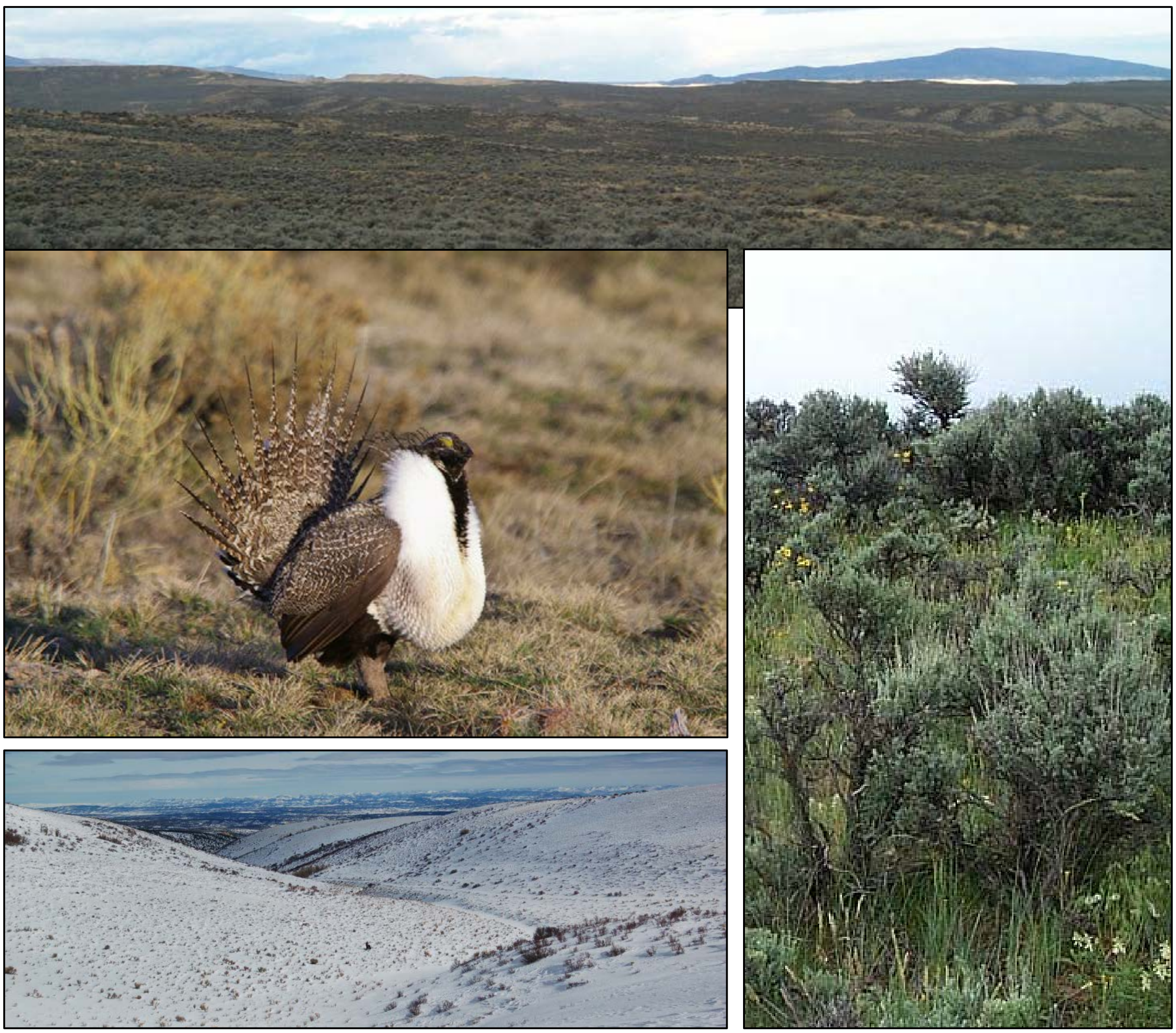
Greater Sage-Grouse Habitat Quantification Tool: A Multi-Scaled Approach for Assessing Impacts and Benefits to Greater Sage-Grouse Habitat

Scientific Methods Document, Version 5



Acknowledgements

The Greater Sage-Grouse Habitat Quantification Tool: A Multi-Scaled Approach for Assessing Impacts and Benefits to Greater Sage-Grouse Habitat, *Scientific Methods Document, and version 5* was developed for the Colorado Habitat Exchange. It is the product of Environmental Defense Fund and its consultant EcoMetrix Solutions Group. It would not have been possible without the input and guidance from our Science Team and the financial support of the Colorado Department of Natural Resources and Colorado Parks and Wildlife.

The authors thank the Colorado Natural Heritage Program and The Nature Conservancy—Wyoming Chapter for constructing the Landscape Disturbance Index and Landscape Quality Index, and members of the Colorado Habitat Exchange Working Group, including Colorado Oil and Gas Association, Colorado Cattlemen's Association, Colorado Department of Natural Resources, Colorado Parks and Wildlife, Environmental Defense Fund, Partners for Western Conservation, and Southwestern Energy Inc. for providing thoughtful input throughout the development of the habitat quantification approach.

