferred. With adequate tools and authorities the park could manage the North Unit for a much larger herd.

Ranch Advisory Partners Analysis for South Unit

Ranch Advisory Partners (2013) conducted an analysis of bison stocking rates based on forage needs for four sites in the vicinity of the three sites analyzed in this report. Their Alternative A mostly overlapped with Site B in this report. Their recommended stocking rate for that area was substantially less than the mid-point value reported here, i.e., 1,072 versus 5,214. The disparity appears to be primarily due to different assumptions and methods and is easily explained. As stated in their report, they took a very conservative approach to establishing a stocking rate. Their primary method utilized BIA data, which was derived from older NRCS data and, according to their report, revised using site-specific clipping data. They also conducted an analysis using the NRCS Web Soil Survey database, but did not apply the method comparable to the way it was applied here nor in a way that was recommended by NRCS personnel (Ranch Advisory Partners 2013:44). Specifically, contrary to the recommendation of NRCS, Ranch Advisory Partners completely excluded low-productivity badlands soils from their analysis, terming these areas as "unusable." Yet Ranch Advisory Partners also stated in their report that:

> "*those badlands soils often do have productive contributions, and they should be considered. However, in an effort to be as conservative as possible for set stocking the unit, the practice (of excluding the soil types) was continued. This likely greatly reduced the South Unit's herd size and also resulted in fewer grazeable acres than BIA's analysis*." (Ranch Advisory Partners 2013:44).

This total exclusion of low-productivity sites appears to explain much of the disparity: when I exclude poor and fair soil types the normal precipitation year estimate is 2,033 animals for Site B, substantially closer to their estimate. Although Ranch Advisory Partners acknowledge that the "badlands soils provide some utility for buffalo"(Ranch Advisory Partners 2013:11) they exclude the productivity in their calculations, and it appears, so does BIA. The other significant difference between their estimate and the mid-point values presented here is that they recommended a stocking rate based on an unfavorable, i.e., drought, year conditions whereas I used normal year productivity for many outputs and summaries. When I use drought year conditions, and exclude areas of poor and fair productivity, the estimate for Site B is 1,182, comparable to their estimate. Yet another, albeit more minor, difference is that I present population estimates that include calves, a cohort that can represent about 18% of a herd; when I remove that cohort, poor and fair soils, and use drought year productivity, the estimate for Site B is 970 animals. The differences are summarized in **Table 12**. To put the disparity another way, the methods used here can come up with the same result as the Ranch Advisory Partners report, i.e., a recommended stock rate of 1,072 bison, if I assume a forage allocation of 7%.

Although I include all soil types in my calculations, including badlands types, I don't dismiss the concerns of Ranch Advisory Partners about inclusion of the badlands types (which is one reason why I strongly recommend a monitoring program accompany any reintroduction). I included these sites based in part on the recommendation of NRCS (Stan Boltz, pers. comm.). The argument for inclusion is that the Web Soil Survey weighted-average setting accounts for "non-site" components that have no forage value (e.g., rock outcroppings) as well as the small amounts of non-dominant vegetated areas within the map unit. Nevertheless, some of this forage may be on slopes too steep for bison, protected by rugged badlands topography, or a substantial distance from more productive soil types (**Figure 11**). The larger tracts of badlands topography may be especially inhospitable, perhaps hosting only the occasional bison bull, at most. Hence, a reasonable argument can be made to reduce bison numbers by the forage carrying capacity of the "red" (i.e., badlands) areas in the maps and stocking rate tables (which ranges from 26-36% of the sites). Conversely, the yellow areas are typically comprised of level or rolling terrain accessible to bison (**Figure 8**) and that forage should be included in forage calculations. Having said that, even if the "red" badlands types prove to be inaccessible to bison the mid-point values presented here for Sites A (854), B (5,214), and C (3,666) are still well within what the sites can support in part because those numbers were derived using a forage allocation of only 33%, whereas many grazing operations go up to 50%. For example, if the productivity from all the badlands soil types (the red category) are excluded for Site C, yet the number of stocked bison remains at 3,666 animals, the forage allocation would rise from 33% to 38%.

Figure 11. A poor productivity (red category) soil type and badlands topography.

Ultimately, the selected stocking rate should depend on the goals for the site, logistical considerations, and other factors as well as the energetic carrying capacity. There is a lot of latitude in stocking rates, with many acceptable targets. The Ranch Advisory Partners analysis is not wrong (nor is the analysis in this report); it is simply based on deliberately conservative assumptions and, it appears, goals.

Ranch Advisory Partners appear to take a slightly different philosophical approach than what is used here. For example, they viewed livestock lingering and heavy use at one site while another site received relatively little use as a "grazing distribution issue" (Ranch Advisory Partners 2013:12). Yet, from a biodiversity perspective, this uneven grazing is a positive. Non-uniform grazing intensities (within limits) creates the patchy landscape heterogeneity that is needed to conserve biodiversity (Fuhlendorf and Engle 2001, Fuhlendorf et al. 2006, Uresk and Mergen 2012). Whereas a species such as sharp-tailed grouse (*Tympanuchus phasianellus*) can be better maintained by light grazing, other species need heavier grazing. Two of the significant resources in the South Unit, as identified by the South Unit GMP/EIS (National Park Service 2012), are the black-tailed prairie dog and black-footed ferret (*Mustela nigripes*); both can best be maintained by moderate to heavy grazing levels. They would likely not prosper from the Ranch Advisory Partners recommendations. If management wants to conserve these species, and other biodiversity in the South Unit, it should manage for a spectrum of grazing intensities and conditions and try to avoid uniform very-light grazing.

Table 12. Comparison of forage utilization stocking rates between estimates.

Variable	Ranch Advisory Partners	This Report	Comments
Land Area	Excluded acreage deemed "unusable"	Included all areas (but present data on poor sites for comparison purposes).	This difference is substantial and accounts for about half the disparity in estimated carrying capacity.
Moisture Conditions	Based on unfavorable, i.e., drought conditions.	Use normal conditions (but also present unfavorable and favorable conditions).	The difference is substantial and explains just under half of the disparity.
Calves	Not counted in total herd size.	Counted in herd size.	Difference is minor as calves account for about 18% of a herd.
Method/Data	Present values from BIA method but also used variation of NRCS method.	NRCS	Difference appears negligible when similar assumptions used.
Forage Allocation	40%	15, 33, and 50% with 33% as baseline	The difference between 33 and 40% results in about a 20% change in herd size.
Intake Rate	1,000 lbs per month for cow-calf pair, or 33 lbs per day, when using the BIA method. 30 lbs per animal per day using NRCS method.	Used .26 of body weight and assumed 1,000 lb animal, or 26 lbs per day, but frame results using other intake rates.	The difference appears to be negligible.

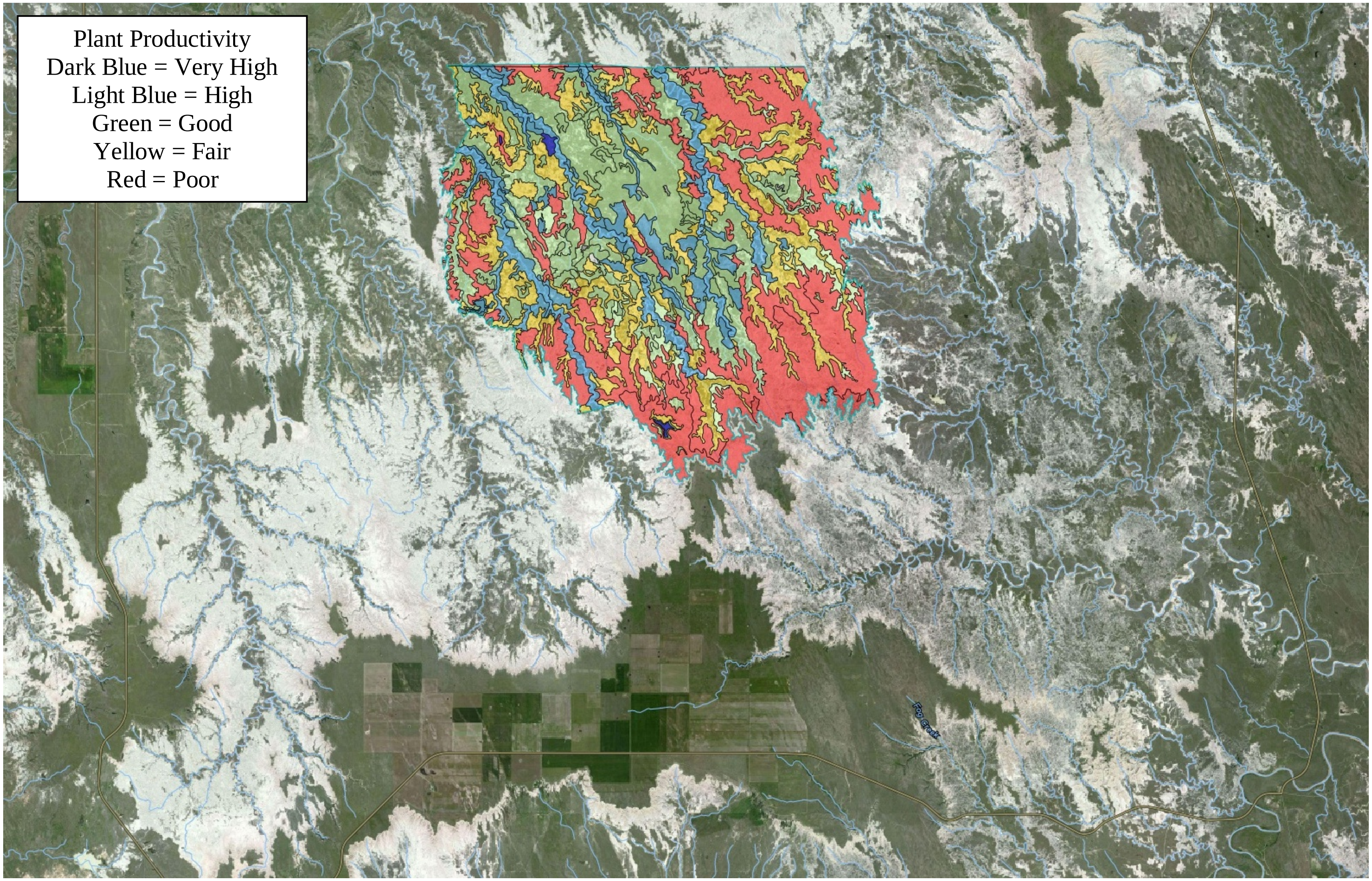

Figure 12. Map of relative plant productivity in Site A in a normal year.

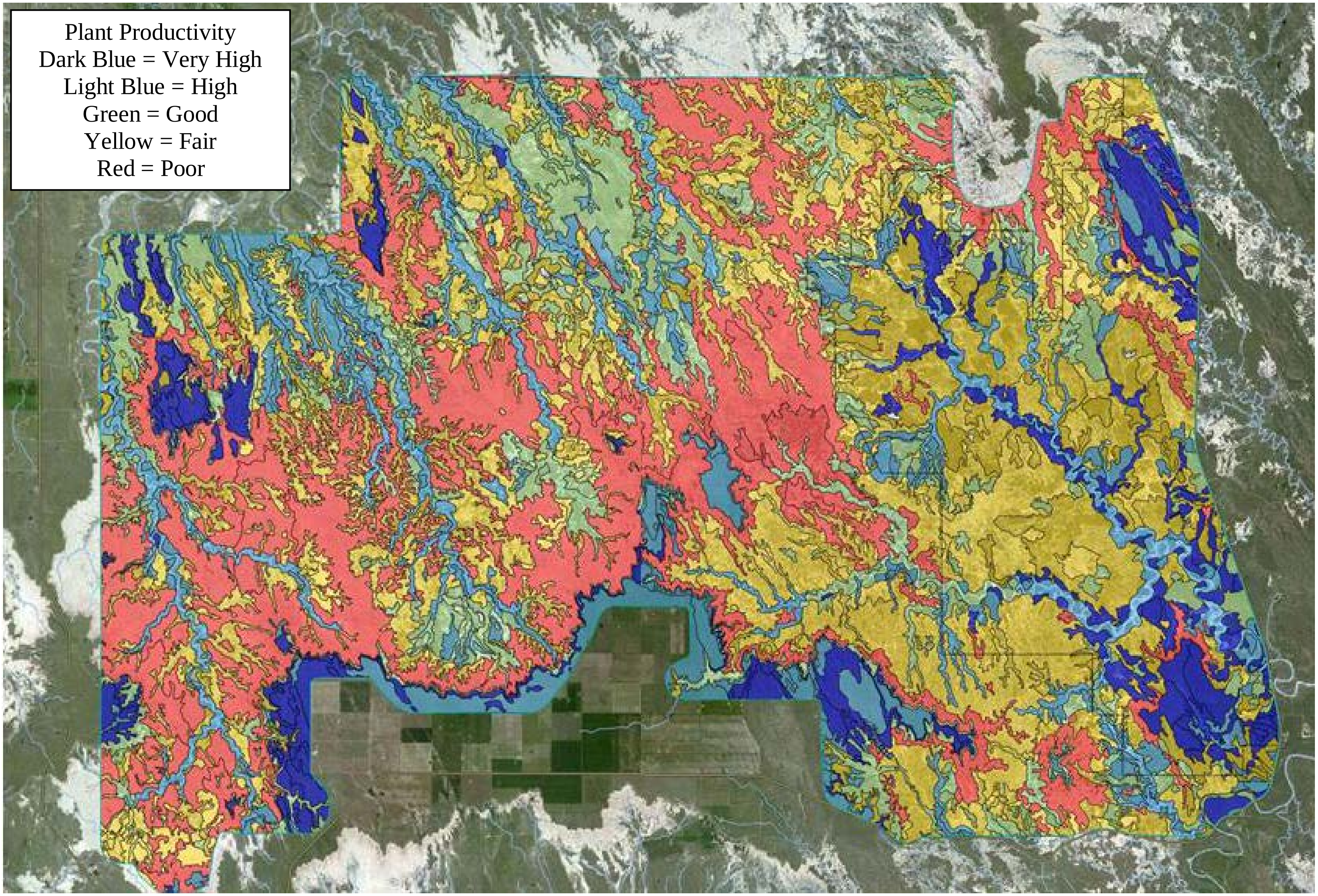

Figure 13. Map of relative plant productivity in Site B in a normal year.

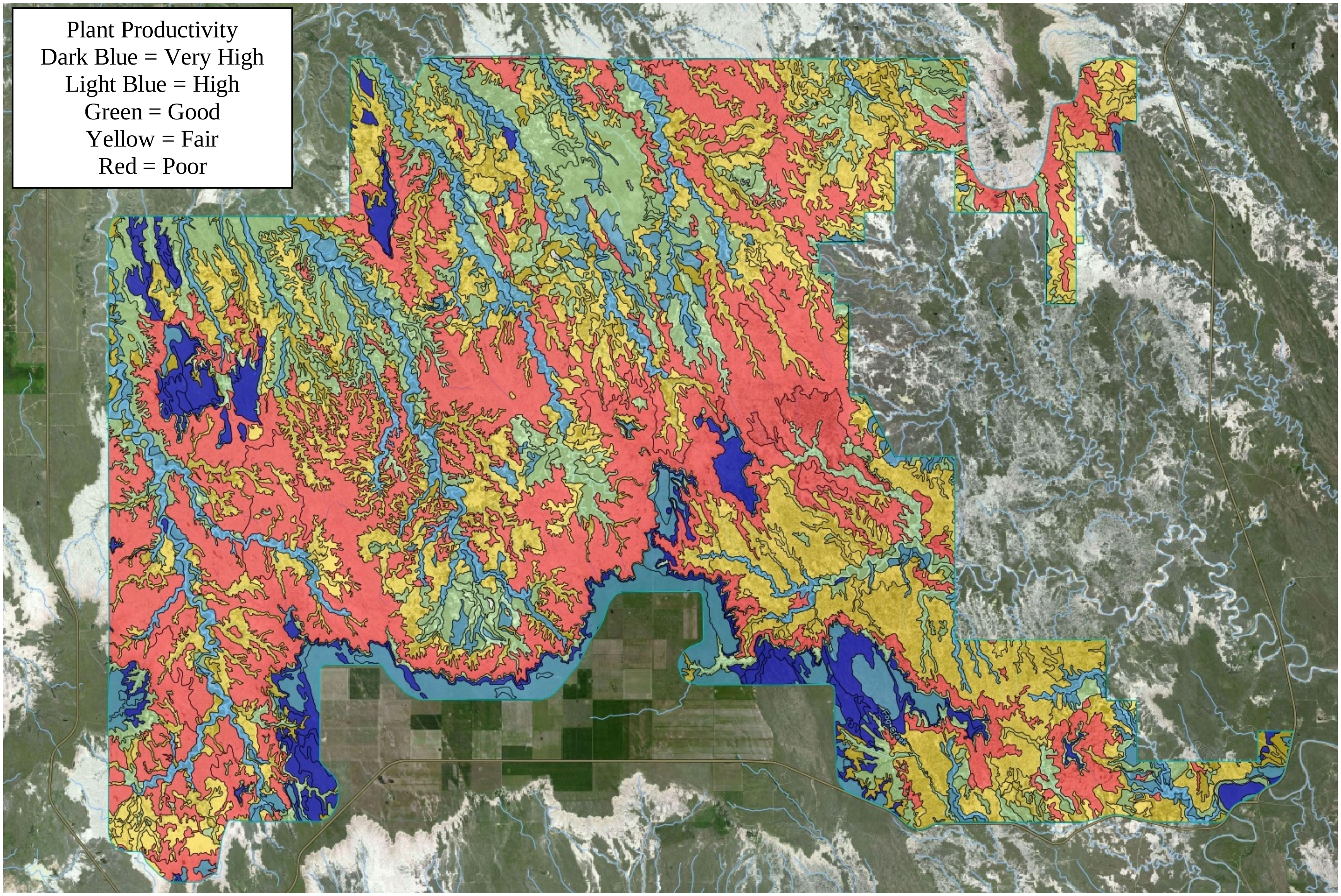

Figure 14. Map of relative plant productivity in Site C in a normal year.

Culling Strategies

Once a herd is established it will eventually need to be maintained at the population target(s) for the site. The most likely approach for keeping the bison population at the desired goal is to periodically round up and remove surplus animals. Management has numerous options regarding the number and type of animals to be removed with there being tradeoffs among the alternatives. I evaluated and present four plausible culling strategies under 10 different herd sizes. The strategies could be used at any of the three geographic sites and are not affected by site characteristics (other than as they relate to herd size) therefore I do not discuss the results by site, but rather, by culling strategy and herd size.

The Growth Stage

For all modeled scenarios I started with an initial herd of 500 animals comprised of 1-7 year olds, as I assume that is the number and type of animals that will come from Badlands NP North Unit to start a herd in the South Unit. If the desired herd size is greater than 500 then there will need to be a period of herd growth to reach the population target. I assumed there would be no culls during this stage. Assuming 15% annual growth a starter herd of 500 could reach 3,500 animals in about 16 years whereas a starter herd of 1,000 (comprised of the same age-sex structure) could reach that level in 11 years (**Figure 15**). However, the survival rates reported by (Millspaugh et al. 2005) and (Pyne et al. 2010) result in differing rates of growth.

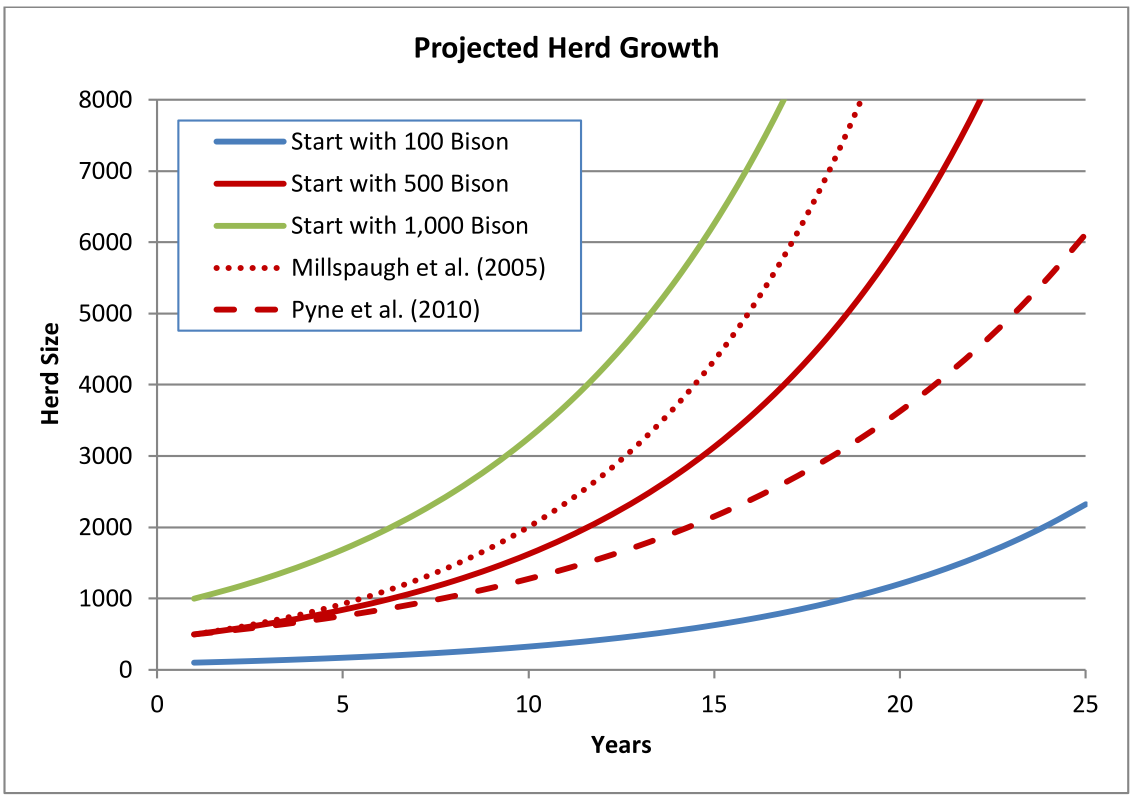

Figure 15. Projected bison herd growth under varying initial population sizes.

The Correction Stage

I assumed a founder herd comprised of younger animals (ages 1-7) from Badlands NP. This herd will have maximum productivity about Years 3-10 after an introduction as the animals reach their age of peak reproduction and survival. **Figure 16** shows this high fecundity and survival during this time period. For the graph I assumed a fixed rate of culling (80% of yearlings and 10% of males) once the herd exceeds the target population: in the long run this rate of harvest is adequate to stabilize a population (although culls may not be necessary in all years). However, during the "correction stage" that rate of cull is inadequate to keep up with the high fecundity and survival of the animals. This temporary bump in productivity does not appear in larger herd sizes as those herds develop a more natural age-sex structure by the time the first harvest occurs. I do not analyze this stage in detail as it's short-term and the difference from the long-term is negligible. It is presented only to show that culls and revenue generation may be slightly higher than the long-term mean during this period.

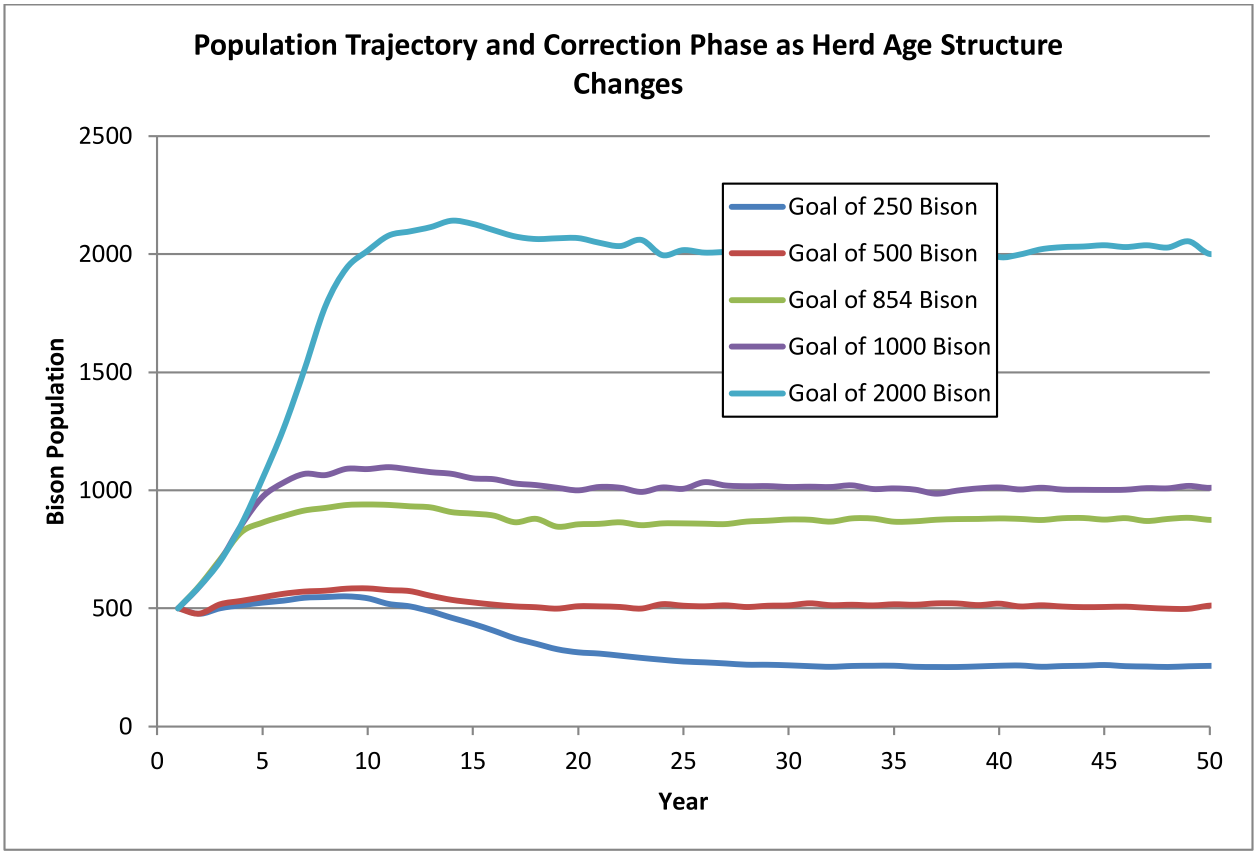

Figure 16. Population trajectory for 5 population levels and correction phase.

The Long-term Maintenance Stage

I evaluated four different culling strategies. The goal of each strategy was to keep the long-term mean population size near the target level for the herd. The simulations included stochasticity (i.e., randomness) to mimic natural fluctuations in reproduction and survival. The three annual culls maintain a very stable herd size with relatively low variability (± 50 animals) whereas a cull every fourth year shows greatly inter-year variability of ± 250 animals (**Figure 17**). There are pros and cons to each scenario. Annual culls can provide a more dependable and frequent harvest and revenue. The cull every fourth year probably requires less work over the long run, although the per-cull effort cull will be greater due to the larger number of animals to be processed. The cull every fourth year could arguably better mimic natural processes as bison numbers likely varied between years due to precipitation and other factors; however, I modeled a fixed culling frequency that would likely be out of sync with precipitation over the long term. Furthermore, large variability in herd sizes can create bottlenecks that reduce genetic diversity (see the Genetics section). The annual variability in pre-harvest population size will affect the number of animals harvested and the amount of revenue generated (discussed in the Revenue section).

The differing culling strategies will also affect the herd composition. For example, an annual cull only of yearlings creates an unnatural age structure within a herd whereby there is a dramatic drop in cohort abundance between the yearling class and the 2-year old class (**Figure 18**). It also results in a herd comprised of a higher percentage of older animals, especially in the female cohort as they have very high survival rates in the middle years. Adding adult males to the annual yearling harvest creates even more of an unnatural age and sex structure as adult males make up a very small percentage of the herd. These impacts to herd composition can in turn affect revenue generation, genetics, and other factors.

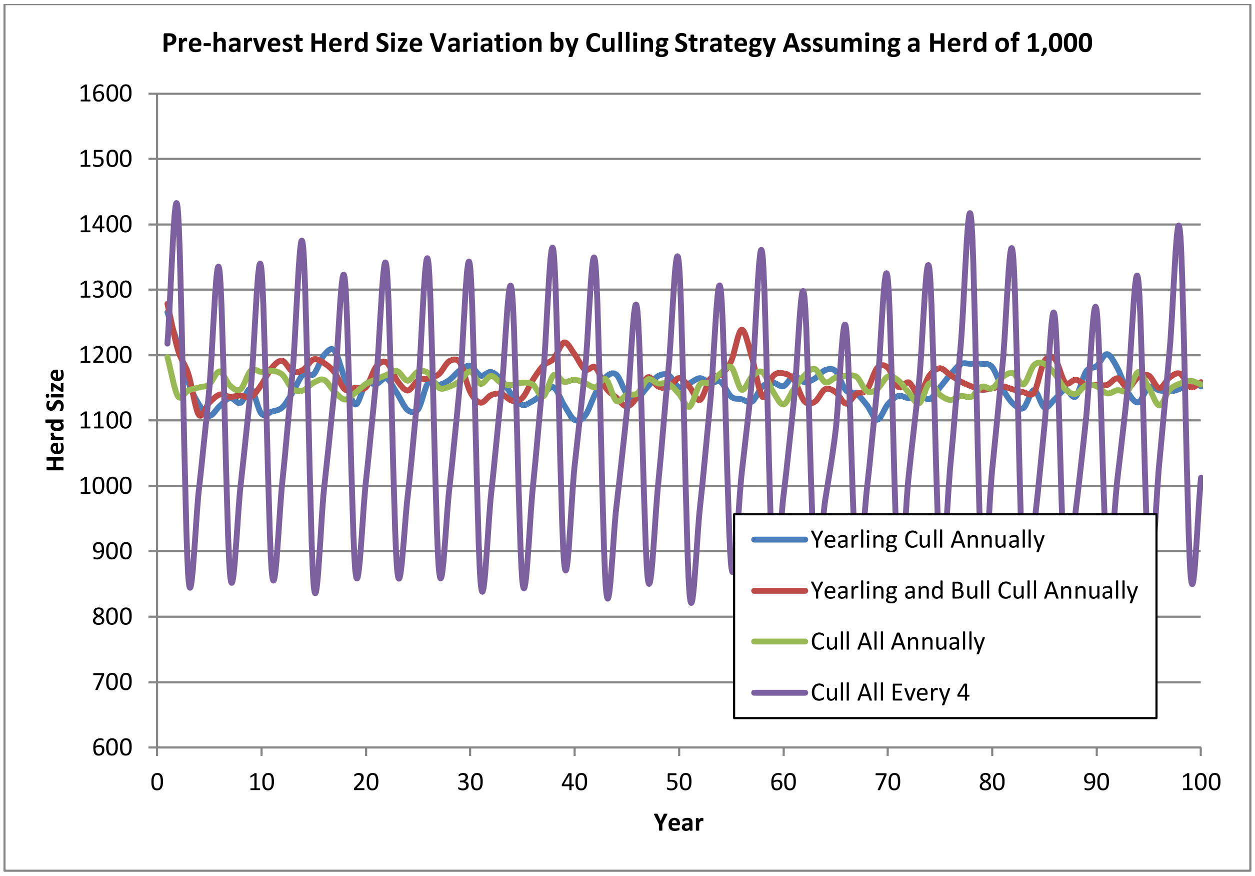

Figure 17. Annual variability in herd size under four culling strategies.

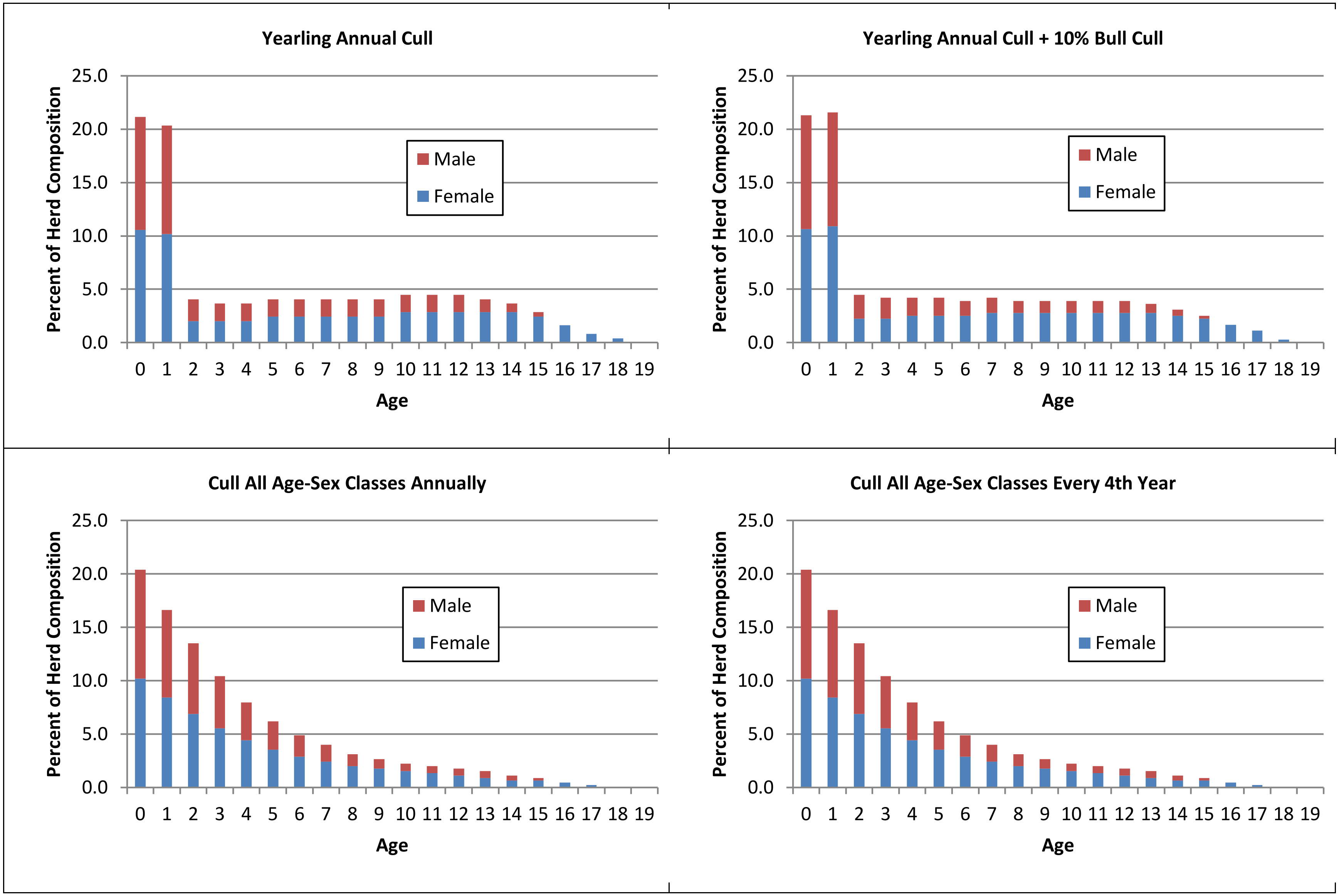

Figure 18. Typical age and sex composition of the herd under various culling strategies.

For a herd of 1,000 animals about 150, or 15%, of the herd would need to be removed annually on average to keep the population stable. This could consist of only a single cohort such as yearlings, or could be spread across all cohorts. A notable exception to this are the adult males. Because bison are a polygynous species adult bulls could be removed with no effect on reproduction and population growth (however, there could be other impacts such as genetic deterioration). A cull every fourth year would have to remove about 4x the rate of animals as the annual culls.

Table 13 shows the average number of animals in each cohort that would be harvested under each culling strategy for a herd of 1,000 animals once the herd has a stable age and sex structure. The numbers are directly correlated to herd size, so the numbers could be extrapolated to other herd sizes. For example, whereas an *Annual Yearling Cull* would remove 150 animals for a herd of 1,000 it would remove 300 animals for a herd of 2,000.

My model included stochasticity (i.e., randomness) to simulate the annual fluctuations in reproduction and survival that occur in a bison herd. In <1% of the years there was no need for a cull in the annual culling strategies because the population did not reach the desired population level. In other words, after the cull in year *X* reduced the population to the desired level the subsequent winter mortality was so great and the following spring reproduction so low that the population could not get back to the target level by the time for the next harvest. The strategy to cull every fourth year has enough animals to conduct the cull (i.e., exceeded the population goal) as one would expect for that scenario.

Stochasticity also caused variability in the number of animals culled each year. In **Table 13** the standard deviation for the inter-year variability in total animals harvested was 80 for the *Annual Yearling* and *Annual Yearling + Bull Cull*, and 50 for the annual cull of all age classes. This inter-year variability in the number of animals culled would also cause variability in the revenue generated from the culls.

Table 13. Average of each cohort culled by strategy assuming herd of 1,000.

	Female Calves	**Male Calves**	**Yearling Females**	**Yearling Males**	**Adult Females**	**Adult Males**	**Total Animals**	**Standard Deviation**
Annual Yearling Cull	0	0	74.7	74.7	0	0	149.4	82
Annual Yearling + Bull Cull	0	0	81.9	81.8	0	16.7	180.4	81
Annual Cull All Age Classes	14.8	14.9	11.9	11.9	53.6	40.2	147.3	50
Cull All Classes Every 4th Yr								
Average Across Years	14.2	14.2	11.9	11.4	51.2	38.4	141.3	-
Year of Cull	*56.8*	*56.8*	*47.6*	*45.6*	*204.8*	*153.6*	*565.2*	*202*

* Each scenario started with a herd of 1,000 bison comprised of a stable age and sex structure for that culling scenario. Culls removed enough animals to reduce the herd to 1,000. Each simulation ran for 100 years. In <1% of the years the herd did not exceed 1,000 bison prior to the cull (due to stochastic factors) so no cull was conducted; however, the values are averaged across 100 years of simulation.

Revenue Generation

For modeling revenue I assumed per-animal live-weight dollar values of $780, $1550, and $1680 for female calves, yearlings, and adults, respectively, and $840, $1740, and $2800 for males. I assumed a starting herd of 500 animals, comprised of animals aged 1-7. If the desired herd size is larger than that then revenue may need to be deferred until the herd reaches the desired population goal (however, partial culls could occur during that period, but such culls—especially if they take the female cohort—would slow growth and the year at which the population target is reached). For example, if the desired herd size is 3,500 bison it would take 13-17 years before the population goal would be reached, but the revenue would be substantially more than smaller herd sizes (**Figure 19**).

As discussed in the section on culling strategies, the modeled herds attain maximum productivity about 3-10 years following introduction as the founder animals reach their most productive age (the correction stage). That modest bump of high productivity, which is most prominent for smaller herd sizes, can be seen in **Figure 19**.