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Executive Summary

To be completed at a later date.

1.0 HQT Overview

The Greater Sage-Grouse Habitat Quantification Tool: A Multi-Scaled Approach for Assessing Impacts and Benefits to Greater Sage-Grouse Habitat, *Scientific Methods Document, version 5* (HQT) is an approach to estimating the condition, or habitat value, of a given location on the landscape for Greater Sage-grouse (*Centrocercus urophasianus*; hereafter GRSG). The HQT uses a "functional acre" approach, applied through a set of measurements and methods that relate to the habitat attributes influencing GRSG selection of seasonal habitats across varying spatial and temporal scales (Stiver et al. 2010). The purpose of the HQT is to serve as a means of quantifying the change in condition of habitats for GRSG resulting from management action—either as an impact ("debit") or as a benefit ("credit") in the Colorado Habitat Exchange (Exchange).

The HQT describes how the quality of GRSG habitat and change in quality resulting from management actions is quantified. Conditions specific to each seasonal habitat type (i.e., breeding, summer, and winter) are accounted for independently. In other words, a separate functional acre score is calculated for each seasonal habitat type. The Exchange Operations Manual (Exchange Manual) defines how these scores are used by the Exchange.

To quantify the quality of GRSG habitat, the pre-project conditions at the site are measured to determine the current ecological performance of the site based on specific, pre-determined habitat requirements of the species, measured as a preliminary "functional acre" score. The number of functional acres is then adjusted to account for local context, landscape condition and position. Next the projected (not actual) post-project condition is evaluated to determine the extent to which the site's ability to support the species is projected to change as a result of the project. The post-project condition is the basis for the credit/debit estimate for the proposed project. Once the project is underway, the actual, change in conditions is verified using the HQT and credits are released according to the actual credit/debit amount and the credit release schedule for the project, as defined in the Exchange Manual.

This version of the HQT has been developed for use in the Exchange but is a framework that can be easily adapted for use throughout the species' range. The intent of the Exchange is to provide financial incentives for achieving a net habitat benefit through conservation investment and compensatory mitigation for GRSG across large landscapes. Using the "functional acre" as its basic unit of currency, the Exchange provides a trading platform for conservationists, private landowners and developers that simultaneously takes into account both habitat quantity and quality.

1.1 The Functional Acre Approach

The HQT describes how to determine the number of “functional acres” of impact or benefit generated by a given project. The term “functional acres” refers to the size of a site (acres) multiplied by its quality (or “functionality”). The functionality of a site represents its level of performance relative to optimal conditions and takes into account species-specific habitat features at multiple scales that are known to be meaningful to GRSG, including the quality and structure of vegetation on the site and the degree of human disturbance on and surrounding the site.

The “functional acre” approach provides several advantages over traditional mitigation approaches. First, it establishes a common “currency” (functional acres) for the Exchange. The integration of habitat area and quality allows for accurate accounting of biological impacts and benefits because they can be compared directly, as “apples to apples”, which provides a clearer understanding of whether or not conservation goals are being met (McKenney and Kiesecker 2010, Gardner et al. 2013). A common currency standardizes the calculation of credits and debits, which affords the opportunity to conduct mitigation consistently across multiple projects, and land ownership and jurisdictional boundaries. It also provides a common language and metric for mitigation across agencies and industries, while striving to be responsive to new science as it emerges.

Second, the functional acre approach accounts for not only the physical footprint of development, but also for biological impacts known as “behavioral avoidance,” by accounting for distance-effects associated with anthropogenic features (Manier et al. 2013). Accounting for behavioral avoidance as part of the currency of the Exchange offers two strengths: 1) a more accurate representation of the full biological impact on GRSG; and 2) a strong incentive for targeting debits and credits to the most appropriate places on the landscape, clustering development where it will have the least species impact and focusing conservation efforts where they will have the greatest benefit. Furthermore, in step with current thinking about full life cycle conservation, the HQT strives to reflect the species’ needs throughout the annual cycle, based on best available science.

Third, fundamental to the functional acre approach is a focus on the measured habitat conditions resulting from impactful or beneficial management. Rather than rewarding the completion of management actions or practices that may or may not succeed, the Exchange focuses the activities of developers, ranchers and conservationists on what matters most to the GRSG – the resulting habitat outcomes of the practices, not the practices themselves. Paying for outcomes rather than practices has also been shown to achieve more conservation per dollar spent than paying for management practices (Just and Antle 1990, Antle et al. 2003). The outcomes-based functional acre approach of the HQT enables the Exchange to provide strong incentives to achieve habitat and landscape outcomes required by GRSG.