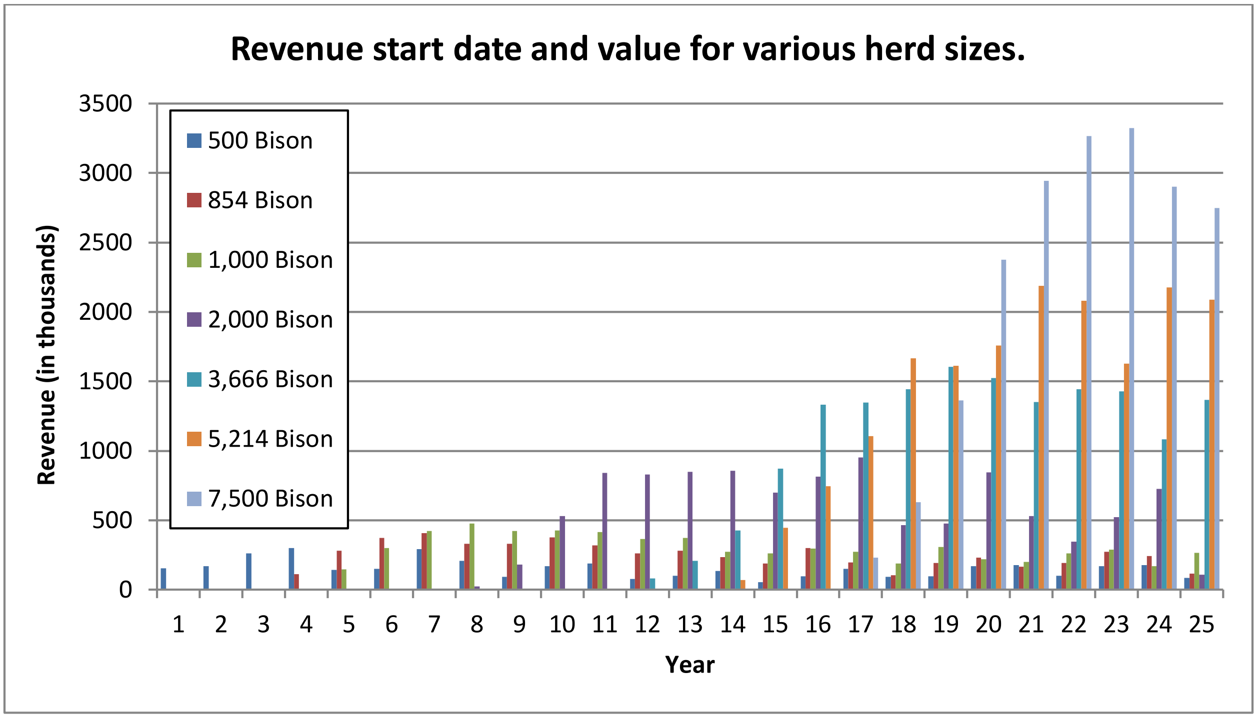

Figure 19. Revenue generation assuming *Annual Yearling + Bull Cull* for first 25 Years.

The *Annual Yearling + Bull Cull* produced the greatest economic return, about $315,000 annually for a herd of 1,000 animals once it reaches a stable age and sex structure (**Table 14**). That herd produced substantially more than the *Annual Yearling Cull*. Part of the greater return is due to the inclusion of the valuable adult males, but part of it is because the reduction in adult males leaves more forage for cows which thereby increases recruitment which leads to more yearlings to cull. However, the *Yearling + Bull Cull* does much poorer in terms of genetic conservation, as discussed in the next section. The *Annual All Age Classes Cull* generated about $265,000 for a herd of 1,000, the *All Age Classes Every Fourth Year Cull* generated about $255,000 (on average), and the *Annual Yearling Cull* generated about $245,000 annually. These values can be extrapolated proportionally to estimate the annual revenue generation of other herd sizes (e.g., an *Annual Yearling + Bull Cull* for a herd of 2,000 would generate $630,000 annually). **Figure 20** shows how those values extrapolate across the 10 modeled herd sizes.

Table 14. Revenue generated by culling strategy assuming herd of 1,000.

	Female Calves	Male Calves	Yearling Females	Yearling Males	Adult Females	Adult Males	Total
Annual Yearling Cull	$0	$0	$115,785	$129,978	$0	$0	$245,763
Annual Yearling + Bull Cull	$0	$0	$126,945	$142,332	$0	$46,760	$316,037
Annual Cull All Age Classes	$11,544	$12,516	$18,445	$20,706	$90,048	$112,560	$265,819
Cull All Classes Every 4th Yr							
Average Across Years	$11,076	$11,928	$18,445	$19,836	$86,016	$107,520	$254,821
Year of Cull	*$44,304*	*$47,712*	*$73,780*	*$79,344*	*$344,064*	*$430,080*	*$1,019,284*

* Each scenario started with a herd of 1,000 bison comprised of a stable age and sex structure for that culling scenario. Culls removed enough animals to reduce the herd to 1,000. Each simulation ran for 100 years. In 1% of the years in the annual cull scenarios the herd did not exceed 1,000 bison prior to the cull (due to stochastic factors) so no cull was conducted; however, the values are averaged across 100 years of simulation.

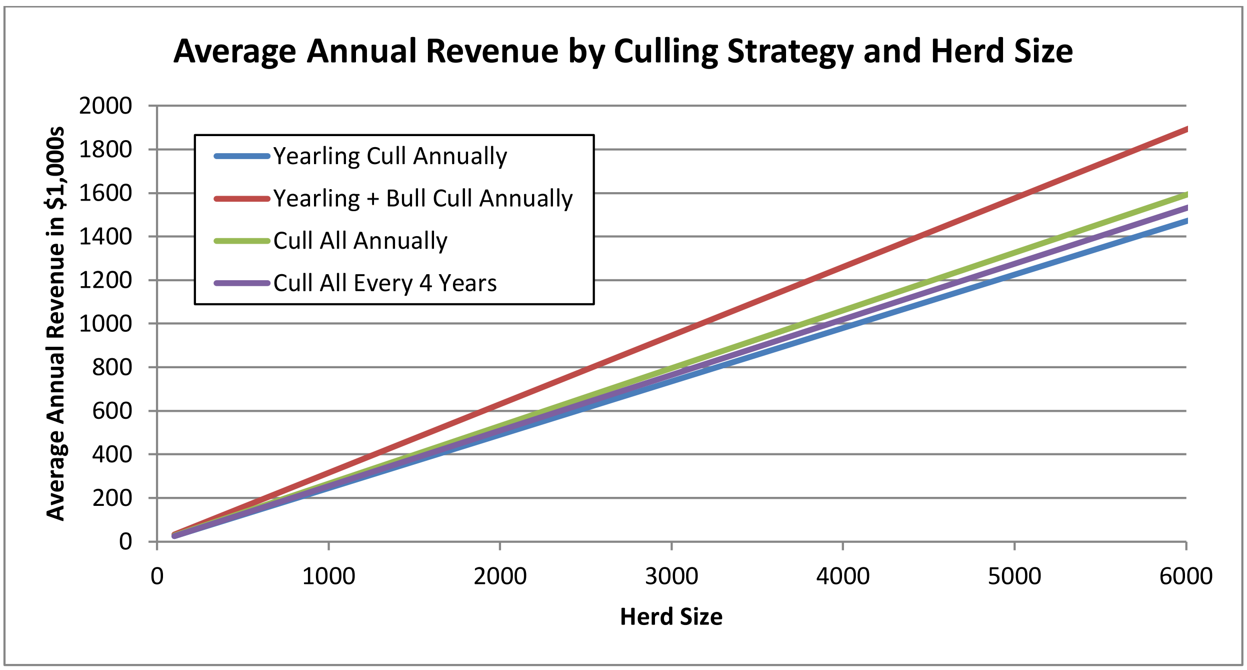

Figure 20. Average annual revenue generated by cull strategy across herd sizes.

National Park Service units do not sell bison so sale value from NPS herds is unavailable. However, Custer State Park in South Dakota sells, via auction, about 200-500 animals annually from its herd of 1,500. The auction includes all age and sex classes except older bulls. Annual auction sale value in 2011-13 was $317,200, $401,750, and $478,150, respectively, comparable to the results presented here. In addition, the park sells hunting permits. In 2014 it plans for 8 trophy bull permits at $5,000 each, 15 non-trophy bull permits at $2,256 each, 10 non-trophy cow permits at $1,756, for a total of $91,400. The revenue realized from the South Unit could be increased if a similar program was used.

Stochastic models simulate annual variability in wildlife populations by adding random changes to survival and reproduction. The randomness can in turn affect the number of animals culled and revenue generation. **Figure 21** shows the variability that could be expected in revenue generation under the culling strategies, assuming a herd of 1,000 animals.

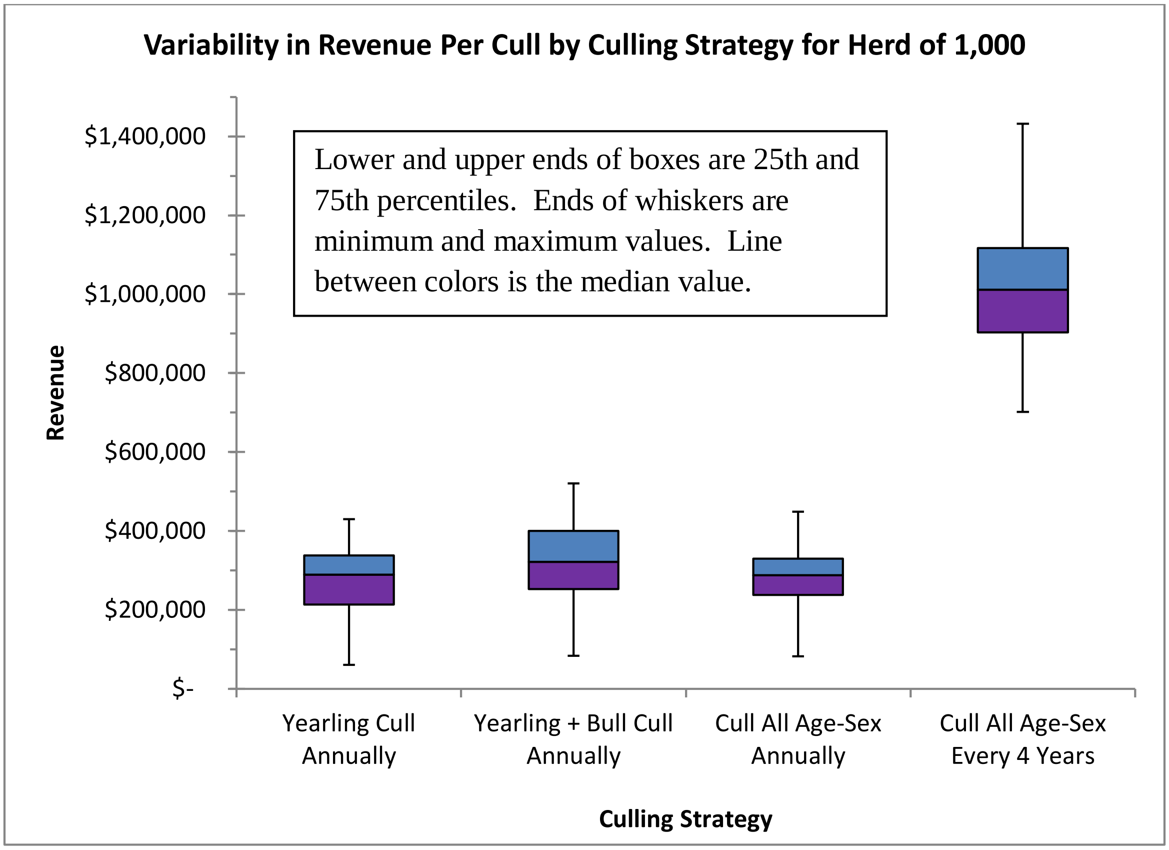

Figure 21. Variability in annual revenue generation under 100 iterations.

The amount of revenue generated from a bison program can be reasonably, but not precisely, predicted. Some factors, such as the market value of bison, are outside the operator's control. Based on recent history it's not unreasonable to expect a 25% fluctuation in bison prices over time. Other factors are under management's control, but all of the various options and scenarios cannot be presented here. For example, management could decide to harvest bulls via a guided trophy hunt program as is done at Custer State Park. The permit fees for such hunts ($5,000 in 2014) are almost twice the carcass-weight value ($2,800) modeled here.

Genetics

The genetic health of bison is a serious concern within the federal government and the larger conservation community. Due to the severe bottleneck the species went through at the end of the 19th Century, and the long period of small isolated populations the genetic diversity of bison is much less than it probably was historically. Conserving genetic health should be a high priority in any conservation herd. I modeled the genetic diversity and theoretical inbreeding depression of reintroduced bison under various culling strategies and herd sizes. In all cases I started with a population of 500 animals seeded with the existing genetic diversity of the Badlands NP herd.

Genetic Diversity

Over time genetic diversity will decline in a bison herd unless mutations occur or animals are introduced. I modeled various herd sizes using the *Annual Yearling + Bull* culling strategy and the existing genetic diversity of the Badlands North Unit bison herd. When herd sizes reached about 1,000 animals the rate of decline in neutral genetic diversity slowed (**Figure 22**). This is consistent with the analysis by Gross and Wang (2005) and Halbert and Derr (2008). However, this does not mean that a herd of 1,000 animals assures genetic conservation. Larger herds simply reduce the rate of future loss of genetic diversity and, theoretically, they reduce the risk of loss of important or adaptive genetic diversity (e.g., disease resistance). Also, a herd of 1,000 animals can still be impaired depending on its history. In this study I started with a genetic diversity of 0.6, which is approximately the level of genetic diversity in bison herds in NPS units in the Northern Great Plains. Yet that level could already have undetected impacts on the herds. There is some evidence that the Wind Cave NP bison herd, the oldest of the three herds and the one with the fewest founders, may be suffering from 100 years of inbreeding depression (Licht, unpub. data).

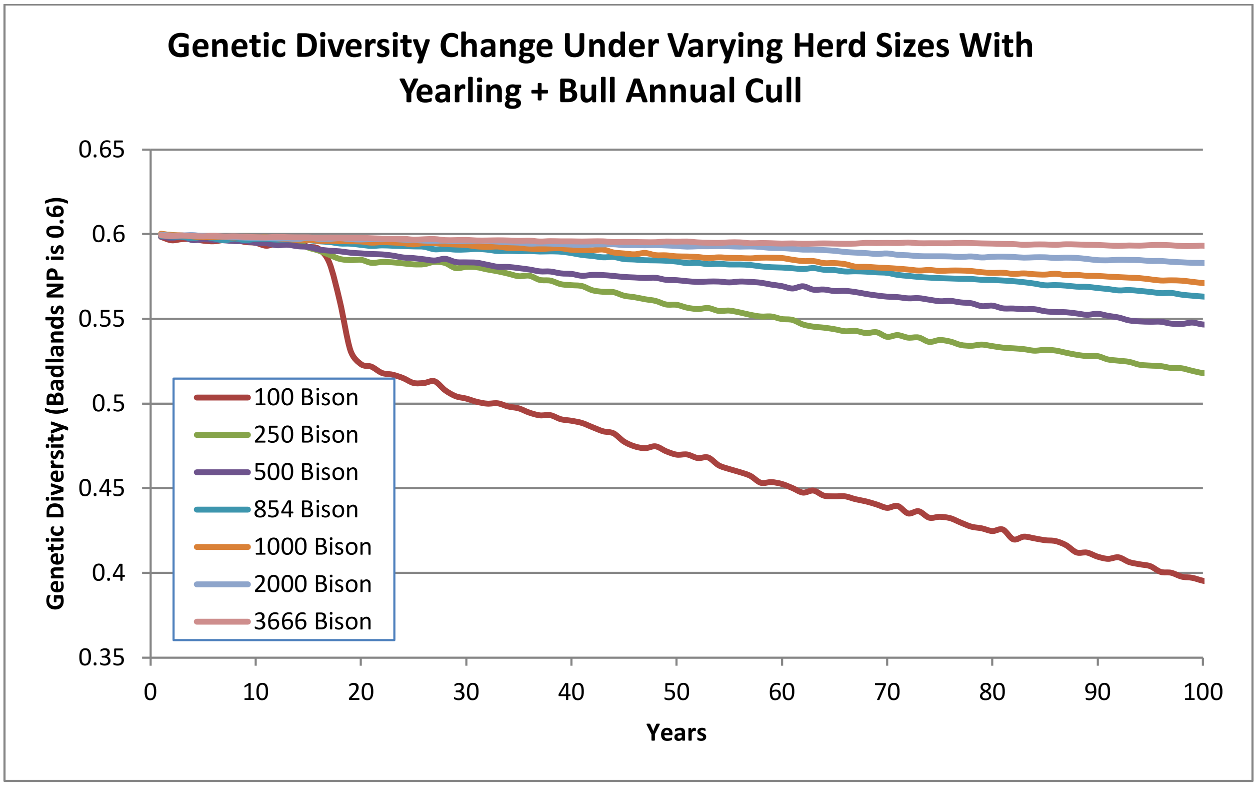

Figure 22. Genetic diversity decline for varying herd sizes and 80% annual yearling cull.

Halbert and Derr (2008) designed a genetic management plan for the Badlands National Park North Unit bison herd that stresses the importance of herd size. They recommended a strategy whereby a herd should be allowed to reach its maximum carrying capacity during normal and wet precipitation years and then, if necessary, reduced in drought years, versus, a strategy that maintains a herd at drought levels in all years. The results of this study are consistent with that recommendation.

The unusual trajectory and poor performance of the 100-animal herd warrants discussion. At about year 15 this herd appears to have suffered from very few prime age males in the herd due to the culling strategy. This caused the precipitous drop in gene diversity. The herd ended up with a gene diversity of about 0.38, the very same level as the genetically and demographically impaired Texas State Bison herd (Halbert et al. 2004). However, this result is probably unimportant as it seems unlikely that a herd of that size would be selected for the proposed park.

I modeled the retention of neutral genetic diversity in herd sizes as large as 10,000 animals. Although it's unlikely that a herd of that size would be stocked on the sites analyzed in this report, such an analysis is useful as it shows the degree to which genetic diversity could be conserved if a South Unit bison herd was managed as a metapopulation of other herds, i.e., there was occasional exchange of bison between the South Unit herd and other herds.

Among the four culling strategies the *Annual Yearling Cull* best conserved genetic diversity (**Table 15**). This can be explained in part by the fact that a yearling-only cull would not take entire family groups at one time whereas the multi age/sex class culls could. The multi-age/sex cull that occurred every 4th year performed worse than the cull of all sex-age classes annually. The reason for this is that a drastic cull every fourth year produces a short-term bottleneck for the population when the herd size is greatly reduced. The worse performing culling strategy was the *Annual Yearling + Bull Cull*. The reason for the poor performance is explained by the relatively small number of adult males in the herd. If the adult bull cull (i.e., hunt) took only very old (12+) bulls the effect of this strategy on herd genetics would be less severe as the breeding career of these animals is over. Whether that could be implemented in the field is unknown.

Table 15. Modeled 100-year genetic changes under various culling strategies (herd of 1,000).

	Percent Change in Gene Diversity[1]	Final Expected Heterozygosity (Gene Diversity)	Final Observed Heterozygosity	Final Number Alleles
Yearling Cull Annually	-2.6%	0.5845	0.5864	4.22
Yearling Plus Bull Cull Annually	-5.2%	0.5691	0.5719	4.17
Cull All Age-Sex Classes Annually	-3.5%	0.5791	0.5809	4.13
Cull All Age Sex Classes Every 4th Yr	-4.4%	0.5739	0.5756	4.16

1 From starting value of 0.60. In 100 years.

Inbreeding Depression

Genetic diversity in the form of neutral heterozygosity and number of alleles is an important characteristic in bison herds. However, for many the more important concern is when declining genetic diversity impacts herd demographics such as reproduction and survival. At exactly what level, and to what degree, genetic diversity impairs bison demographics is not well known. Halbert et al. (2004) found demographic impairment in the Texas State Bison Herd that had genetic diversity of 0.38, but whether impairment occurs above that level is unknown. VORTEX uses the concept of lethal equivalents (LEs) to model demographic impairments from inbreeding depression. Higher levels of LEs, and reduced genetic diversity, reduce recruitment and juvenile survival in the model (Lacy et al. 2014). Halbert and Derr (2008) used 3.14 LEs—the VORTEX default value at the time—when they modeled the Badlands NP herd. However, the default value is now 6.29, a value established from a range of mammal studies (O'Grady et al. 2006, Lacy et al. 2014). I modeled LEs of 1.57, 3.14, and 6.29 as well as a baseline with no LEs to show the theoretical impacts on herd performance over time.

For modeling inbreeding depression I started with an initial population of 1,000 animals and a normal age structure. For harvest I used a fixed yearling harvest at approximately 17% and an adult male harvest at 10% (in contrast to the modeling of genetic diversity, I did not use a variable harvest rate as that would have masked the results: see Methods). Harvests were conducted in all years (again, conducting harvest only when the population exceeded the carrying capacity, as I did in other simulations, would have masked the effect of inbreeding depression). This fixed rate of harvest produced a steady population over time when inbreeding depression was disabled (**Figure 23**). I then seeded the starting population with the allele frequencies used by Halbert and Derr (2008) and a kinship of 0.4 (a value derived from a 50-year simulation of the Badlands NP herd) and enabled inbreeding depression.

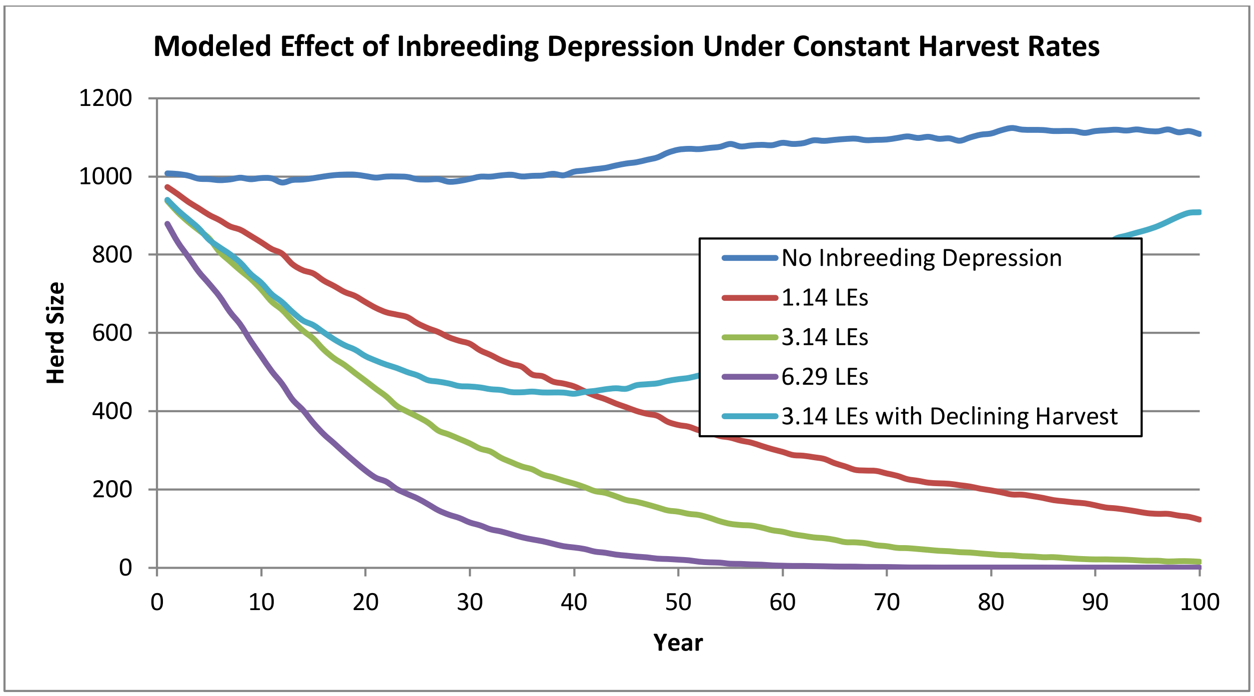

Figure 23. The modeled effect of inbreeding depression on herd size over time.

When I enabled inbreeding depression and set the lethal equivalents to 1.57, 3.14, or 6.29, modeled herd size severely declined over time and even went extinct at the higher LEs (**Figure 23**). The only way to maintain the population in the face of inbreeding depression and the modeled LEs was to reduce the harvest by 2% annually over the 100-year simulation. The severe impacts of inbreeding depression on modeled herd demographics raises numerous questions, one of which is how could Badlands NP and other NPS herds have persisted for so long if inbreeding depression is that consequential on herd demographics. A plausible explanation is that inbreeding depression on bison does not affect demographics at the rate it does for other species (in other words, the LEs for bison is much lower than for other species). Another explanation is that the effects of inbreeding depression may be just starting to manifest themselves on park herds. There is some evidence that inbreeding depression may be starting to impact NPS herds (e.g., low weights and reduced recruitment at the 100-year old Wind Cave NP herd); however, much more research/analysis remains to be done. A reason that the modeled South Unit herd shows severe inbreeding depression is that the modeled herd already had 50 years of inbreeding built into the population; the model carries inbreeding depression out another 100 years which is older than any existing NPS herds.

In summary, inbreeding depression is possible in a reintroduced bison herd and warrants monitoring. At some point survival and recruitment may decline, necessitating introduction of new bison genes into the herd. Yet caution should be taken as a new lineage may not integrate with the existing herd as expected (Berger and Cunningham 1994) or may have other unforeseen harmful consequences. Although there have been discussions for decades about introducing new animals into existing NPS herds for genetic augmentation no action has been taken because of the unknowns and uncertainties about such an action. Management should decide as early as possible if the proposed South Unit herd will consist only of Badlands NP North Unit animals, i.e., a metapopulation of that herd, or if it will be comprised of numerous herds. If the latter then the effects of inbreeding depression will theoretically be reduced.

Other Considerations

Water

Bison make regular visits to surface water to drink, if not daily, then every few days. Adult bison can consume, and likely need, about 12 gallons of water daily. A ready supply of water is a prerequisite for a bison reintroduction. At the time of this report information was still being collected by the National Park Service-Midwest Region on the status of water within the three sites. The information was being collected via remote imagery and ground-truthing. This analysis and summary is based on the information available at this time.

The only natural permanent year-round supply of water within the three sites appears to be the White River (**Figure 24**), located in the extreme southeast corner of the South Unit and Sites B and C in this report (**Figure 3**). Approximately 1.6 miles of the river flows through the project sites, specifically, by and around the White River Visitor Center. There is currently no flow gauge within the project area; however, there are stations approximately 25 linear miles upstream near Oglala, South Dakota, and 30 linear miles downstream near Interior, South Dakota (U. S. Geologic Survey 2014). (A water quality station was operated from 1964-67 at Rockyford; see National Park Service (1998) for that historic data.) The following flow values and analyses uses the mid-point of the Oglala and Interior datasets (the confluences and rates of inflows upstream and downstream of the project area appear similar).

Peak flows on the White River occur in April-June although there is tremendous variability due to flash flood events (**Figure 25**). Flows start declining in July and reach their typical lowest rates in mid-winter. There are days where no flow was recorded at both gauging stations, generally in July-January; however, the incomplete datasets do not allow for accurately reporting the percentage of days with no flow.

Figure 24. The White River in the project area.

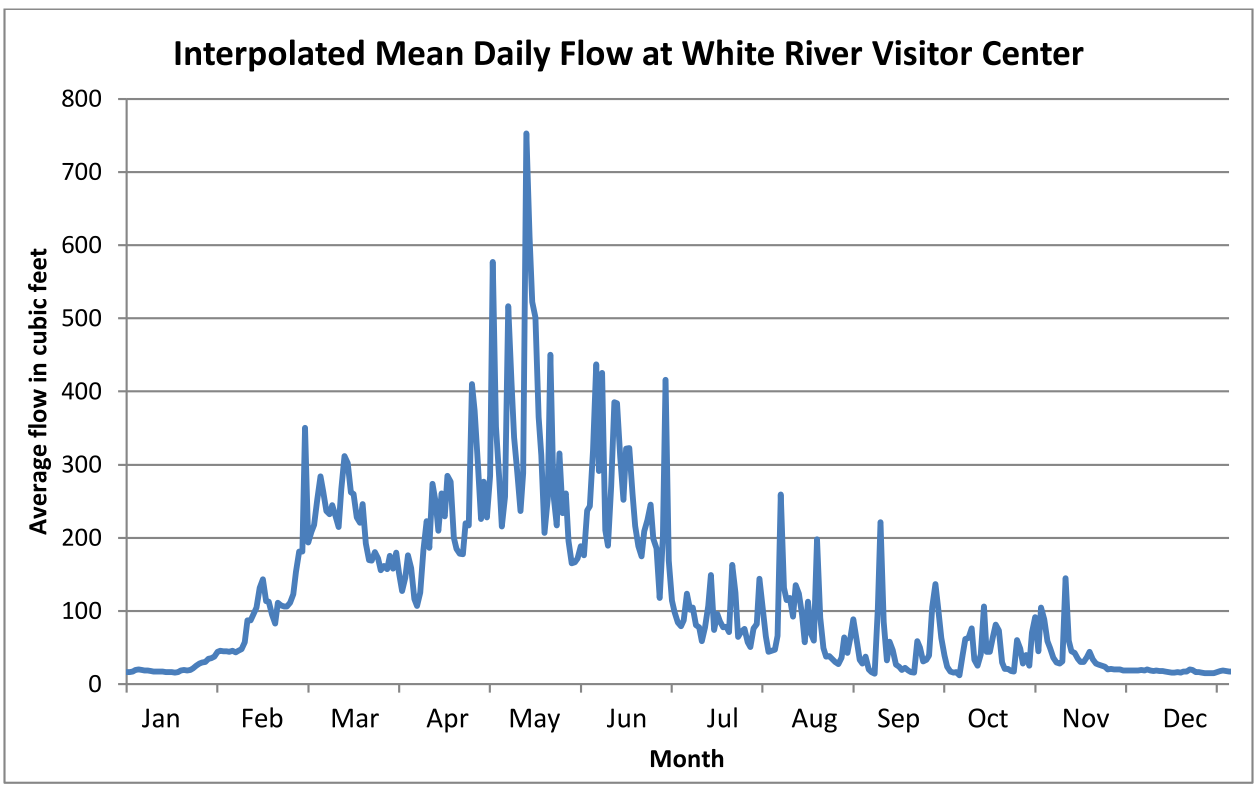

Figure 25. Interpolated average daily flow of White River.

The Cheyenne River is the other major river in the region. Prior to European settlement of the region bison in the project area likely make regular use of that river as well. The river lies a mere 0.5 mile from the northwest corner of Sites B and C and its inclusion would be a significant contribution to a bison restoration as there would then be a dependable source of water at both corners of Sites B and C.

In addition to the White River, there are many natural drainages within the three sites, the larger of which are Battle, North Cottonwood, and Cedar Creek drainages. During normal and wet periods these and other drainages can provide drinking water to ungulates. There are also low areas and depressions where water can pond following rain and snow-melt events. A field review in October of 2014 found water in many of these drainages and depressions. Bison can actually enhance and prolong surface water at these sites via their hoof action, i.e., ground water can flow into the small depressions made by the feet of the bison.

In addition to the natural rivers, drainages, and temporary wetlands, there is also a distribution of anthropogenic stock ponds within the three sites (**Figure 26**). The exact number is unknown, but it may number a hundred or more. Satellite imagery, and preliminary mapping by the National Park Service-Midwest Region, suggests that the largest site, Site B, contains at least 159 potential sources of surface water. However, preliminary ground-truthing found that about a 1/3 of the sites identified in the imagery did not sustain surface water. The National Wetlands Inventory (NWI) wetlands mapper (U. S. Fish and Wildlife Service 2014) indicates several large impoundments in Site A alone (and by inclusion, Sites B and C), including sites of 17, 6, 4, and 1 acres, in addition to about a dozen more sites less than an acre. The NWI mapper shows a similar distribution of impoundments in the east half of Site B where the higher plant productivity is found. Conversely, the western 1/3 of Site B (and western ½ of Site C) has comparatively few water sources.

Figure 26. Stock pond in the project area.

A herd of 1,000 bison typically includes about 180 calves, leaving about 820 adults. That many adults need just under 10,000 gallons of water daily (water consumption by calves is negligible). Needs are greatest in summer when cows are lactating and air temperatures are highest.

The flow of the White River at the Interior gauge is generally about 50 cubic feet/second in mid to late summer, a period when bison water needs are greatest. That equates to about 375 gallons per second, or enough water to satisfy a herd of 1,000 bison in about 26 seconds of flow. The lowest mean flows are September through January, with average daily rates of about 15 cubic feet/second. Even when water is not flowing there is still standing water in the river that may meet bison needs; however, it is conceivable that in extreme droughts the river may be insufficient to meet herd needs. Furthermore, the location of the river, in the extreme southeast corner of the project area, likely limits its potential use by bison.

There is no good quantitative information on the volume of water contained within the drainages, seasonal wetlands, and stock ponds within the three sites; however, it appears to be adequate to meet bison needs. Consider that an acre-feet of water contains 325,851 gallons, or about a months' worth of water for a herd of 1,000 bison. Further evidence that existing water in the project area is adequate to meet bison needs is that portions of the three sites are currently used for grazing cattle and appear sufficient to meet their needs.

Bison generally drink daily, hence, the distribution of surface water affects daily and short-term movements by bison. However, compared to cattle bison spend less time lingering and foraging near water (Fuhlendorf et al. 2010, Kohl et al. 2013). Yet, in larger landscapes, such as Sites B and C, the availability of surface water can affect bison seasonal movement and habitat use patterns. During drought periods especially, bison may disproportionately graze and trample areas near drinking water (Kohl et al. 2013). This can lead to an increase in heterogeneity of grazing intensities and habitat conditions within a landscape. If conservation of biological diversity is a goal such variability should be allowed, assuming it is within the range of natural variability for the region and consistent with other project goals.

In conclusion, it appears that there is adequate water for bison, including even large herds, within the three potential bison sites. Yet, precise quantitatively-backed estimates cannot be made due to the lack of data. Because of that, monitoring of water resources should accompany any bison reintroduction program.

Biodiversity

Bison are the predominate native grazer in the Great Plains and are often considered a keystone species in grassland ecosystems (Knapp et al. 1999, Fuhlendorf et al. 2010). Their reintroduction to the project area would likely play a critical role in restoring and conserving biological diversity.

Cattle are currently found in the project area and they are sometimes viewed as a surrogate to bison in performing the grazing process and maintaining biological diversity in grasslands. The degree to which that is true depends on a myriad of factors such as stocking densities and rotational practices (Fuhlendorf et al. 2010, Kohl et al. 2013). Under similar grazing patterns cattle can indeed mimic many of the natural processes of bison. However, even when those factors are comparable there are still noteworthy differences between the two species that can affect a site's biological diversity. For example, cattle are much more likely to linger and forage in riparian areas and consume more woody browse than do bison. Over time cattle can impair riparian areas. For example, substantial cottonwood regeneration occurs in the North Unit of Badlands National Park where bison are present yet regeneration is mostly absent in the South Unit where cattle occur (**Figure 27**). For more discussion about the similarities and differences between the two species see Fuhlendorf et al. (2010), Kohl et al. (2013), and Appendix C.

Figure 27. Cattle (left) impair cottonwood regeneration whereas bison (right) do not.

The reintroduction of bison to the site at densities that remove 15-50% of the annual plant productivity would restore a natural process and native keystone species, and likely lead to an increase in plant and animal biodiversity at the site. The degree that bison affect the site's biological diversity is dependent on stocking densities and other factors and therefore, only generalizations can be made here. Studies have found that bison create heterogeneity on the landscape, both via their grazing and other behaviors such as wallowing (Collins and Barber 1986). In some cases bison may revisit grazed patches repeatedly as their grazing stimulates new plant growth (Knapp et al. 1999). Bison selection for grasses tends to open up thick stands of grass allowing for an increase in forbs (Coppedge et al. 1998). Bison grazing may lead to an increase in the composition, form, and function of plant diversity that can lead to an increase faunal diversity.

The presence of bison should improve habitat for several wildlife species (**Figure 27**). Black-tailed prairie dogs should benefit as they tend to colonize grazed areas as they prefer sites with short vegetation (the same conditions can be created by cattle, fire, and other processes). The two species have a mutualistic relationship as bison tend to disproportionately graze in prairie dog colonies for the nutritious forage and the bison grazing helps keep vegetation short, which allows prairie dogs to detect predators. The presence of prairie dogs benefits a host of other species including the endangered black-footed ferret, a species entirely dependent on prairie dogs. The South Unit GMP/EIS (National Park Service 2012) explicitly identified prairie dogs and ferrets as significant resources in the South Unit. The presence of prairie dogs could also lead to an increase in burrowing owls (*Athene cunicularia*), a species that nest in prairie dog burrows. Likewise, swift fox (*Vulpes velox*) use prairie dog colonies due to the abundant prey in such areas and the short-vegetation structure which allows them to detect predators such as the coyote (*Canis latrans*). Prairie dog towns and bison grazing should also benefit pronghorn antelope (*Antilocapra americana*) as both species increase the amount of forbs on a site, which pronghorn prefer. Depending on the grazing intensity there could be slight shifts in the grassland bird community. For example, heavy grazing is likely to increase the presence of horned larks (*Eremophila alpestris*) at a site and decrease the number of western meadowlarks (*Sturnella neglecta*). Light grazing would have the opposite effect. Most of these impacts would occur in the flatter areas with higher plant productivity as that is where the bison would spend most of their time and these species are most commonly found.

The diversity and heterogeneity created by bison will be most substantial if bison are reintroduced and an active burn program is conducted. The combination of the two would create a rich, diverse, and healthy ecosystem. Burning should be done in patches (e.g., 100 acre burns), thereby creating the landscape diversity that bison prefer as well as many other species.

Although roundups and hunting will remove most bison, some animals will die of old age and other natural causes. Dead bison should be allowed to decompose in situ. In the short-term the carrion is an important and substantial food for many scavengers; in the long run bison decomposition sites are rich in minerals and nutrients which will lead to more plant diversity.

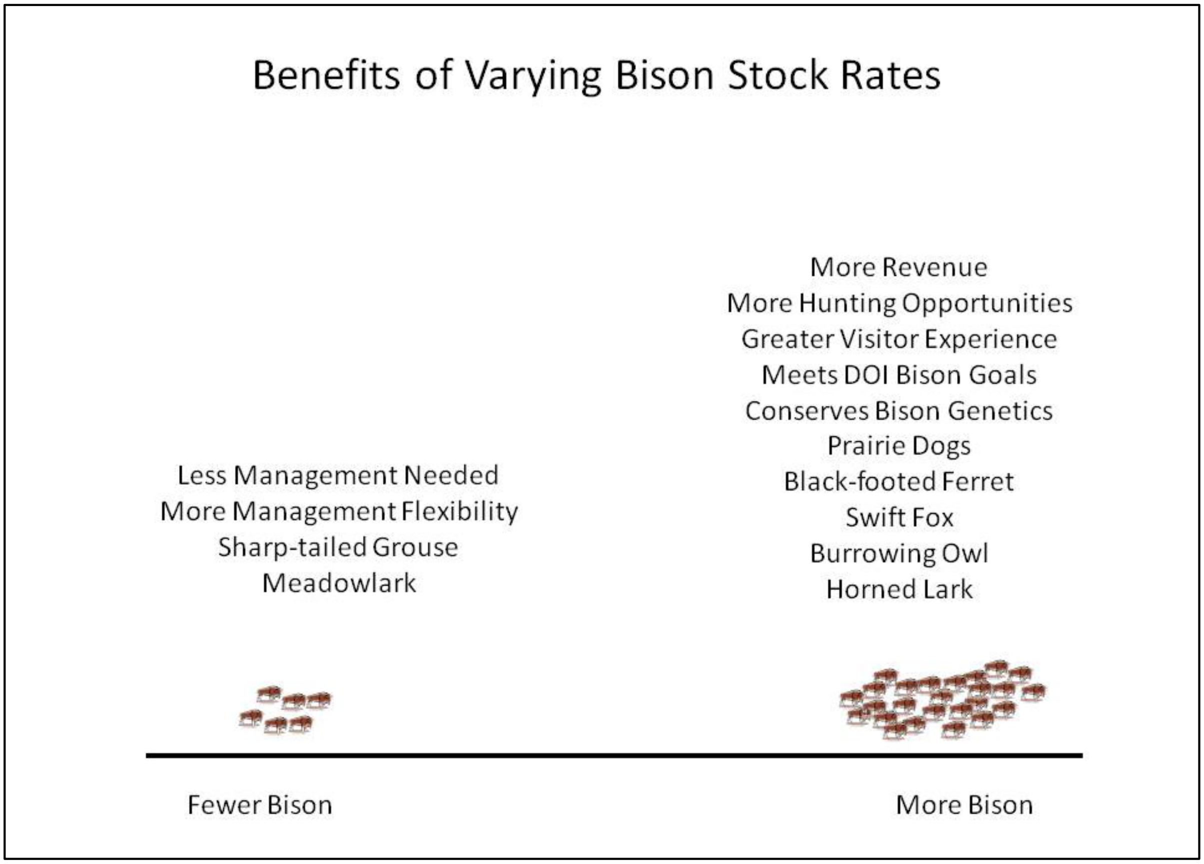

Figure 28. Benefits of a large versus a small bison herd.