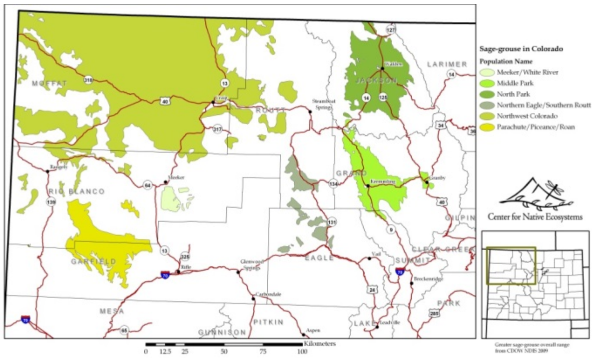
1.2 A Framework for Quantifying Habitat Functionality

The HQT was developed to account for the habitat characteristics or attributes, both natural and anthropogenic, which influence GRSG habitat selection across multiple scales. These habitat characteristics were based on different orders of selection (Stiver et al. 2010), which represent four levels of spatial scale at which habitat attributes influence where GRSG reside and obtain resources necessary for survival and reproduction. Johnson (1980:69) describes this hierarchical nature of selection as: "a selection process will be of higher order than another if it is conditional upon the latter." As an example, selection of food items will be of a higher order than selection of a feeding site because selection of a particular feeding site determines the array of food items available to be selected. While the term "selection" may be interpreted as relating to individual bird behavior, in this context we apply the term broadly (per Johnson 1980, Connelly et al. 2003, Stiver et al. 2010) to describe the four geographic scales at which GRSG occur, are organized into populations, and use habitat. These four scales also correspond to scales at which GRSG policy and management are typically implemented (Stiver et al. 2010). Connelly et al. (2003) describe the progression of habitat selection across orders as follows:

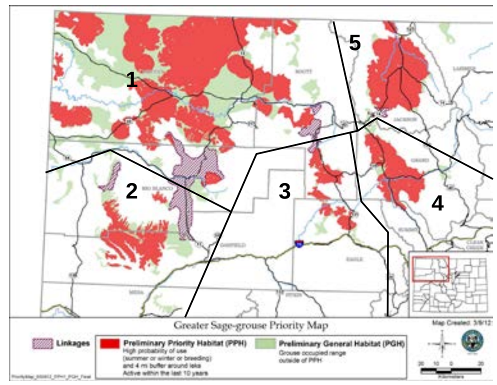
- 1^{st} order selection represents the geographic range of the GRSG population of interest—1^{st} order habitat attributes are those necessary for the species to occur.
- Within this geographic range, 2^{nd} order selection is based on habitats required by subpopulations; for example the habitats necessary to support the GRSG associated with a lek or lek complex.
- 3^{rd} order selection refers to the habitats used by individuals in the subpopulation and is defined by the attributes necessary for an individual to survive and thrive throughout a year; this order is relevant at the scale of a home range.
- 4^{th} order selection establishes the food and cover attributes at particular sites.

Although the orders of selection are described as stand-alone, these orders are inherently related and the value of a location for GRSG as quantified at a given order is only as good as the values measured at other orders. For example, the habitat conditions within a patch of sagebrush (4^{th} order) may be highly conducive to successful nesting and early brood-rearing, but if suitable late brood-rearing habitat is not accessible from that patch (3^{rd} order) or that patch is located in the middle of a forest (2^{nd} order), the value of that patch for GRSG is diminished or negligible. The orders considered in the HQT are illustrated in Figure 1.

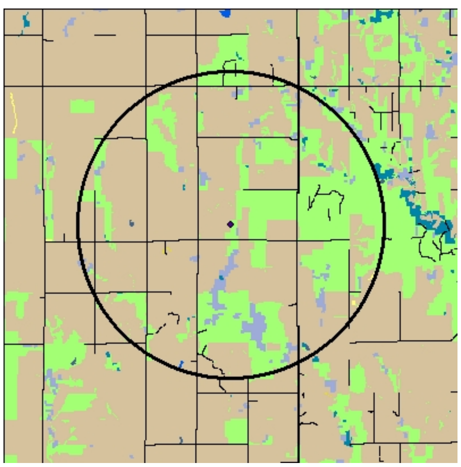
1st Order
Occupied range for the species in CO



2nd Order
Habitats required by subpopulations



3rd Order
Habitats used by individuals in the subpopulation



4th Order
Habitat conditions at the site of proposed activities

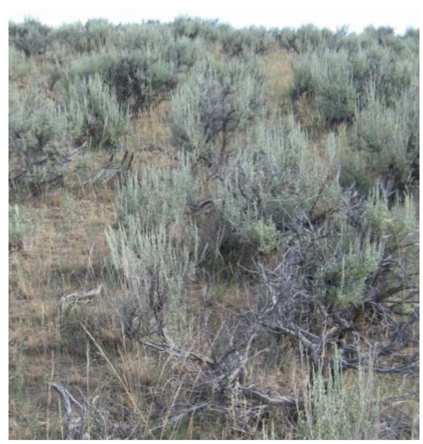


Figure 1. Orders of Selection Specific to the Colorado Habitat Exchange for Greater Sage-Grouse

The use of multiple scales of measurement enables the HQT to accomplish three essential tasks to program management:

1. **Measure impacts (debits) and benefits (credits) for transactions.** This is a measurement of the functionality at the 4th order (site) and how it is affected by the 3rd order (local context). This measure is the basis for calculating debit and credit amounts as defined in the Exchange Manual.
2. **Ensure that credits and debits reflect habitat quality in order to facilitate net habitat benefits across large landscapes.** This is a measurement of the relative quality or "value" of landscapes in which development or mitigation sites are located (2nd order).

3. **Track the contribution of the Exchange to species habitat and population conservation goals in Colorado over time.** This is a measure of the overall performance of the Exchange by evaluating the program's cumulative net benefit and understanding how habitat benefits contribute to conservation goals in Colorado (1st order).

1.3 Components of the HQT

There are four components of the HQT:

1. This **HQT Scientific Methods document** includes a description and definition of the attributes measured and scored at each of the four scales of habitat selection, methods of measurement for each attribute, and supporting documentation (e.g., peer-reviewed literature, gray literature and datasets, expert opinion and knowledge) illustrating why those specific attributes and methods are used. It also includes the data collection methods (Appendix F) and describes the monitoring and adaptive management process for monitoring and evaluating the accuracy, effectiveness, and efficiency of the HQT and subsequent adaptation of the HQT (section 6.0).

2. The **HQT Calculator** is a Microsoft Excel-based spreadsheet that performs the calculations using field data and the information contained in the HQT Scientific Methods document. Unique calculators have been created for debit projects and credit projects. Each includes instructions for using the Calculator.

3. The **HQT User's Guide** is a description of how to apply the desktop analyses portion of the HQT.

4. The **HQT Field Guide** is a description of how vegetation attributes should be measured in the field. It has not yet been finalized.

2.0 Habitat Quality and Species Performance

Habitat represents a particular combination of resources (e.g. food, shelter, and water) and environmental conditions that support survival and reproduction (Morrison et al. 2006). Habitat can vary in quality and therefore its ability to support survival and reproduction over time. Inherent in the HQT approach is that there is a direct relationship between high quality habitat and population resiliency. Conversely, poor quality habitat is assumed to result in low survival and reproduction (Van Horne 1983), leading to poor population resiliency. Marginal habitat may support some amount of occupancy by a species, but these marginal conditions may still result in low survival and/or reproduction and questionable resiliency, which will likely lead to population declines without high levels of immigration.

Vegetation vertical and horizontal structure and diversity are important attributes influencing habitat selection by birds (Cody 1985). These structural elements influence cover and food resources. Animal species range in their ecological niche from generalists to specialists in their habitat requirements (Ricklefs 1979), and the life history traits and habitat use of a specialized species like GRSG can be influenced more dramatically if the vegetation composition, structure, and/or juxtaposition are changed. Vegetation composition and structure makes a difference in quantity and quality of habitat for GRSG, and therefore specific vegetation features that are known to be particularly important to GRSG when evaluating habitat quality are considered in the HQT.

GRSG population persistence has been linked to the availability of sagebrush habitat; the dependence of the species on sagebrush through all seasonal periods has been well documented and cannot be over-emphasized (Connelly et al. 2004). Different vegetation structure and composition is required for different seasonal periods of habitat use. Although GRSG use a variety of habitats throughout the year, sagebrush is a common and required component (Connelly et al. 2000; Connelly et al. 2011c).

The HQT focuses on three seasonal periods and their habitat associations. There are many citations outlining these seasons, summarized by Hagen et al. (2007), Connelly et al. (2011c) and Connelly et al. 2004, and it is not the goal of this document to conduct an exhaustive review of the literature on GRSG seasonal habitat nomenclature. The seasonal periods include breeding, summer, and winter habitat. The transitional periods where habitat selection is less uniform (Connelly et al. 2000) are not considered in the HQT. Focusing on these three seasons also provides the HQT consistency with the Colorado Greater sage-grouse conservation plan (CCP) (Greater Sage-grouse Steering Committee 2008). The breeding season includes habitats associated with the pre-nesting, nesting and very early brood-rearing season (approximately mid-March – June); the summer season includes habitats associated with brood-rearing females, males, and unsuccessful females (approximately July – September); and the winter season includes habitats that are almost exclusively sagebrush dominated (November – mid-March) (Greater Sage-grouse Steering Committee 2008; Connelly et al. 2011c).

GRSG leks are situated in areas with minimal shrub cover adjacent to relatively dense sagebrush stands where strutting male exposure is maximized, but escape, thermal, and feeding cover is readily available (Patterson 1952, Gill 1965). One of the most important landscape characteristics for leks may be their proximity and configuration with nesting habitat (per theories of lek evolution and mating behavior; Gibson 1996). Across the range of the species, nesting GRSG consistently select areas with more sagebrush canopy cover and taller grasses compared to available habitats (Hagen et al. 2007), and tall, dense herbaceous cover – including residual (e.g., standing dead) grasses – in selected dense sagebrush stands tends to increase the probability of a successful hatch (Holloran et al. 2005). GRSG females generally rear their broods for the first two to four weeks following hatch in the immediate vicinity of their nest within sagebrush-dominated habitats (Connelly 1982, Thompson 2012). Thermal and predator protection of young chicks (e.g., dense sagebrush stands; Thompson et al. 2006) and food availability (e.g., insects and succulent forbs; Johnson and Boyce 1990, Drut et al. 1994) are important for chick survival during the early brood-rearing period. Lekking, nesting and early brood-rearing habitats are generally considered together as breeding habitats (Connelly et al. 2000).