Monitoring

There is uncertainty in any wildlife reintroduction, and the potential reintroduction of bison to the South Unit of Badlands National Park and adjacent lands is no exception. Although there is little uncertainty about the viability of a reintroduced bison population, there is a higher degree of uncertainty about the impacts and outputs of such a project. For example, Ranch Advisory Partners generally imply that there is no forage value, or that bison would not use, badlands type soils, whereas the Natural Resources Conservation Service suggested they would (Ranch Advisory Partners 2013). A rigorous scientifically-designed monitoring program can help answer those questions, refine management, and protect resources.

The first three potential monitoring projects listed in **Table 16** are strongly recommended. The others should be considered if feasible and/or depending on project goals. Other potential monitoring projects could be identified during a planning process for the project.

Table 16. Potential monitoring projects.

Resource	Objective	Potential Methods
High Priority		
Vegetation	Measure biomass and composition.	Robel pole for short-term monitoring of grazing. Point-intercept method used at Badlands NP for long-term changes in composition and cover. Satellite imagery. Photo points.
Bison Movements	Determine movements and habitat us.	GPS telemetry.
Water	Surface water.	Measure water area and volume. Satellite imagery.
Moderate Priority		
Prairie Dogs	Area of prairie dog colonies.	Walk perimeter of town with GPS units.
Birds	Relative abundance	Point or line sampling in breeding season.
Bison Genetics	Monitor genetic diversity and cattle introgression.	Samples collected during roundups and harvests.

Vegetation monitoring is probably the highest priority due in part to uncertainties about the productivity of the site and the bison use of the area. Vegetation is currently being monitored in National Park Service units in the Northern Great Plains, including the North Unit of Badlands National Park, using a point-intercept/plot method (Symstad et al. 2012). However, such an approach has short-comings for monitoring the impact of grazing, specifically, the method does not quickly detect changes in plant biomass. A more efficient method for monitoring grazing impacts would be the use of visual obstruction readings, e.g., using a Robel pole (Robel et al. 1970). Uresk and Mergen (2012) calibrated the relationship between visual obstruction readings and standing herbage biomass for the Buffalo Gap National Grasslands. Their method could be used to collect range data just prior to a culling operation with the results determining the size of the cull. They recommended leaving minimal residual standing herbage at band six, i.e. 3 inches. They also recommended that 10-15% of a landscape should be in short and tall vegetation classes for conservation of plant and wildlife diversity. Other possible monitoring methods can be found in U. S. Department of Agriculture (2003), Herrick (2005), and Symstad et al. (2012).

Whereas vegetation monitoring should be a long-term commitment, monitoring of bison movements can be of shorter duration. Monitoring should continue until the desired herd size is reached and there is a high degree of confidence that natural bison movements and habitat use are understood. Due to the remoteness of the three sites, and the difficulty in accessing them, GPS telemetry should be used. Monitoring should feed directly back into management actions using an adaptive management approach. Adaptive management, in its most rigorous and scientific definition, consists of developing a series of explicit and specific hypotheses, implementing the action, collecting and interpreting the data, and then, if necessary, revising management. The series of steps can be repeated indefinitely.

Conclusion and Recommendations

Bison conservation is a high concern within the scientific and conservation communities in part because of the imperiled status of brucellosis free, genetically healthy, naturally behaving, and ecologically significant bison populations (Redford and Fearn 2007, Sanderson et al. 2008, Gates et al. 2010). New initiatives and goals within the U. S. Department of the Interior and the National Park Service have elevated bison conservation within the federal government (U. S. Department of the Interior 2008, National Park Service 2011). These initiatives, along with scientific studies and recommendations (Dratch and Gogan 2008), recognize that new populations can contribute to global bison conservation. Furthermore, National Park Service policies call for the restoration of native species whenever feasible (National Park Service 2006b). American Indian tribes have a long history and association with bison and have and can continue to play a significant role in the conservation of the species. As a result, a serious, comprehensive, and scientific evaluation of the feasibility of restoring and conserving bison in and adjacent to the South Unit of Badlands National Park is warranted. This report provides such an analysis.

Benefits

A complete list of the benefits of bison restoration to the three sites studied here is better done in a full environmental analysis and with input from sociologists, economists, anthropologists, and others; however, a partial list is provided below. The benefits include:

1. <u>Restoring a native species to the park.</u> National Park Service policies call for the restoration of native species when certain conditions are met (National Park Service 2006b). A bison restoration to the South Unit of Badlands National Park clearly meets the conditions.

2. <u>Restoring an ecological process to the park that enhances the conservation of biodiversity.</u> Bison are considered a keystone species (Knapp et al. 1999). Restoring bison would restore grazing, one of the three drivers of prairie ecosystems and prairie health (Knapp et al. 1998). Bison grazing, along with other bison behaviors (e.g., urination, wallowing), should result in more diverse plant and animal communities at the park (Reynolds et al. 2003). Restoring grazing is also consistent with National Park Service policies which call for the restoration of natural processes (National Park Service 2006b).

3. <u>Improving visitation rates, stay lengths, and visitor experience and understanding.</u> The South Unit gets relatively little visitation, and much of it is for just a few hours, probably due in part to its relative lack of charismatic wildlife species such as bison. The presence of bison would likely increase visitation and improve the visitor experience.

4. <u>Benefitting local communities via increased ecotourism.</u> National parks with high visitation rates contribute greatly to local communities and economies. Communities such as Pine Ridge, Wounded Knee, Kyle, and Wall could all benefit from bison restoration at the park.

5. <u>Restoring a Native American ethnographic, cultural, and material resource.</u> Bison were a critical and central element of Native Americans, including the Oglala Sioux Tribe. The

South Unit lies within the Pine Ridge Reservation. The restoration of bison could have many benefits to the tribe.

6. Contributing to U. S. Department of the Interior and National Park Service bison goals. The Department of the Interior *Bison Initiative* establishes several priorities and goals for bison conservation including increasing "existing DOI herds to 1,000 or more bison, or establish new herds or metapopulations that can reach that size" (U. S. Department of the Interior 2008). Similarly, the National Park Service *Call to Action* calls for the restoration of bison (National Park Service 2011). Restoring bison to the South Unit could aid in meeting federal goals.
7. Establishing a metapopulation that contributes to the genetic conservation of bison. Bison are a species of conservation concern in part because of concerns about declining genetic diversity (Redford and Fearn 2007, U. S. Department of the Interior 2008, Gates et al. 2010). Dratch and Gogan (2008) recommended a metapopulation approach be used to effectively increase the size of existing NPS bison herds and thereby aid in the conservation of genetic diversity. Metapopulation management approaches could greatly increase the genetic diversity of the Badlands and proposed tribal herds.
8. Establishing a satellite herd that provides redundancy in case of a catastrophe to other National Park Service herd(s). In the 1964 and again in 1979 Wind Cave National Park slaughtered a large portion of its bison herd due to the prevalence of brucellosis (National Park Service 2006a). It's conceivable that such a depopulation could happen again, greatly compromising the viability and integrity of the herd. If animals of Badlands National Park North Unit origin were conserved at another site the off-site herd could be used to replenish the North Unit herd in case of catastrophe.

This report generally avoids specific and detailed recommendations. Rather, it provides a range of scenarios, options, and outputs and leaves the final decisions and action items up to others. There is a lot of latitude in regards to a bison reintroduction and management program at the sites. The final decisions and courses of action hinge greatly on what funding, infrastructure, staff, and authorities are available for a bison management program. If the bison program, funds, and authorities are meager and inadequate then a small herd may have to suffice, or in the words of some, a "show herd." A bison model similar to what was used here shows that if management can only cull in 25% of the years, but those years are unknown and random, yet management wants to keep the herd below a certain level in at least 95% of the years, then when culls do occur they should reduce the herd to only 10% of that target population level (Licht in prep). Due in part to limited funding for roundups Badlands NP manages the North Unit at about only 40% of its potential. Conversely, if adequate funding, staff, infrastructure, and culling tools are available then bison management at the sites could reliably and predictably maintain larger herd sizes. Under such a scenario the bison population could "follow the rain" whereby in wet periods the herd could be allowed to grow and when a drought period occurs the herd could be quickly and efficiently reduced. Such a scenario likely follows natural processes and conditions in the region. Such a scenario would also provide the greatest benefits in terms of bison conservation (e.g., genetics), ecosystem health, biodiversity, revenue generation, and visitor experience, among other measures.

This document uses the best available information to predict the bison potential and outputs under various scenarios. However, all reintroductions have some level of uncertainty. In the case of this project much of that uncertainty revolves around how bison will used the landscape. It's critical that any reintroduction be accompanied by a rigorous and scientifically-designed monitoring program. At a minimum the monitoring program should measure changes in plant biomass and composition over time, bison use of water resources, and bison habitat use. The results from such monitoring need to be fed back into management decisions.

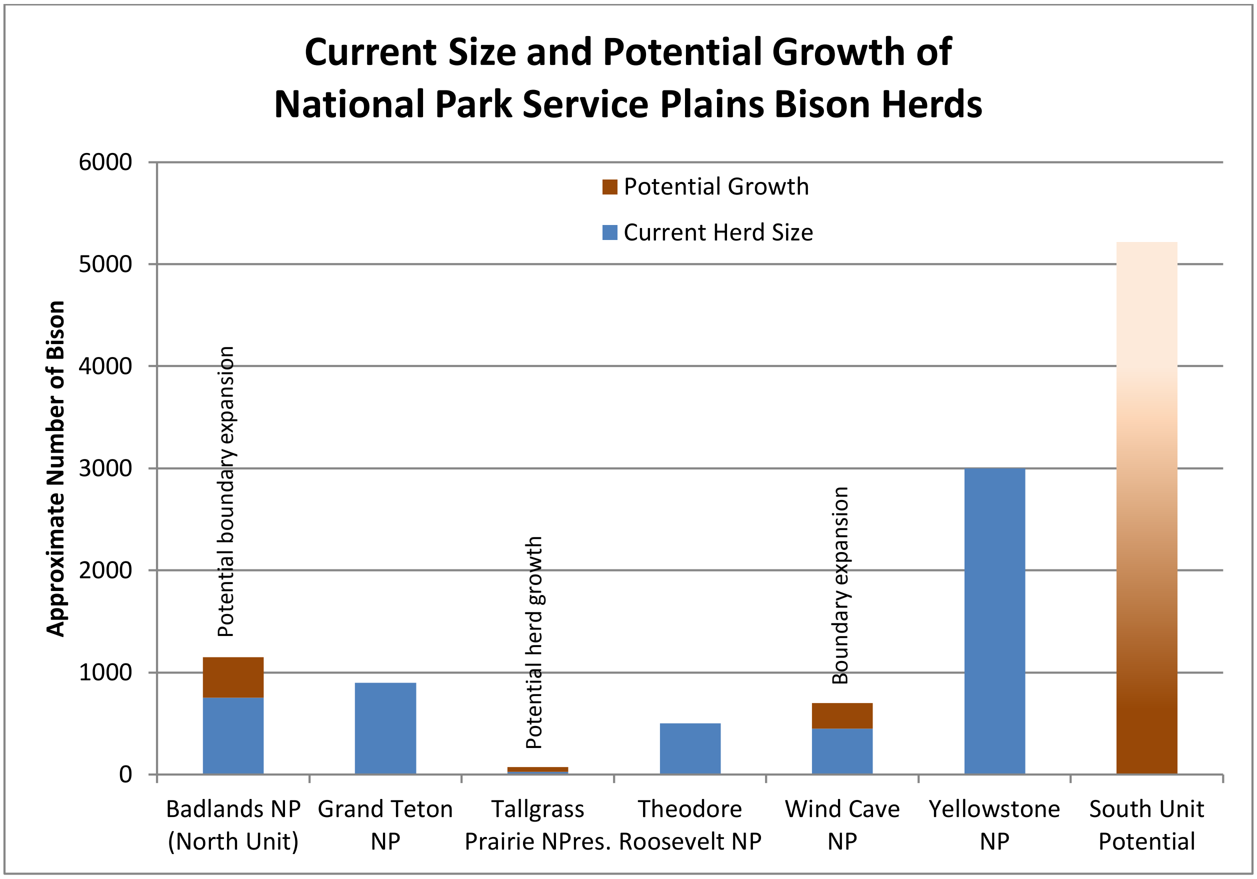

Figure 29. NPS units with bison, projected growth, and the South Unit.

The South Unit of Badlands National Park and adjacent lands have the capacity to play a significant role in global bison conservation. Indeed, the site has potential to exceed any existing public bison herds (**Figure 28**). More importantly, such a herd would have many other benefits ranging from ecologic to economic to cultural to recreational to aesthetic.

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Appendix A. Overview of Bison Ecology

The following discussion is not intended to be a comprehensive review of bison ecology and management. Rather, it is a brief summary of the information and issues relevant to reintroducing bison to the South Unit of Badlands National Park. For a more comprehensive review of bison ecology and management see Berger and Cunningham (1994) and Reynolds et al. (2003).

The Plains bison is generally considered the largest animal in North America. Adult males are often reported as weighing 1,500-2,000 pounds while the average weight of adult females is generally reported as around 1,000 pounds. However, there is considerable variability across the species' range (Reynolds et al. 2003).

Bison are generally brown; however, white bison are occasionally observed and these animals are held in reverence by many Native American tribes. White bison can either be true albinos (with pink eyes) or leucistic (white fur, but with blue eyes). McHugh (1979) speculated that these genetic aberrations occur at the rate of 1 per 100,000-1 million animals. No white bison have been reported from NPS units.

Bison are primarily grazers and are often the largest consumer of forage in prairie ecosystems. Across their range bison diets generally consist of about 90 percent grass (Reynolds et al. 2003). Bull bison tend to take a higher proportion of C_4 (i.e., warm season) grasses than female bison, juveniles, or calves (Post et al. 2001). Calves tend to have the most nutritious diets, although these differences could be more the result of post-parturition herd movements than they are selective foraging by calves. The diet for all sex and age classes can change throughout the year. For example, a study in a tallgrass prairie in eastern Kansas found that bison select warm season (C_4) grasses during the summer months and cool season (C_3) grasses during other seasons (Post et al. 2001). During winter months bison often rely heavily on shortgrass species such as buffalo grass (*Bouteloua dactyloides*), blue grama (*Bouteloua gracilis*), and hairy grama (*Bouteloua hirsuta*), as these grasses cure better. Surprisingly and unfortunately, much of the research on bison diets comes from outside of the mixed-grass prairie ecosystem (Reynolds et al. 2003).

Grazing, along with other behaviors such as wallowing, nutrient cycling, and hoof impacts, have earned bison the title of a keystone species by some scholars (Knapp et al. 1999, Fuhlendorf et al. 2010). Selective grazing of grasses by bison releases forbs from competition pressure with graminoids and thereby increases plant diversity in prairie ecosystems (Coppedge et al. 1998). This release of forbs benefits other species such as pronghorn antelope, insects, and seed-eating birds. Hence, grazing is considered an ecological driver in the Great Plains.

Bison grazing strongly interacts with fire (Vinton et al. 1993, Fuhlendorf and Engle 2004), another driver of grassland ecosystems. Fire creates high quality forage by reducing the ratio of dead to live plant material and increasing the nutrient content of growing vegetation. This attracts bison and other grazers, often for considerable periods and from considerable distances (Biondini et al. 1999). In turn, heavy grazing reduces plant biomass, dead material, and fuel loads, thereby reducing fire intensity and affecting fire patterns and behavior. The inter-relationship of fire and grazers can create a diverse landscape consisting of a mixture of early seral stages in close proximity to late seral stages.

Many scholars now feel that bison did not historically migrate long distances (Hart 2001). A common model is that bison were nomadic, moving across the landscape to meet their foraging and drinking needs. The presence of water, recent fire events, plant phenology and composition, and precipitation likely influenced movements (Vinton et al. 1993, Hart 2001, Fuhlendorf and Engle 2004). The successful restoration of bison to enclosed parks and other sites is evidence that they can exist and prosper on relatively small sites, even in northern climates.

Bison have a strong social order that has implications for management, especially for management of small populations and/or on small reserves. Mature bulls tend to spend most of the year in very small groups or travel alone, only associating with the cows for extended periods during the summer mating season (Berger and Cunningham 1994). Cows, juveniles, and calves form larger herds that generally persist in size throughout the year although individuals may move between herds. The herds are often lead by a matriarchal animal with the subordinate animals having an established pecking order. Dominance is often strongly correlated with age (Rutberg 1983). Disruption to the herd composition and social hierarchy can lead to altered behavior and movement patterns and increased tension within the herd. In one incident, calves introduced into an established herd received high levels of antagonism by resident animals (Coppedge et al. 1997).

Bison mating occurs during summer, peaking in late July to early August (Berger and Cunningham 1994, Reynolds et al. 2003). During the mating season adult males join the large cow-calf herds. Males become increasingly aggressive toward each other, with much bellowing, gesturing, and sparring. Serious fights, including those that result in serious injuries or fatalities, are less common, but do occur. Dominant males tend females in estrous and will not tolerate other males nearby. Often several males will aggressively pursue a female in estrous. A small percentage of prime-age adult males may do most of the breeding (Berger and Cunningham 1994). As a result, the genetically "effective population size" of the herd may only be about a third of the total population (Halbert 2003, Gross and Wang 2005).

Most birthing takes place in early May in the Northern Plains, although a small number of calves may be born before and after that period, including as late as October when bison roundups typically occur. Prior to parturition females may wander away from the main herd to give birth; this behavior may be more common in habitats with woody vegetation (Lott 1991). Single calves are the norm. Many studies have reported that the sex-ratio of fetuses or newborns tends to lean toward males although the disparity is negligible (Reynolds et al. 2003). First year survival tends to be slightly higher for female calves. Cow-calf pairs maintain close contact at first, but the calves become more independent as time goes on. Cows may not calve every year, especially if nutritional needs are not met (Gogan et al. 2013). Females typically first breed at the age of two and first give birth at age of three (Berger and Cunningham 1994, Millspaugh et al. 2008, Gogan et al. 2013). Males can probably breed starting around three years of age, however, prime age males (6-9 years old) typically do most of the breeding and may be sought out by females (Berger and Cunningham 1994).