Post-nesting, GRSG broods remain in sagebrush-dominated habitats until range desiccation induces them to move to habitats still supporting succulent herbaceous vegetation; GRSG may use a variety of sagebrush and other habitats (e.g., springs and seeps, riparian corridors, stock ponds, wet meadows and irrigated agricultural fields adjacent to sagebrush habitats) during summer (Peterson 1970, Wallestad 1971, Neel 1980, Fischer et al. 1997). Selection of wintering habitats by GRSG is influenced by snow depth and hardness, topography (i.e., elevation, slope, and aspect), and vegetation height and density (Gill 1965, Greer 1990, Schroeder et al. 1999). During the winter GRSG rely almost exclusively on sagebrush exposed above the snow for forage and shelter (Patterson 1952, Remington and Braun 1985, Robertson 1991, Schroeder et al. 1999, Connelly et al. 2000, Crawford et al. 2004).

2.1 The Importance of Spatial and Temporal Scale

As with many ecological processes, habitat selection occurs at multiple spatial scales, with individuals choosing to settle in a location by keying in to different features at different scales (Hilden 1965, Johnson 1980, Wiens et al. 1987, Wiens 1989, Orians and Wittenberger 1991, Fuhlendorf and Smeins 1996, Fuhlendorf et al. 2002, Morrison et al. 2006). This applies to vegetation in particular, as birds may perceive physical vegetation structure first over a relatively large, landscape scale, and then settle across the landscape according to more fine scale vegetation composition and other factors (Wiens et al. 1987). Temporal (time) scales also vary among ecological processes and may not be linear especially in varying environments (Wiens 1989). The time required for a vegetation community to respond to management practices or changes in habitat and its influence on GRSG vital rates varies by ecosystem, geography, climate, and land use. For GRSG, time lags of two to ten years have been observed for population response to infrastructure development (Holloran 2005; Harju et al. 2010; Walker et al. 2007) or even longer with changes in habitat structure (e.g. fire) (Connelly et al. 2011b). Despite the uncertainty that will inevitably arise around this topic, temporal scales must be taken into consideration when establishing a mitigation project, and as spatial scales of a project or evaluation area increase, so should temporal scales.

Temporal scale for sagebrush projects deserves especially close consideration given that recovery of sagebrush is an especially difficult and slow process due to abiotic variation, short-lived seedbanks, and long generation time of sagebrush; where soils and vegetation are highly disturbed, sagebrush restoration can be challenging if not impossible (Monsen 2005).

3.0 Habitat Quantification Methods and Attributes

The ultimate objective of the Exchange is to contribute to conservation of GRSG by providing net habitat benefit to the species through compensatory mitigation. It is assumed that improved habitat conditions ultimately result in larger and more secure GRSG populations. Therefore, the Exchange should monitor and report cumulative habitat impacts and benefits that are anticipated to have a net habitat contribution to populations.

To make a direct link between habitat management and population response, an estimate of population impacts from activities at the 4th and 3rd orders would be needed. That is not currently feasible and it is not an objective of the Exchange to directly link site-level management actions to a population-level response of GRSG. The Exchange is focused on actions that occur at the site level, and the methods required to accurately measure conditions at that scale (e.g., vegetation plots) are not conducive to large-scale assessments. However, additional research could contribute to a greater understanding of how cumulative habitat changes contribute to population viability. Furthermore, as long as debits are offset by credits, and as credits accumulate beyond debits, the Exchange will contribute to net increases in high quality habitat that we believe to be likely to sustain resilient GRSG populations over time.

3.1 Greater Sage-Grouse Occupied Range in Colorado

Colorado Parks and Wildlife (CPW) regularly assesses the distribution of GRSG within the state. Occupied habitats are currently considered Preliminary Priority Habitats (PPH), Preliminary General Habitats (PGH), or Linkages.[1] PPH are areas having the highest conservation value given the goal of maintaining sustainable GRSG populations in Colorado. PGH are defined as GRSG occupied range outside of PPH. The occupied range of the species plus linkages at the 1st order (i.e. the species range in Colorado) are considered in the HQT; to be eligible to participate in the Exchange a project site must be located within either PPH, PGH or Linkages as identified by CPW (Figure 2). When populations expand or are observed to shift geographically over time, these boundaries and/or criteria for inclusion will be re-evaluated.

Credits and debits are tracked, exchanged and reported within a distinct mapped geographic region called a service area. The Colorado Habitat Exchange's five service areas (Figure 2) are based on the priority habitat map developed by CPW.