Bison survival is high, especially in sites where natural predators are no longer present. For example, Millspaugh et al. (2005) reported annual survival for bison at National Park Service units in the Northern Great Plains as about 98% until the animals reach age 12. Pyne et al. (2010) reported similar survival rates for calves and yearlings, but a lower 94% survival for adult females and 80% survival for adult males at Badlands National Park. The disparity between the studies, which relied on the same Badlands National Park roundup database, appears to be due to assumptions about recapture probabilities. The onset of senescence is generally reported as being around 13-15 years (Halbert et al. 2005, Pyne et al. 2010).

In the absence of natural predators, disease may be the most significant natural mortality factor in bison. Diseases such as pneumonia, arthritis, arteriosclerosis, brucellosis, and tuberculosis along with parasites are known in bison. Although bison and cattle are closely related and share many parasites, the presence of a disease or parasite in one species does not necessarily mean the other species will contact it or be vulnerable. For example, Van Vuren and Scott (1995) found that even when bison and cattle share a range they do not have the same levels or types of parasites. For a list of diseases relevant to bison see the notes from an NPS bison workshop conducted at the Tallgrass Prairie National Preserve in 2003 (National Park Service 2004), the bison management plan for Wind Cave National Park (National Park Service 2006), or Reynolds et al. (2003).

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Appendix B. Bison Management in NPS Units

The conservation and history of bison is well chronicled (Reynolds et al. 2003). Bison may have once numbered in the tens of millions (Shaw 1995), but were almost extirpated in the late 1800s. At their population nadir there may have been fewer than a thousand bison left in the world. Through public and private restoration efforts they recovered from those perilous lows. By one estimate there were 385,000 animals as of 2001 (Bragg et al. 2002). However, Reynolds et al. (2003) stated that "there is a misconception that the North American bison as a wildlife species is secure and will survive in perpetuity." As a result of the genetic and other concerns, the International Union for the Conservation of Nature and Natural Resources (IUCN: also known as the World Conservation Union) places the "American bison" in the "Lower Risk, Conservation Dependent" category in the Red List of Threatened Species. The organization has recently made bison conservation a high priority and has developed a Bison Specialist Group operating under the Species Survival Commission. The State of South Dakota classifies bison as livestock except for animals within the National Park System; those animals are identified as wildlife.

The reason for the concerns about bison conservation is that a large percentage of bison are in private ownership and are managed primarily for profit and sometimes to the detriment of conservation goals. For example, private herds often have degraded genetics and skewed demographics (Bragg et al. 2002, Halbert 2003). Halbert (2003) found considerable evidence of cattle introgression in bison, especially in private and state herds. Yet even federal herds have genetic concerns. Halbert et al. (2007) found evidence of limited cattle introgression in the Badlands and Theodore Roosevelt National Park herds.

In addition to concerns about cattle introgression, genetic diversity remains a very high concern for bison conservationists (Gross and Wang 2005, Halbert et al. 2007, Dratch and Gogan 2008). Gross and Wang (2005) modeled NPS bison herds and concluded that a herd size of 400 was needed for a 90% probability of retaining 90% of heterozygosity for 200 years and 1,000 animals were needed for a 90% probability of retaining 90% of alleles. The Yellowstone National Park herd is the only federal herd that consistently reaches the latter goal.

Bison herd sizes at Badlands, Theodore Roosevelt, and Wind Cave National Parks and Tallgrass Prairie National Preserve, are typically about 700, 650, 400, and 20 animals, respectively; however, populations in recent years have exceeded those numbers due to new agency policies prohibiting the use of *cost recovery* to fund roundups; see the discussion below). Yellowstone National Park and Grand Teton support another 3,900 free-ranging animals between them. The U.S. Fish and Wildlife Service has five herds ranging from hundreds of animals to just a few dozen, bringing the Department of the Interior population to about 7,500 animals in 11 herds[1].

[1] The reported number of federal herds depends on how herds are defined. For example, Theodore Roosevelt National Park has two isolated herds as does Fort Niobrara National Wildlife Refuge. Bison occasionally venture into Grand Canyon National Park from neighboring lands, but they are generally not considered a federal herd. Bison are present at Wrangell-St. Elias National Park and Preserve in Alaska, but they are predominantly wood bison and the site is outside the historic range of plains bison. Chickasaw National Recreation Area has a small

Management Practice	Badlands NP	Tallgrass N. Pres.	Theodore Roosevelt NP	Wind Cave NP
Average Herd Size	700	20	650	400
Population Goal (Winter)	Less than 700	75	100-300 in NU and 200-500 in SU	400-500
Acres Available to Bison	60,000	1,074	70,500	28,132
Forage Allocated to Ungulates	33% based on dry year productivity	25%	35% (includes elk)	25% (includes elk)
Bison Intake Rate	1.2 AUE to 1,000 lb cow with 2.6% intake	26 lbs day or 3% body weight	15 lbs dry weight per day; 1.7% of body weight for yearlings and adults	1.2 AUE to 1,000 lb cow with 2.6% intake
Typical Culling Strategy	50-80% of yearlings	Proposed 45% every 3rd year across all age-sex classes	Proportional across all age classes except calves	80% of yearlings annually
Disease Testing	Test for brucellosis	Test for brucellosis, tuberculosis, Johne's on import; proposed testing for brucellosis and tuberculosis	Test for brucellosis, tuberculosis, and Johne's - all negative	History of brucellosis; eradicated via shooting. Vaccinations until 1998. Test for brucellosis.
Vaccinations	When required for transport	Proposed for brucellosis for calves; when needed	Brucellosis vaccine when requested	When needed for transport
Water Management	Permanent impoundments. Sage Creek. Some artificial water maintained for bison.	Streams present with stock ponds from prior land use	Little Missouri River. Some artificial water maintained to distribute grazing.	3 perennial streams and 12 developed sources to distribute grazing
Survey Methods	Roundups and fall and winter horseback/aerial surveys	Absolute counts from foot or vehicle	Roundups and aerial and foot survey	Roundups
Vehicle Collisions	None (gravel county road through bison pasture)	None (no public roads in pasture).	Four during the last 3 years (3 in SU and 1 in NU)	Average 8-9 accidents per year; 0-8 bison deaths annually last 30 years; but, 14 in winter of 2013-14.
Escapes	About 4 annually	None	Average 15 annually in SU and 6.5 in NU	< 4 in past 16 years
Herd Origin	50 bison from Theodore Roosevelt NP in 1963-64 and 3 from Fort Niobrara NWR	13 from Wind Cave NP in 2009	29 bison (5 bulls: 24 cows) from Fort Niobrara NWR in 1956	6 bulls:8 cows from NY in 1913 and 2 bulls:4 cows from Yellowstone in 1916
Management Plans	Bison Management Plan in prep	Bison Management Plan in 2009.	No bison-specific plan.	December 2006

National Park Service policies call for conserving the three widely recognized elements of biological conservation: i.e., the preservation of natural conditions, natural processes, and species composition (National Park Service 2006b). These policies are followed to the extent practicable when it comes to bison management. However, management must sometimes mitigate for absent or impaired natural processes. For example, natural predation (e.g., by wolves) does not occur at National Park Service units in the Northern Great Plains so managers must cull surplus animals. They try to do this in a way that results in relatively natural conditions. For example, Wind Cave National Park culls yearlings at a 1:1 sex ratio (Millspaugh et al. 2005, National Park Service 2006a): this results in a relatively natural sex structure. It also better conserves genetic diversity (Perez-Figueroa et al. 2012).

Badlands, Theodore Roosevelt, and Wind Cave National Parks all have permanent corrals and processing facilities to remove surplus bison. (Small bison operations sometimes use portable corrals, some of which can be purchased from commercial manufacturers.) Grandin (1999) provides guidance on handling bison and the construction of handling facilities. NPS bison roundups generally take place over a couple days in October and involve dozens of people to process the animals (including veterinarians on site). Animals are typically pushed into the corrals via helicopter at Theodore Roosevelt and Wind Cave National Parks: Badlands uses riders on horse to move the bison. In all cases animals are marked with microchips implanted in the ear. Various morphological, health, and genetic measurements and samples are taken. The animals may be tested for brucellosis and tuberculosis depending on state requirements (both the state in which the park is located and the state where surplus bison may be transferred to).

Brucellosis is a noteworthy disease of bison because of its potential and perceived impacts on cattle and effects on bison management. The disease has been the source of much controversy, management, and research at Yellowstone National Park (National Park Service 2000). Brucellosis appears to be an exotic disease brought over by domestic cattle (Meagher and Meyer 1994). It is a contagious bacterial disease that in one form (*Brucella abortus*) can infect both bison and cattle. In bison it can cause a cow to abort a fetus; however, the animals soon develop immunity and successfully reproduce in later years. However, no such resistance or immunity develops in cattle. The disease is transmitted through ingested organic materials including placentas and uterine discharges. In the 1960s to 1980s Wind Cave National Park shot several hundred bison in a successful effort to eradicate brucellosis from their bison herd (National Park Service 2006a). Yellowstone National Park and partner agencies have recently made a commitment to eliminate the disease from the Greater Yellowstone Region (National Park Service 2000); however, elimination is confounded by the presence of the disease in elk

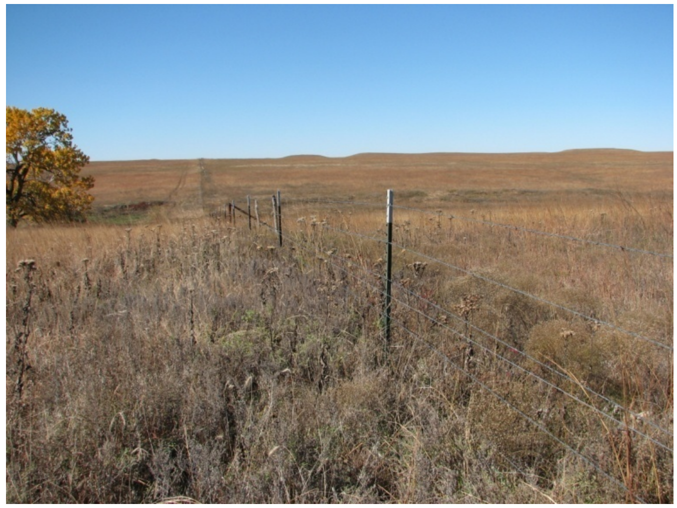
(Schumaker 2013, Treanor 2013, White et al. 2013). South Dakota is currently declared brucellosis-free state.

Bovine tuberculosis is another noteworthy disease in part because of states concerns and requirements regarding the disease. Bison appear to have first contacted the disease from domestic cattle (Tessaro et al. 1990). The bacterium *Mycobacterium bovis* can be transmitted through the air or by ingested milk, urine, feces, and other bodily fluids, although inhalation appears to be the primary transmission in bison (Tessaro et al. 1990).

Bison are a feature tourist attraction in parks in which they occur. Bison are generally docile animals that are indifferent or slightly intolerant of people. All parks with bison allow people to travel on foot in areas where bison occur and have established hiking trails in such areas. At some parks, such as Yellowstone National Park, bison wander through administrative areas, park housing, visitor centers, and other places where people congregate. Badlands and Theodore Roosevelt National Parks have unfenced campgrounds within areas where bison roam and both parks, along with Wind Cave National Park, allow backcountry camping in areas with bison.

However, bison can be aggressive to people under some circumstances and have caused injuries and fatalities at national and state parks. Bulls during the breeding season and cows with young calves are especially dangerous. Bison managers often advise visitors to stay at least 25 yards away from bison. At some parks park-promulgated regulations require visitors to stay at least 25 yards from bison and violators can be ticketed. At some sites with bison and large numbers of tourists, such as Custer State Park, managers take extra precautions during the breeding season including regular oversight of visitors near bison. Agitated or aggressive bison may display warning signs including prolonged direct eye contact with the intruder, head waving, snorting and grunting, pawing of the ground, a bucking action, and a raised tail.

All bison herds in the Great Plains are fenced to varying degrees. Woven-wire fencing is often used, especially in public herds. Badlands, Wind Cave, and Theodore Roosevelt National Parks all use woven-wire fencing, typically 7-8 feet high (Figure 11). Many private herds rely simply on 5-strand barbed-wire fencing and/or electric high-tensile fences. Tallgrass Prairie National Preserve uses a 5-strand barbed-wire fence that has an electric strand offset between the second and third wire (Figure 12); park staff question whether the electric strand is even necessary (Kristen Hase, Tallgrass National Preserve, pers. comm.). Bison-proof fences typically cost a few thousand dollars per mile to erect. Some parks also place fences around administrative areas to keep bison out, e.g., Wind Cave National Park. Cattle guards are generally effective in blocking bison movements where fences meet roads.



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Appendix C. Differences Between Bison and Cattle

This study evaluates reintroducing bison to the South Unit of Badlands National Park. One of the benefits of reintroducing bison to the site is that bison grazing, a critical ecological process in grasslands, is restored. However, cattle are sometimes perceived as being ecologically synonymous with bison, and hence, there have been several studies comparing the two and their functional role in grassland ecosystems (Towne et al. 2005, Fuhlendorf et al. 2010, Kohl et al. 2013). Cattle grazing is currently conducted within the sites analyzed in this study. Yet a direct comparison between bison and cattle, e.g., revenue generation, is problematic because it depends in large part on the management practices employed, fluctuating market prices, the scope of the analysis (e.g., does it include non-consumptive values), among other factors. The following is a more qualitative comparison of the two species.

The primary and most obvious similarity between bison and cattle is that both species remove primary productivity (i.e., plants) and convert it to energy, tissue, and waste products. As part of that process they affect vegetation condition, composition, and function which in turns affects grassland wildlife, hydrology, soils, and other resources. With active management the similarities can become greater (Towne et al. 2005, Fuhlendorf et al. 2010, Kohl et al. 2013). For example, managers can move cattle across the landscape in a way that mimics the more nomadic natural tendencies of bison. Managers can also use a patch-burn approach that both cattle and bison respond to similarly (Fuhlendorf et al. 2006). With good management both species can benefit rangeland resources whereas with poor management (e.g., long-term extreme under or overstocking) both species can cause adverse impacts on rangeland resources.

However, even under similar management practices bison and cattle do have differences, some of which are subtle and some of which are more profound. Even the subtle differences can affect the biological diversity of a site. This is not surprising as bison evolved in the relatively arid Great Plains and other Great Plains species evolved in concert with them whereas domestic cattle generally derived from wetland-associated species in Europe and Asia.

There are a number of notable differences between bison and cattle. Generally speaking, in terms of grazing behavior bison move across the landscape more, they select areas with intermediate biomass, they spend less time actually grazing, their diet consists of a higher portion of grasses versus forbs and woody material, and they are better able to digest low-quality, high-fiber, low-protein graminoids. These differences can result in differences to a site's biodiversity. For example, in a controlled study Towne et al. (2005) found a 15% difference in plant community composition after 10 years of grazing by bison versus sites grazed by cattle. In another study, deer mice (*Peromyscus maniculatus*) abundance was higher in areas grazed by bison than those grazed by cattle, perhaps due to bison creating larger grazed patches or perhaps due to the increase in seed-producing forbs on the bison sites (Matlack et al. 2001). Sometimes the biodiversity benefits of bison are more subtle and indirect. For example, when snow is on the ground bison may disproportionately graze hilltops where the wind-blown snow cover is less. This pattern may enhance habitat for the early spring courtship and dancing rituals of sharp-tailed grouse and prairie chickens.

Other bison behaviors, such as wallowing, males disturbing the ground during the breeding season, and horning trees also differ from cattle behavior and can alter species richness and grassland biodiversity (Coppedge et al. 1998). Collins and Barber (1986) found that disturbance via wallowing and other means increased diversity in a mixed-grass prairie.

Issue	Bison	Cattle
Grazing Time	Spend about a quarter of their time grazing.[1]	Spend about half their time grazing.[1]
Forage Digestibility	Bison are better able to digest low-quality, high-fiber, low-protein forage.	Do not digest low-quality, high-fiber, low-protein forage as well as bison, although they do digest high-quality forage at a comparable rate.
Tract Retention Time	Forage remains in the digestive tract for about 78 hours.	Forage in digestive tract about 69 hours.
Plant Selectivity	Bison diets consist of about 90% grass.[2,3]	Cattle diets are only about 70% grass with the remainder forbs and woody material.[2,3]
Micro-habitat Selectivity	Areas with intermediate plant biomass.[1]	Areas with high plant biomass.[1]
Movement	Bison move farther distances while grazing and are more likely to graze steep slopes and hilltops.	Cover less ground while grazing and less likely to reach hard to access areas.
Behavior	Bison wallow, thereby creating micro-habitats in grassland landscapes. Rutting bison roll and paw at the ground disturbing the soil and altering vegetation. Rutting bison may horn trees, while all ages and sexes may rub them, injuring and sometimes killing them.	Domestic cattle do not display the localized soil-disturbing behaviors that bison do, thereby not creating the same type and frequency of micro-habitats on the landscape.
Water and Riparian Areas	Spend less time near water.[1,4]	Spend more time near and in streams and ponds.[1,4]
Woody Areas	Infrequent in woody areas.[4]	Spend more time near woody vegetation, perhaps in part for foraging reasons and in part for shelter.[4]
Metabolism	Slows down during the winter to conserve energy.	Does not noticeably slow in the winter.
Climate	Much better to withstand extreme temperatures, including extreme cold periods. Better able to forage in deep snow	Can succumb to extreme cold conditions, especially when experienced in combination with food deprivation.

[1] Kohl et al. (2013).

[2] Plumb and Dodd (1993)

[3] Van Dyne et al. (1980)

[4] Fuhlendorf et al. (2010)

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Appendix D. NRCS Plant Productivity Data

The following output comes directly from the Natural Resources Conservation Service Web Soil Survey. These values were used to establish bison stocking rates for the three sites. Within the sites (i.e., the tables below) there may be multiple rows for the same soil type; this is because more than one NRCS soil map was within the Area of Interest.

Site A.