[1] Priority habitat map is available online:
http://cpw.state.co.us/Documents/Maps/WildlifeSpecies/Birds/GrSG_PPH_PGH_20120309_Final.pdf)

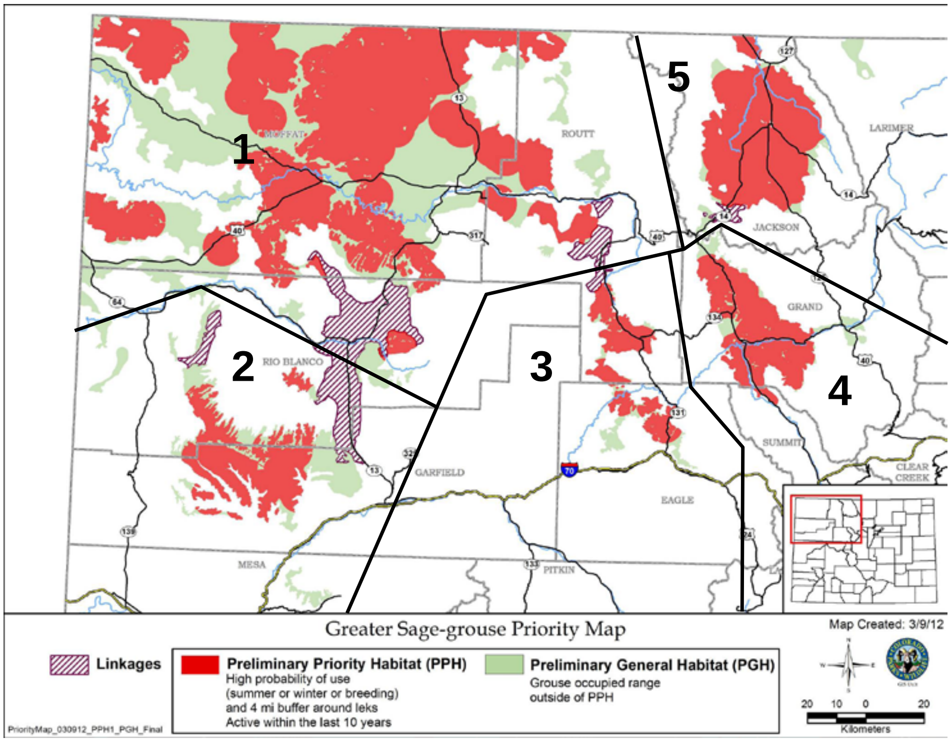


Figure 2. Service Areas Identified in Colorado

3.2 Assessment of Site Condition

When a project area is within the occupied range of GRSG in Colorado, the HQT is an approach to establishing the conditions or "function" of a project area. Debit and credit project areas (or sites) are defined by the footprint of the project (i.e. for debit projects this is the land on which the development will occur, and for credit projects this is the area of land that is outlined in the participant's contract) plus the area of behavioral avoidance effect of any anthropogenic or natural feature (e.g. transmission line or conifer cover) that occurs on the site. The calculation of functional acres initially focuses on quantifying the condition of a site at the 4^{th} order based on vegetative cover, structure, composition and topography. The 4^{th} order attributes are indicative of habitat suitability and quality for the GRSG, including conditions that support breeding, summer, and winter habitats, and in part, are identified as components of structural habitat guidelines that are important in GRSG habitat selection (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007; Greater Sage-grouse Steering Committee 2008). The functional acre score resulting from these 4^{th} order measures is then adjusted based on the quality of the surrounding habitat context. The concept model presented in Figure 3 illustrates the site-level attributes being measured and the role they play in providing suitable breeding, summer, and winter habitat for GRSG.

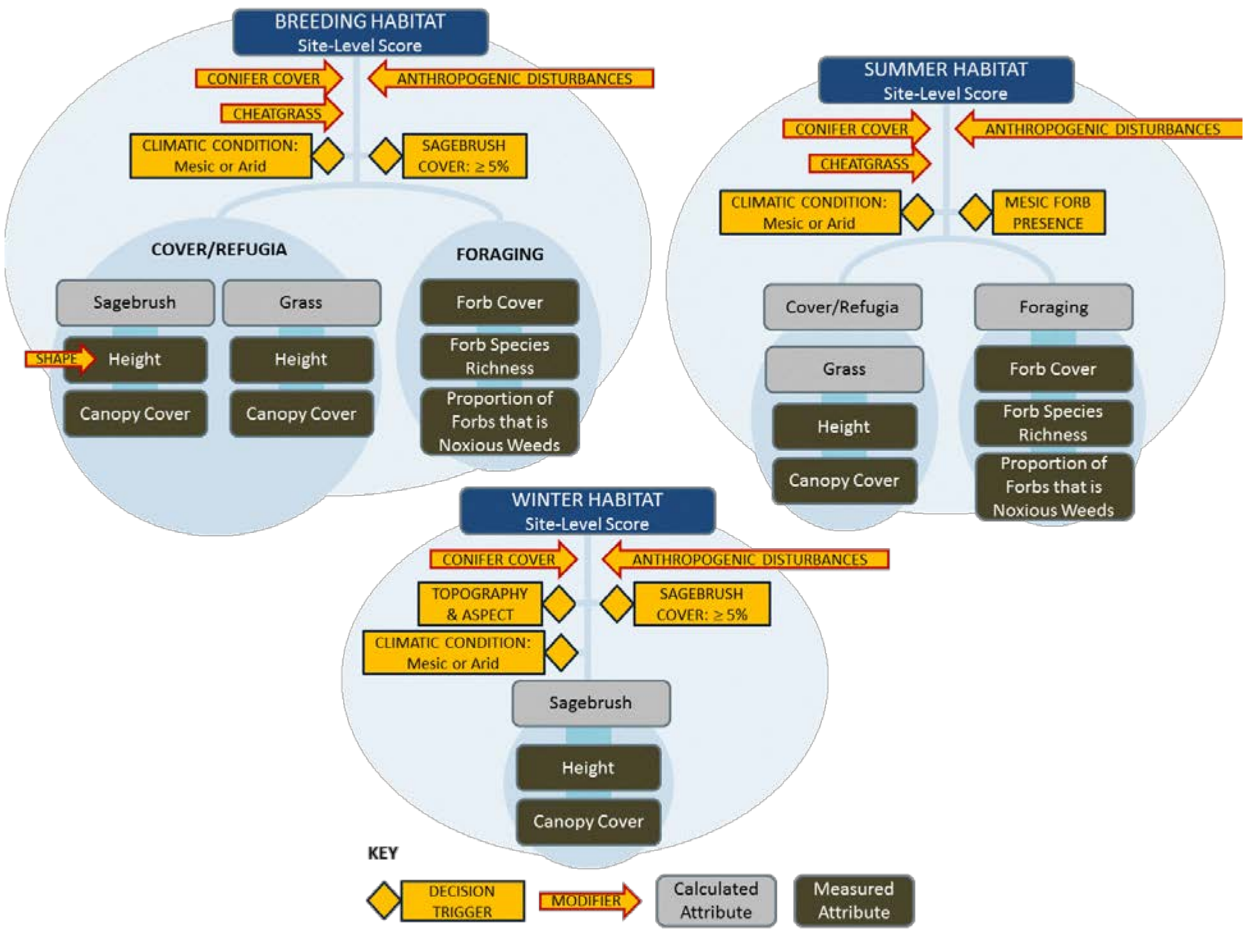


Figure 3. Conceptual Model Depicting GRSG Life History Requirements

3.2.1 Decision Triggers

Decision triggers are used to establish which set of scoring curves needs to be used at a given site, and whether an attribute can reduce the site vegetation condition score to zero. In the HQT, local climatic condition and topography and aspect establish which set of scoring curves should be used; sagebrush cover and presence of facultative forbs can reduce the seasonal habitat score to zero. The triggers used in the HQT are described in Table 1.

For example, sagebrush cover has to be greater than or equal to 5% to consider a site potential breeding habitat, so 5% sagebrush cover is a trigger for breeding habitat. If sagebrush cover is <5% at a site it cannot be considered suitable breeding habitat and therefore the site is not scored for breeding habitat value; that value is 0. A set of decision triggers also determines whether scoring curve for mesic conditions (i.e., sites generally in >30 cm annual precipitation zone) or curves meant for arid/xeric conditions (i.e., sites generally in 18-30 cm annual precipitation zone) should be used. The triggers used in the HQT are described in Table 1.

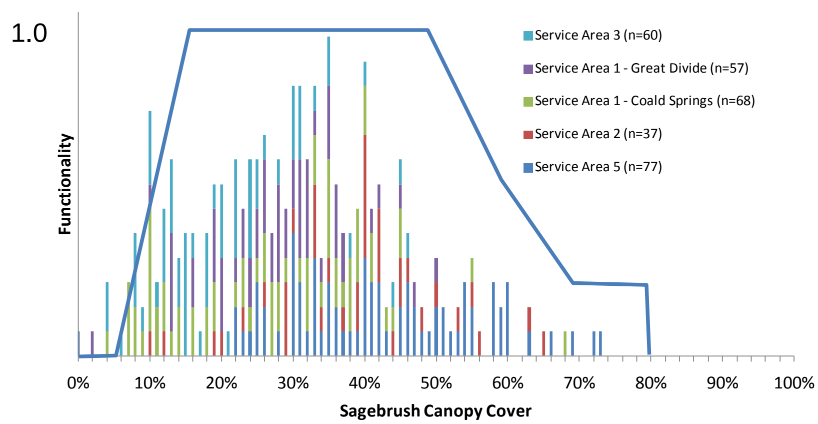
Table 1. Decision Triggers Used in the HQT