Site A.				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) Year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
N464B	Kyle clay, 2 to 6 percent slopes	33.5	0.10%	1145	38357.5	1820	60970	2390	80065
N656D	Pierre clay, 6 to 15 percent slopes	11	0.00%	1145	12595	1800	19800	2355	25905
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	82.6	0.30%	1095	90447	1655	136703	2150	177590
N711G	Samsil-Pierre, thin solum complex, 6 to 60 percent slopes	120.5	0.50%	989	119174.5	1390	167495	1785	215092.5
N814B	Swanboy clay, 0 to 6 percent slopes	8.5	0.00%	798	6783	1295	11007.5	1701	14458.5
U020G	Badland	5,298.90	22.00%	205	1086275	392	2077169	521	2760727
U027F	Badland-Orella complex, 6 to 40 percent slopes	3,361.40	13.90%	286	961360.4	481	1616833	598	2010117
U110A	Cedarpass silt loam, 0 to 3 percent	24.5	0.10%	960	23520	1770	43365	2265	55492.5
U110B	Cedarpass silt loam, 3 to 6 percent slopes	47.40	0.20%	945	44793	1745	82713	2240	106176
U120A	Cedarpass-Denby complex, 0 to 3 percent slopes	169.40	0.70%	1011	171263.4	1792	303564.8	2315	392161
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	916.1	3.80%	536	491029.6	1288	1179937	1620	1484082
U165A	Denby silty clay, 0 to 3 percent slopes	720.7	3.00%	1120	807184	1850	1333295	2425	1747698
U190D	Epping, moist-Kadoka silt loams, 9 to 20 percent slopes	79.3	0.30%	859	68118.7	1550	122915	2064	163675.2
U192G	Epping-Keota-Badland complex, moist, 9 to 50 percent slopes	42.10	0.20%	838	35279.8	1413	59487.3	1985	83568.5
U200F	Fairburn clay loam, 9 to 40 percent slopes	18.50	0.10%	816	15096	1398	25863	1794	33189
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	975.9	4.00%	565	551383.5	995	971020.5	1345	1312586
U315A	Interior loam, 0 to 3 percent slopes, occasionally flooded	25.90	0.10%	1010	26159	1550	40145	1885	48821.5

Site A.				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) Year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	1,825.40	7.60%	700	1277780	1797	3280244	2133	3893578
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	113.4	0.50%	976	110678.4	1564	177357.6	1985	225099
U340B	Interior, moderately deep, occasionally flooded-Cedarpass 0 to 6	656.70	2.70%	568	373005.6	1581	1038243	1967	1291729
U348E	Jayem-Valentine, dry complex, 6 to 30 percent slopes	34.50	0.10%	1695	58477.5	2225	76762.5	2825	97462.5
U350A	Kadoka-Thirtynine silt loams, 0 to 3 percent slopes	17.7	0.10%	1041	18425.7	1840	32568	2345	41506.5
U350B	Kadoka-Thirtynine silt loams, 3 to 6 percent slopes	56	0.20%	1035	57960	1816	101696	2335	130760
U350C	Kadoka-Thirtynine silt loams, 6 to 9 percent slopes	23.7	0.10%	1029	24387.3	1801	42683.7	2317	54912.9
U355C	Kadoka-Epping, moist silt loams, 3 to 9 percent slopes	153.5	0.60%	904	138764	1608	246828	2118	325113
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40 percent	1,717.00	7.10%	759	1303203	1366	2345422	1775	3047675
U510A	Thirtynine silt loam, 0 to 2 percent slopes	6.3	0.00%	1005	6331.5	1784	11239.2	2297	14471.1
U556C	Orella silt loam, very shallow, 1 to 9 percent slopes	752.10	3.10%	810	609201	1255	943885.5	1555	1169516
U560C	Orella-Badland complex, 1 to 9 percent slopes	391.6	1.60%	605	236918	955	373978	1190	466004
U560F	Orella-Badland complex, 9 to 45 percent slopes	440.00	1.80%	646	284240	966	425040	1208	531520
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	3,051.70	12.70%	470	1434299	1160	3539972	1465	4470741
U740C	Tuthill-Jayem fine sandy loams, 3 to 9 percent slopes	0.6	0.00%	1731	1038.6	2335	1401	2943	1765.8
U745A	Manter, cool-Tuthill fine sandy loams, 0 to 3 percent slopes	16.7	0.10%	1303	21760.1	2010	33567	2515	42000.5
U745C	Manter, cool-Tuthill fine sandy loams, 6 to 9 percent slopes	4.2	0.00%	1384	5812.8	2172	9122.4	2731	11470.2
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	2,063.40	8.60%	994	2051020	1559	3216841	2065	4260921
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	505.9	2.10%	901	455815.9	1371	693588.9	1798	909608.2
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	252.5	1.00%	814	205535	1268	320170	1668	421170
UW	Water	34.80	0.10%	0	0	0	0	0	0
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	14.7	0.10%	1095	16096.5	1655	24328.5	2150	31605

Site A.				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) Year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U020G	Badland	0.50	0.00%	205	102.5	392	196	521	260.5
U027F	Badland-Orella complex, 6 to 40 percent slopes	38.90	0.20%	286	11125.4	481	18710.9	598	23262.2
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	1.50	0.00%	565	847.5	995	1492.5	1345	2017.5
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	7.8	0.00%	700	5460	1797	14016.6	2133	16637.4
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40 percent	1.4	0.00%	759	1062.6	1366	1912.4	1775	2485
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	3.50	0.00%	470	1645	1160	4060	1465	5127.5
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	0.00	0.00%	901	0	1371	0	1798	0
Total		24,122			13259811		25227609		32199821

Site B.

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
West Half									
N464B	Kyle clay, 2 to 6 percent slopes	85.6	0.07	1145	98012	1820	155792	2390	204584
N464C	Kyle clay, 6 to 9 percent slopes	3.2	0.00	1145	3664	1820	5824	2390	7648
N542F	Samsil silty clay loam, 10 to 40 percent slopes	178.2	0.14	994	177130.8	1418	252687.6	1830	326106
N656B	Pierre clay, 2 to 6 percent slopes	13.6	0.01	1181	16061.6	1854	25214.4	2425	32980
N656D	Pierre clay, 6 to 15 percent slopes	159.7	0.13	1145	182856.5	1800	287460	2355	376093.5
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	1,904.80	1.50	1095	2085756	1655	3152444	2150	4095320
N711G	Samsil-Pierre, thin solum complex, 6 to 60 percent slopes	1,657.70	1.31	989	1639465	1390	2304203	1785	2958995
N814B	Swanboy clay, 0 to 6 percent slopes	232.9	0.18	798	185854.2	1295	301605.5	1701	396162.9
U020G	Badland	12,883.30	10.17	205	2641077	392	5050254	521	6712199
U027F	Badland-Orella complex, 6 to 40 percent slopes	7,086.30	5.59	286	2026682	481	3408510	598	4237607
U110A	Cedarpass silt loam, 0 to 3 percent	80.4	0.06	960	77184	1770	142308	2265	182106
U110B	Cedarpass silt loam, 3 to 6 percent slopes	66.6	0.05	945	62937	1745	116217	2240	149184
U120A	Cedarpass-Denby complex, 0 to 3 percent slopes	272.7	0.22	1011	275699.7	1792	488678.4	2315	631300.5
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	981.8	0.78	536	526244.8	1288	1264558	1620	1590516
U165A	Denby silty clay, 0 to 3 percent slopes	1,059.10	0.84	1120	1186192	1850	1959335	2425	2568318
U190D	Epping, moist-Kadoka silt loams, 9 to 20 percent slopes	105.7	0.08	859	90796.3	1550	163835	2064	218164.8
U192G	Epping-Keota-Badland complex, moist, 9 to 50 percent slopes	1,277.80	1.01	838	1070796	1413	1805531	1985	2536433
U195E	Mitchell-Epping silt loams, moist, 9 to 30 percent slopes	5.2	0.00	1005	5226	1570	8164	2120	11024
U200F	Fairburn clay loam, 9 to 40 percent slopes	13.4	0.01	816	10934.4	1398	18733.2	1794	24039.6
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	2,047.00	1.62	565	1156555	995	2036765	1345	2753215

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U235B	Interior-Riverwash complex, 0 to 6 percent slopes, frequently flooded	62.8	0.05	394	24743.2	1530	96084	1894	118943.2
U240A	Bridgeport loam, cool, 0 to 3 percent slopes, rarely flooded	10.7	0.01	1604	17162.8	2396	25637.2	2896	30987.2
U305A	Hoven silt loam, 0 to 1 percent slopes	10.2	0.01	1450	14790	2148	21909.6	3368	34353.6
U315A	Interior loam, 0 to 3 percent slopes, occasionally flooded	166.6	0.13	1010	168266	1550	258230	1885	314041
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	4,384.20	3.46	700	3068940	1797	7878407	2133	9351499
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	134.2	0.11	976	130979.2	1564	209888.8	1985	266387
U340B	Interior, moderately deep, occasionally flooded-Cedarpass 0 to 6	1,066.20	0.84	568	605601.6	1581	1685662	1967	2097215
U348E	Jayem-Valentine, dry complex, 6 to 30 percent slopes	804	0.63	1695	1362780	2225	1788900	2825	2271300
U350A	Kadoka-Thirtynine silt loams, 0 to 3 percent slopes	17.7	0.01	1041	18425.7	1840	32568	2345	41506.5
U350B	Kadoka-Thirtynine silt loams, 3 to 6 percent slopes	142.9	0.11	1035	147901.5	1816	259506.4	2335	333671.5
U350C	Kadoka-Thirtynine silt loams, 6 to 9 percent slopes	27.7	0.02	1029	28503.3	1801	49887.7	2317	64180.9
U355C	Kadoka-Epping, moist silt loams, 3 to 9 percent slopes	127.2	0.10	904	114988.8	1608	204537.6	2118	269409.6
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40	2,100.90	1.66	759	1594583	1366	2869829	1775	3729098
U495F	Vivian gravelly loam, dry, 6 to 40 percent slopes	244.6	0.19	755	184673	1200	293520	1565	382799
U510A	Thirtynine silt loam, 0 to 2 percent slopes	6.3	0.00	1005	6331.5	1784	11239.2	2297	14471.1
U556C	Orella silt loam, very shallow, 1 to 9 percent slopes	1,004.60	0.79	810	813726	1255	1260773	1555	1562153
U560C	Orella-Badland complex, 1 to 9 percent slopes	693.8	0.55	605	419749	955	662579	1190	825622
U560F	Orella-Badland complex, 9 to 45 percent slopes	1,797.50	1.42	646	1161185	966	1736385	1208	2171380
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	7,073.50	5.58	470	3324545	1160	8205260	1465	10362678
U615A	Savo-Tuthill silt loams, 0 to 3 percent slopes	1,087.50	0.86	1063	1156013	1860	2022750	2380	2588250
U740A	Tuthill-Jayem fine sandy loams, 0 to 3 percent slopes	103.5	0.08	1699	175846.5	2307	238774.5	2905	300667.5
U740C	Tuthill-Jayem fine sandy loams, 3 to 9 percent slopes	725.5	0.57	1731	1255841	2335	1694043	2943	2135147

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U745A	Manter, cool-Tuthill fine sandy loams, 0 to 3 percent slopes	688.5	0.54	1303	897115.5	2010	1383885	2515	1731578
U745B	Manter, cool-Tuthill fine sandy loams, 3 to 6 percent slopes	846.6	0.67	1329	1125131	2046	1732144	2561	2168143
U745C	Manter, cool-Tuthill fine sandy loams, 6 to 9 percent slopes	309	0.24	1384	427656	2172	671148	2731	843879
U755E	Valentine loamy sand, dry, 6 to 25 percent slopes	51.1	0.04	1500	76650	1920	98112	2510	128261
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	2,476.10	1.95	994	2461243	1559	3860240	2065	5113147
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	807.1	0.64	901	727197.1	1371	1106534	1798	1451166
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	290.7	0.23	814	236629.8	1268	368607.6	1668	484887.6
UW	Water	36	0.03		0		0		0
N464B	Kyle clay, 2 to 6 percent slopes	0.2	0.00	1145	229	1820	364	2390	478
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	14.5	0.01	1095	15877.5	1655	23997.5	2150	31175
U027F	Badland-Orella complex, 6 to 40 percent slopes	38.3	0.03	286	10953.8	481	18422.3	598	22903.4
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	5.4	0.00	700	3780	1797	9703.8	2133	11518.2
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	3.4	0.00	470	1598	1160	3944	1465	4981
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	0	0.00	1095	0	1655	0	2150	0
U020G	Badland	0.1	0.00	205	20.5	392	39.2	521	52.1
U027F	Badland-Orella complex, 6 to 40 percent slopes	0.1	0.00	286	28.6	481	48.1	598	59.8
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	0.2	0.00	565	113	995	199	1345	269
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	0	0.00	700	0	1797	0	2133	0
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40	0.4	0.00	759	303.6	1366	546.4	1775	710
U495F	Vivian gravelly loam, dry, 6 to 40 percent slopes	0.5	0.00	755	377.5	1200	600	1565	782.5
U615A	Savo-Tuthill silt loams, 0 to 3 percent slopes	1.1	0.00	1063	1169.3	1860	2046	2380	2618
U745B	Manter, cool-Tuthill fine sandy loams, 3 to 6 percent slopes	0.1	0.00	1329	132.9	2046	204.6	2561	256.1

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
East Half									
U020G	Badland	9,342.70	7.38	205	1915254	392	3662338	521	4867547
U027F	Badland-Orella complex, 6 to 40 percent slopes	2,542.30	2.01	286	727097.8	481	1222846	598	1520295
U110A	Cedarpass silt loam, 0 to 3 percent	369.8	0.29	960	355008	1770	654546	2265	837597
U110B	Cedarpass silt loam, 3 to 6 percent slopes	140.6	0.11	945	132867	1745	245347	2240	314944
U120A	Cedarpass-Denby complex, 0 to 3 percent slopes	133.6	0.11	1011	135069.6	1792	239411.2	2315	309284
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	1,215.70	0.96	536	651615.2	1288	1565822	1620	1969434
U165A	Denby silty clay, 0 to 3 percent slopes	333.7	0.26	1120	373744	1850	617345	2425	809222.5
U190D	Epping, moist-Kadoka silt loams, 9 to 20 percent slopes	63.6	0.05	859	54632.4	1550	98580	2064	131270.4
U192G	Epping-Keota-Badland complex, moist, 9 to 50 percent slopes	1,019.30	0.80	838	854173.4	1413	1440271	1985	2023311
U195E	Mitchell-Epping silt loams, moist, 9 to 30 percent slopes	19.9	0.02	1005	19999.5	1570	31243	2120	42188
U200F	Fairburn clay loam, 9 to 40 percent slopes	5	0.00	816	4080	1398	6990	1794	8970
U205F	Fairburn-Orella, very channery-Whitewater complex, 6 to 40 percent	6,445.90	5.09	762	4911776	1294	8340995	1663	10719532
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	46.2	0.04	565	26103	995	45969	1345	62139
U235B	Interior-Riverwash complex, 0 to 6 percent slopes, frequently flooded	299.4	0.24	394	117963.6	1530	458082	1894	567063.6
U240A	Bridgeport loam, cool, 0 to 3 percent slopes, rarely flooded	143.8	0.11	1604	230655.2	2396	344544.8	2896	416444.8
U305A	Hoven silt loam, 0 to 1 percent slopes	4.1	0.00	1450	5945	2148	8806.8	3368	13808.8
U315A	Interior loam, 0 to 3 percent slopes, occasionally flooded	48.7	0.04	1010	49187	1550	75485	1885	91799.5
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	1,272.30	1.00	700	890610	1797	2286323	2133	2713816
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	794.3	0.63	976	775236.8	1564	1242285	1985	1576686
U340B	Interior, moderately deep, occasionally flooded-Cedarpass 0 to 6	1,631.70	1.29	568	926805.6	1581	2579718	1967	3209554
U342C	Interior, poorly drained-Interior, frequently flooded-Epping, moist 0-9	69.7	0.06	845	58896.5	1400	97580	1735	120929.5

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U348E	Jayem-Valentine, dry complex, 6 to 30 percent slopes	685.8	0.54	1695	1162431	2225	1525905	2825	1937385
U355C	Kadoka-Epping, moist silt loams, 3 to 9 percent slopes	403.2	0.32	904	364492.8	1608	648345.6	2118	853977.6
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40 percent	51.5	0.04	759	39088.5	1366	70349	1775	91412.5
U495F	Vivian gravelly loam, dry, 6 to 40 percent slopes	299.7	0.24	755	226273.5	1200	359640	1565	469030.5
U510A	Thirtynine silt loam, 0 to 2 percent slopes	10.6	0.01	1005	10653	1784	18910.4	2297	24348.2
U556C	Orella silt loam, very shallow, 1 to 9 percent slopes	1,438.10	1.14	810	1164861	1255	1804816	1555	2236246
U560C	Orella-Badland complex, 1 to 9 percent slopes	661.4	0.52	605	400147	955	631637	1190	787066
U560F	Orella-Badland complex, 9 to 45 percent slopes	792.7	0.63	646	512084.2	966	765748.2	1208	957581.6
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	4,102.50	3.24	470	1928175	1160	4758900	1465	6010163
U615A	Savo-Tuthill silt loams, 0 to 3 percent slopes	576	0.45	1063	612288	1860	1071360	2380	1370880
U740A	Tuthill-Jayem fine sandy loams, 0 to 3 percent slopes	108.5	0.09	1699	184341.5	2307	250309.5	2905	315192.5
U740C	Tuthill-Jayem fine sandy loams, 3 to 9 percent slopes	387.1	0.31	1731	670070.1	2335	903878.5	2943	1139235
U745A	Manter, cool-Tuthill fine sandy loams, 0 to 3 percent slopes	766.7	0.61	1303	999010.1	2010	1541067	2515	1928251
U745B	Manter, cool-Tuthill fine sandy loams, 3 to 6 percent slopes	779.9	0.62	1329	1036487	2046	1595675	2561	1997324
U745C	Manter, cool-Tuthill fine sandy loams, 6 to 9 percent slopes	10	0.01	1384	13840	2172	21720	2731	27310
U755E	Valentine loamy sand, dry, 6 to 25 percent slopes	464.1	0.37	1500	696150	1920	891072	2510	1164891
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	511.3	0.40	994	508232.2	1559	797116.7	2065	1055835
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	812.4	0.64	901	731972.4	1371	1113800	1798	1460695
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	325	0.26	814	264550	1268	412100	1668	542100
UW	Water	22.9	0.02	0	0	0	0	0	0
NkD	Norrest silty clay loam, 6 to 15 percent slopes	0.3	0.00	1187	356.1	1942	582.6	2704	811.2
U020G	Badland	0.1	0.00	205	20.5	392	39.2	521	52.1

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	1.1	0.00	536	589.6	1288	1416.8	1620	1782
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	0.3	0.00	700	210	1797	539.1	2133	639.9
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	0.1	0.00	976	97.6	1564	156.4	1985	198.5
U556C	Orella silt loam, very shallow, 1 to 9 percent slopes	0.2	0.00	810	162	1255	251	1555	311
U560C	Orella-Badland complex, 1 to 9 percent slopes	0.6	0.00	605	363	955	573	1190	714
U560F	Orella-Badland complex, 9 to 45 percent slopes	2.2	0.00	646	1421.2	966	2125.2	1208	2657.6
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	0.1	0.00	994	99.4	1559	155.9	2065	206.5
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	1.4	0.00	901	1261.4	1371	1919.4	1798	2517.2
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	0.3	0.00	814	244.2	1268	380.4	1668	500.4
Aa	Lohmiller silty clay loam, channeled, 0 to 2 percent slopes	546.8	0.43	2405	1315054	3230	1766164	3720	2034096
AvE	Anselmo-Valentine complex, 5 to 20 percent slopes	236.4	0.19	1695	400698	2225	525990	2825	667830
Ba	Badland-Denby-Interior complex, 0 to 90 percent slopes	3,348.80	2.64	879	2943595	1307	4376882	1747	5850354
Bk	Bankard loamy sand, 0 to 3 percent slopes	49.2	0.04	1520	74784	1970	96924	2610	128412
Br	Badland	830.3	0.66	261	216708.3	382	317174.6	510	423453
Cy	Denby silty clay, 0 to 4 percent slopes	589	0.46	1226	722114	1972	1161508	2791	1643899
EhF	Epping-Kadoka association, 9 to 40 percent slopes	0.1	0.00	1091	109.1	1932	193.2	2667	266.7
EkE	Epping-Kadoka silt loams, 9 to 18 percent slopes	122.6	0.10	1081	132530.6	1916	234901.6	2643	324031.8
Er	Epping-Rock outcrop complex, 9 to 40 percent slopes	96	0.08	737	70752	1350	129600	1789	171744
Gr	Nihill gravelly loam, 2 to 30 percent slopes	124.5	0.10	741	92254.5	1215	151267.5	1635	203557.5
HhA	Haverson loam, 0 to 3 percent slopes, rarely flooded	170.3	0.13	1815	309094.5	2715	462364.5	3710	631813
HlA	Haverson loam, 0 to 3 percent slopes, occasionally flooded	73.4	0.06	2290	168086	3105	227907	3565	261671
Ht	Hisle-Swanboy complex, saline, 0 to 6 percent slopes	35	0.03	670	23450	1135	39725	1550	54250