Attribute		Trigger	Definition
Triggers That Determine Which Scoring Curves are Used	Local Climatic Conditions	Determine whether site is either mesic conditions or arid/xeric conditions for breeding, summer, and winter habitats	The wide range of GRSG results in different vegetation potentials regionally in Colorado that are influenced primarily by soil characteristics and annual precipitation. Encouraging the identification of suitable and high quality habitat within each region of the state requires consideration of these conditions and how they impact functionality scores. For example, vegetation in arid conditions has different potential than vegetation in mesic conditions. These conditions influence plant community composition, productivity and presence (Winward 2004). This site variability is addressed by using different scoring curves and tables for sites in mesic and xeric conditions, but annual precipitation changes are different than site conditions (e.g. drought conditions). • Arid condition: sites generally in 18-30 cm annual precipitation zone (Winward 2004); *Artemisia tridentata wyomingensis* is a common big sagebrush sub-species for this type of site; • Mesic condition: sites generally in a >30 cm annual precipitation zone (Winward 2004); *Artemisia tridentata vaseyana* is a common big sagebrush sub-species for this type of site
	Topography and Aspect	Determine the topography and aspect curves (slope <5% or >5%) for winter habitat	GRSG generally prefer relatively open sagebrush flats or open rolling sagebrush hills (Connelly et al. 2011c, Hupp 1987, Hupp and Braun 1998, Doherty et al. 2008), but this can be population specific. However, in winter GRSG inhabit areas with moderate to dense black (*A. nova*) and low (*A. arbuscula*) sagebrush and are also found on ridge tops with a south to west aspect (Hupp and Braun 1989, Doherty et al. 2008). Because some winter sites have relatively short sagebrush, there is no minimum height requirement for black and low sagebrush on ridge tops as there is in open sagebrush flats where snow accumulates. Sagebrush height > 10 cm is the minimum height for winter habitat. Accordingly, the 4th order winter score is based on the topography (percent slope) and aspect of the project site. There are two scoring curves and tables that correspond to the topography at which the sample point is taken: one scoring curve and table is used for slope greater than 5%, and a different scoring curve and table is used for slope less than 5%.
Triggers That Can Reduce Site-Level Scores to Zero	Sagebrush Canopy Cover	≥5% required for breeding and winter habitat	A primary factor influencing the functionality of a site for GRSG is the presence of sagebrush (Connelly et al. 2000, Hagen et al. 2007, Connelly et al. 2011c). GRSG require sagebrush for food and cover during the breeding and winter seasons. Although a precise functionality value between 0 - 5% is unknown, it is the expert opinion of the Science Team that if a site has <5% cover in breeding habitat, the habitat function of a site is reduced to zero at the 4th order.

Attribute		Trigger	Definition
	Facultative Forb Presence	Presence of facultative forb species required for summer habitat, see Appendix D for species list	GRSG use upland as breeding habitat (Connelly et al. 2011c). As the season advances and the understory herbaceous vegetation desiccates, GRSG move to areas where the vegetation remains green throughout the season (Connelly et al. 2011c). GRSG preferentially select sites close to sagebrush, but seek the areas where moisture allows forbs to grow throughout the summer (Connelly et al. 2011c) and they have free access to water. Accordingly, summer habitat is classified based on the presence of specific plant species that indicate the vegetation at the site will remain green over the course of the summer. If there are these specific species present, then the summer score is calculated. If these species are not present, the project site scores 0 for summer habitat.

3.2.2 Scoring Curves

After establishing the specific seasonal habitats being scored and which scoring curves to use, each vegetation attribute measured at the site is scored using the appropriate scoring curve. For example, Figure 4 is the scoring curve and associated table for sagebrush canopy cover in breeding habitat.



% Cover	< 5	5-14	15-19	20-29	30-39	40-49	50-59	60-69	70-79	>80
Functionality	0	0.5	1	1	1	1	0.5	0.25	0.25	0

Figure 4. Sagebrush Canopy Cover Scoring Curve and Associated Table for Breeding Habitat

The scoring curve simply establishes the relationship between sagebrush canopy cover and breeding habitat value, the shape of which was established from literature and expert opinion. Sagebrush canopy cover at every potential GRSG breeding site is between 5 and 100%, and the scoring curve establishes the condition or value of each site relative to optimal conditions—from 0 (non-habitat) to 1.0 (optimal canopy cover). Zero functionality indicates that the site has no value for GRSG, while 100% functionality indicates that the site is fully functional for GRSG. The scoring curves for all of the vegetation attributes measured are included in Appendix A.

Scoring response curves for each attribute were developed by the Science Team. Data used to develop and/or inform the relationships between level of vegetation and seasonal habitat values were from actual breeding (nesting and early-brood-rearing; n = 402), summer (brood-rearing and unsuccessful; n=148), and winter (male and female; n = 63) use sites of GRSG in Colorado collected from 2001 - 2010. Actual sample sizes for each attribute varied by site and the year the data was collected. Data for the attributes were extracted from GRSG use sites in Service Areas 1, 2, 3, and 5 (see Figure 2 for service areas in the HQT). Thus, the data were collected from a range of environmental conditions (xeric to mesic). The Science Team used the CCP data when other data were not available. Habitat measurements outside of Colorado were not used for scoring curves.

Guidance for inflection points on the response curves is generally consistent with the CCP. Minor adjustments and deviations to the inflection points may be different from the CCP because additional data have been collected post CCP publication (CPW, unpublished data; A.D. Apa personal communication).

3.2.3 Vegetation Attributes

Map Units

Map units are predefined for all Exchange participants and are the basis for all credit and debit calculations. A systematic grid provided by the Exchange for all participants delineates map units and indicates specific plot sampling locations in each map unit (Figure 5). Vegetation attributes are measured at the sampling location within each map unit to calculate 4th order habitat quality.