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
KaA	Kadoka silt loam, 0 to 3 percent slopes	22.3	0.02	1521	33918.3	2416	53876.8	3488	77782.4
KbC	Kadoka-Epping silt loams, 3 to 9 percent slopes	146.5	0.12	1168	171112	2012	294758	2808	411372
KeA	Keith silt loam, 0 to 3 percent slopes	1.9	0.00	1521	2889.9	2414	4586.6	3479	6610.1
Lm	Interior silt loam, 0 to 3 percent slopes	2,354.20	1.86	1773	4173997	2331	5487640	2884	6789513
Mm	Mosher-Minatare complex, 0 to 6 percent slopes	305	0.24	1100	335500	1594	486170	2111	643855
Os	Orella-Shale outcrop complex, 3 to 18 percent slopes	6,923.00	5.46	803	5559169	1135	7857605	1459	10100657
RaA	Richfield-Altvan silt loams, 0 to 3 percent slopes	81.7	0.06	1530	125001	2412	197060.4	3455	282273.5
RaB	Richfield-Altvan silt loams, 3 to 5 percent slopes	45.4	0.04	1521	69053.4	2398	108869.2	3456	156902.4
Sw	Swanboy clay, 0 to 3 percent slopes	42.6	0.03	817	34804.2	1315	56019	1715	73059
TnA	Tuthill-Anselmo fine sandy loams, 0 to 3 percent slopes	1.2	0.00	1797	2156.4	2398	2877.6	2996	3595.2
TnC	Tuthill-Anselmo fine sandy loams, 3 to 9 percent slopes	116.4	0.09	1797	209170.8	2398	279127.2	2996	348734.4
TuA	Tuthill-Manter fine sandy loams, 0 to 3 percent slopes	364.1	0.29	1800	655380	2416	879665.6	3023	1100674
TuB	Tuthill-Manter fine sandy loams, 3 to 5 percent slopes	223.7	0.18	1770	395949	2398	536432.6	3041	680271.7
TuC	Tuthill-Manter fine sandy loams, 5 to 9 percent slopes	294.9	0.23	1770	521973	2400	707760	3050	899445
U020G	Badland	214.6	0.17	205	43993	392	84123.2	521	111806.6
U027F	Badland-Orella complex, 6 to 40 percent slopes	112.2	0.09	286	32089.2	481	53968.2	598	67095.6
U110A	Cedarpass silt loam, 0 to 3 percent	363.5	0.29	960	348960	1770	643395	2265	823327.5
U110B	Cedarpass silt loam, 3 to 6 percent slopes	140.7	0.11	945	132961.5	1745	245521.5	2240	315168
U120A	Cedarpass-Denby complex, 0 to 3 percent slopes	199	0.16	1011	201189	1792	356608	2315	460685
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	548.9	0.43	536	294210.4	1288	706983.2	1620	889218
U165A	Denby silty clay, 0 to 3 percent slopes	174.5	0.14	1120	195440	1850	322825	2425	423162.5
U192G	Epping-Keota-Badland complex, moist, 9 to 50 percent slopes	19.1	0.02	838	16005.8	1413	26988.3	1985	37913.5

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U195E	Mitchell-Epping silt loams, moist, 9 to 30 percent slopes	0.1	0.00	1005	100.5	1570	157	2120	212
U205F	Fairburn-Orella, very channery-Whitewater complex, 6 to 40 percent	2,873.00	2.27	762	2189226	1294	3717662	1663	4777799
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	6.1	0.00	565	3446.5	995	6069.5	1345	8204.5
U235B	Interior-Riverwash complex, 0 to 6 percent slopes, frequently flooded	148.3	0.12	394	58430.2	1530	226899	1894	280880.2
U315A	Interior loam, 0 to 3 percent slopes, occasionally flooded	25.5	0.02	1010	25755	1550	39525	1885	48067.5
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	2,106.20	1.66	700	1474340	1797	3784841	2133	4492525
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	181.3	0.14	976	176948.8	1564	283553.2	1985	359880.5
U340B	Interior, moderately deep, occasionally flooded-Cedarpass 0 to 6	585.4	0.46	568	332507.2	1581	925517.4	1967	1151482
U342C	Interior, poorly drained-Interior, frequently flooded-Epping, moist 0-9	5.4	0.00	845	4563	1400	7560	1735	9369
U348E	Jayem-Valentine, dry complex, 6 to 30 percent slopes	768.4	0.61	1695	1302438	2225	1709690	2825	2170730
U355C	Kadoka-Epping, moist silt loams, 3 to 9 percent slopes	66.4	0.05	904	60025.6	1608	106771.2	2118	140635.2
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40 percent	4.5	0.00	759	3415.5	1366	6147	1775	7987.5
U495F	Vivian gravelly loam, dry, 6 to 40 percent slopes	169.3	0.13	755	127821.5	1200	203160	1565	264954.5
U556C	Orella silt loam, very shallow, 1 to 9 percent slopes	680.2	0.54	810	550962	1255	853651	1555	1057711
U560C	Orella-Badland complex, 1 to 9 percent slopes	13.5	0.01	605	8167.5	955	12892.5	1190	16065
U560F	Orella-Badland complex, 9 to 45 percent slopes	20	0.02	646	12920	966	19320	1208	24160
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	758.9	0.60	470	356683	1160	880324	1465	1111789
U615A	Savo-Tuthill silt loams, 0 to 3 percent slopes	0.5	0.00	1063	531.5	1860	930	2380	1190
U740C	Tuthill-Jayem fine sandy loams, 3 to 9 percent slopes	1.1	0.00	1731	1904.1	2335	2568.5	2943	3237.3
U745A	Manter, cool-Tuthill fine sandy loams, 0 to 3 percent slopes	10.3	0.01	1303	13420.9	2010	20703	2515	25904.5
U745B	Manter, cool-Tuthill fine sandy loams, 3 to 6 percent slopes	85.9	0.07	1329	114161.1	2046	175751.4	2561	219989.9
U755E	Valentine loamy sand, dry, 6 to 25 percent slopes	253.2	0.20	1500	379800	1920	486144	2510	635532

Site B (due to acreage limits with the NRCS Web Soil Survey this unit was mapped in 2 sections, i.e., a West Half and a East Half)				Unfavorable (Dry) Year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	488.7	0.39	994	485767.8	1559	761883.3	2065	1009166
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	447.1	0.35	901	402837.1	1371	612974.1	1798	803885.8
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	307.2	0.24	814	250060.8	1268	389529.6	1668	512409.6
UW	Water	31.3	0.02	0	0	0	0	0	0
Vs	Valentine sand, 3 to 30 percent slopes	255.8	0.20	1521	389071.8	1935	494973	2535	648453
W	Water	12.2	0.01	0	0	0	0	0	0
Ww	Wortman-Wanblee silt loams, 0 to 6 percent slopes	820.5	0.65	974	799167	1444	1184802	1922	1577001
Total		126,679			89596222		153987754		196437484

Site C

Site C				Unfavorable (Dry) year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
N464B	Kyle clay, 2 to 6 percent slopes	85.70	0.10%	1145	98126.5	1820	155974	2390	204823
N464C	Kyle clay, 6 to 9 percent slopes	3.20	0.00%	1145	3664	1820	5824	2390	7648
N542F	Samsil silty clay loam, 10 to 40 percent slopes	178.2	0.20%	994	177130.8	1418	252687.6	1830	326106
N656B	Pierre clay, 2 to 6 percent slopes	13.6	0.00%	1181	16061.6	1854	25214.4	2425	32980
N656D	Pierre clay, 6 to 15 percent slopes	159.7	0.20%	1145	182856.5	1800	287460	2355	376093.5
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	1,904.80	2.00%	1095	2085756	1655	3152444	2150	4095320
N711G	Samsil-Pierre, thin solum complex, 6 to 60 percent slopes	1,657.70	1.70%	989	1639465	1390	2304203	1785	2958995
N814B	Swanboy clay, 0 to 6 percent slopes	232.9	0.20%	798	185854.2	1295	301605.5	1701	396162.9
U020G	Badland	22,222.80	23.00%	205	4555674	392	8711338	521	11578079
U027F	Badland-Orella complex, 6 to 40 percent slopes	9,627.50	10.00%	286	2753465	481	4630828	598	5757245
U110A	Cedarpass silt loam, 0 to 3 percent	450.2	0.50%	960	432192	1770	796854	2265	1019703
U110B	Cedarpass silt loam, 3 to 6 percent slopes	207.20	0.20%	945	195804	1745	361564	2240	464128
U120A	Cedarpass-Denby complex, 0 to 3 percent slopes	405.5	0.40%	1011	409960.5	1792	726656	2315	938732.5
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	2,195.10	2.30%	536	1176574	1288	2827289	1620	3556062
U165A	Denby silty clay, 0 to 3 percent slopes	1,391.50	1.40%	1120	1558480	1850	2574275	2425	3374388
U190D	Epping, moist-Kadoka silt loams, 9 to 20 percent slopes	169.3	0.20%	859	145428.7	1550	262415	2064	349435.2
U192G	Epping-Keota-Badland complex, moist, 9 to 50 percent slopes	2,297.10	2.40%	838	1924970	1413	3245802	1985	4559744
U195E	Mitchell-Epping silt loams, moist, 9 to 30 percent slopes	25.10	0.00%	1005	25225.5	1570	39407	2120	53212
U200F	Fairburn clay loam, 9 to 40 percent slopes	18.5	0.00%	816	15096	1398	25863	1794	33189
U205F	Fairburn-Orella, very channery-Whitewater complex, 6 to 40 percent	6,441.80	6.70%	762	4908652	1294	8335689	1663	10712713
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	2,093.20	2.20%	565	1182658	995	2082734	1345	2815354

Site C				Unfavorable (Dry) year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U235B	Interior-Riverwash complex, 0 to 6 percent slopes, frequently flooded	362.2	0.40%	394	142706.8	1530	554166	1894	686006.8
U240A	Bridgeport loam, cool, 0 to 3 percent slopes, rarely flooded	154.4	0.20%	1604	247657.6	2396	369942.4	2896	447142.4
U305A	Hoven silt loam, 0 to 1 percent slopes	14.2	0.00%	1450	20590	2148	30501.6	3368	47825.6
U315A	Interior loam, 0 to 3 percent slopes, occasionally flooded	215.3	0.20%	1010	217453	1550	333715	1885	405840.5
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	5,655.10	5.80%	700	3958570	1797	10162215	2133	12062328
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	928.00	1.00%	976	905728	1564	1451392	1985	1842080
U340B	Interior, moderately deep, occasionally flooded-Cedarpass 0 to 6	2,692.70	2.80%	568	1529454	1581	4257159	1967	5296541
U342C	Interior, poorly drained-Interior, frequently flooded-Epping, moist 0-9	69.7	0.10%	845	58896.5	1400	97580	1735	120929.5
U348E	Jayem-Valentine, dry complex, 6 to 30 percent slopes	1,487.70	1.50%	1695	2521652	2225	3310133	2825	4202753
U350A	Kadoka-Thirtynine silt loams, 0 to 3 percent slopes	17.70	0.00%	1041	18425.7	1840	32568	2345	41506.5
U350B	Kadoka-Thirtynine silt loams, 3 to 6 percent slopes	142.9	0.10%	1035	147901.5	1816	259506.4	2335	333671.5
U350C	Kadoka-Thirtynine silt loams, 6 to 9 percent slopes	27.7	0.00%	1029	28503.3	1801	49887.7	2317	64180.9
U355C	Kadoka-Epping, moist silt loams, 3 to 9 percent slopes	529.5	0.50%	904	478668	1608	851436	2118	1121481
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40 percent	2,152.40	2.20%	759	1633672	1366	2940178	1775	3820510
U495F	Vivian gravelly loam, dry, 6 to 40 percent slopes	543.6	0.60%	755	410418	1200	652320	1565	850734
U510A	Thirtynine silt loam, 0 to 2 percent slopes	16.9	0.00%	1005	16984.5	1784	30149.6	2297	38819.3
U556C	Orella silt loam, very shallow, 1 to 9 percent slopes	2,431.40	2.50%	810	1969434	1255	3051407	1555	3780827
U560C	Orella-Badland complex, 1 to 9 percent slopes	1,354.60	1.40%	605	819533	955	1293643	1190	1611974
U560F	Orella-Badland complex, 9 to 45 percent slopes	2,590.20	2.70%	646	1673269	966	2502133	1208	3128962
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	11,173.10	11.60%	470	5251357	1160	12960796	1465	16368592
U615A	Savo-Tuthill silt loams, 0 to 3 percent slopes	1,663.50	1.70%	1063	1768301	1860	3094110	2380	3959130
U740A	Tuthill-Jayem fine sandy loams, 0 to 3 percent slopes	212	0.20%	1699	360188	2307	489084	2905	615860

Site C				Unfavorable (Dry) year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U740C	Tuthill-Jayem fine sandy loams, 3 to 9 percent slopes	1,112.60	1.20%	1731	1925911	2335	2597921	2943	3274382
U745A	Manter, cool-Tuthill fine sandy loams, 0 to 3 percent slopes	1,454.10	1.50%	1303	1894692	2010	2922741	2515	3657062
U745B	Manter, cool-Tuthill fine sandy loams, 3 to 6 percent slopes	1,626.50	1.70%	1329	2161619	2046	3327819	2561	4165467
U745C	Manter, cool-Tuthill fine sandy loams, 6 to 9 percent slopes	319.00	0.30%	1384	441496	2172	692868	2731	871189
U755E	Valentine loamy sand, dry, 6 to 25 percent slopes	511	0.50%	1500	766500	1920	981120	2510	1282610
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	2,987.00	3.10%	994	2969078	1559	4656733	2065	6168155
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	1,619.40	1.70%	901	1459079	1371	2220197	1798	2911681
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	609.50	0.60%	814	496133	1268	772846	1668	1016646
UW	Water	58.9	0.10%		0		0		0
N464B	Kyle clay, 2 to 6 percent slopes	0.20	0.00%	1145	229	1820	364	2390	478
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	14.5	0.00%	1095	15877.5	1655	23997.5	2150	31175
U020G	Badland	0.20	0.00%	205	41	392	78.4	521	104.2
U027F	Badland-Orella complex, 6 to 40 percent slopes	38.3	0.00%	286	10953.8	481	18422.3	598	22903.4
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	0	0.00%	536	0	1288	0	1620	0
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	5.7	0.00%	700	3990	1797	10242.9	2133	12158.1
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	0.1	0.00%	976	97.6	1564	156.4	1985	198.5
U560C	Orella-Badland complex, 1 to 9 percent slopes	0.6	0.00%	605	363	955	573	1190	714
U560F	Orella-Badland complex, 9 to 45 percent slopes	2.20	0.00%	646	1421.2	966	2125.2	1208	2657.6
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	3.4	0.00%	470	1598	1160	3944	1465	4981
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	0.10	0.00%	994	99.4	1559	155.9	2065	206.5
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	1.4	0.00%	901	1261.4	1371	1919.4	1798	2517.2
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	0.3	0.00%	814	244.2	1268	380.4	1668	500.4

Site C				Unfavorable (Dry) year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
N666E	Pierre-Samsil clays, 6 to 30 percent slopes	0	0.00%	1095	0	1655	0	2150	0
Os	Orella-Shale outcrop complex, 3 to 18 percent slopes	0.5	0.00%	803	401.5	1135	567.5	1459	729.5
U020G	Badland	1.6	0.00%	205	328	392	627.2	521	833.6
U027F	Badland-Orella complex, 6 to 40 percent slopes	2.30	0.00%	286	657.8	481	1106.3	598	1375.4
U110A	Cedarpass silt loam, 0 to 3 percent	7.6	0.00%	960	7296	1770	13452	2265	17214
U110B	Cedarpass silt loam, 3 to 6 percent slopes	0.5	0.00%	945	472.5	1745	872.5	2240	1120
U120A	Cedarpass-Denby complex, 0 to 3 percent slopes	3.4	0.00%	1011	3437.4	1792	6092.8	2315	7871
U125B	Cedarpass-Interior, frequently flooded-Badland complex, 0 to 6	7.30	0.00%	536	3912.8	1288	9402.4	1620	11826
U165A	Denby silty clay, 0 to 3 percent slopes	3.6	0.00%	1120	4032	1850	6660	2425	8730
U195E	Mitchell-Epping silt loams, moist, 9 to 30 percent slopes	0.1	0.00%	1005	100.5	1570	157	2120	212
U205F	Fairburn-Orella, very channery-Whitewater complex, 6 to 40 percent	5.8	0.00%	762	4419.6	1294	7505.2	1663	9645.4
U215F	Epping, moist-Badland complex, 9 to 40 percent slopes	0.20	0.00%	565	113	995	199	1345	269
U235B	Interior-Riverwash complex, 0 to 6 percent slopes, frequently flooded	0.5	0.00%	394	197	1530	765	1894	947
U315A	Interior loam, 0 to 3 percent slopes, occasionally flooded	0.6	0.00%	1010	606	1550	930	1885	1131
U325B	Interior loam, channeled, 0 to 6 percent slopes, flooded	1.8	0.00%	700	1260	1797	3234.6	2133	3839.4
U335B	Interior, occasionally flooded-Cedarpass-Denby complex, 0 to 6	2.10	0.00%	976	2049.6	1564	3284.4	1985	4168.5
U340B	Interior, moderately deep, occasionally flooded-Cedarpass 0 to 6	14	0.00%	568	7952	1581	22134	1967	27538
U342C	Interior, poorly drained-Interior, frequently flooded-Epping, moist 0-9	0	0.00%	845	0	1400	0	1735	0
U348E	Jayem-Valentine, dry complex, 6 to 30 percent slopes	0.3	0.00%	1695	508.5	2225	667.5	2825	847.5
U355C	Kadoka-Epping, moist silt loams, 3 to 9 percent slopes	0.2	0.00%	904	180.8	1608	321.6	2118	423.6
U360F	Keota, thick surface-Epping-Badland complex, moist, 9 to 40 percent	0.4	0.00%	759	303.6	1366	546.4	1775	710
U495F	Vivian gravelly loam, dry, 6 to 40 percent slopes	0.6	0.00%	755	453	1200	720	1565	939

Site C				Unfavorable (Dry) year		Normal Year		Favorable (Wet) year	
Map unit symbol	Map unit name	Acres in AOI	Percent of AOI	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs	Lbs. per acre	Total lbs
U556C	Orella silt loam, very shallow, 1 to 9 percent slopes	16.7	0.00%	810	13527	1255	20958.5	1555	25968.5
U560C	Orella-Badland complex, 1 to 9 percent slopes	0.5	0.00%	605	302.5	955	477.5	1190	595
U560F	Orella-Badland complex, 9 to 45 percent slopes	0.5	0.00%	646	323	966	483	1208	604
U565E	Orella-Interior, moderately deep, frequently flooded-Badland 0 to 25	11.3	0.00%	470	5311	1160	13108	1465	16554.5
U615A	Savo-Tuthill silt loams, 0 to 3 percent slopes	1.6	0.00%	1063	1700.8	1860	2976	2380	3808
U740C	Tuthill-Jayem fine sandy loams, 3 to 9 percent slopes	1.1	0.00%	1731	1904.1	2335	2568.5	2943	3237.3
U745A	Manter, cool-Tuthill fine sandy loams, 0 to 3 percent slopes	0	0.00%	1303	0	2010	0	2515	0
U745B	Manter, cool-Tuthill fine sandy loams, 3 to 6 percent slopes	0.1	0.00%	1329	132.9	2046	204.6	2561	256.1
U755E	Valentine loamy sand, dry, 6 to 25 percent slopes	0.4	0.00%	1500	600	1920	768	2510	1004
U802B	Whitewater-Denby silty clays, 1 to 6 percent slopes	7	0.00%	994	6958	1559	10913	2065	14455
U805C	Whitewater-Orella silty clays, 3 to 9 percent slopes	2.1	0.00%	901	1892.1	1371	2879.1	1798	3775.8
U820B	Wortman-Wanblee silt loams, 0 to 6 percent slopes	4.5	0.00%	814	3663	1268	5706	1668	7506
Total		96,680			60078135		108255041		138061725

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov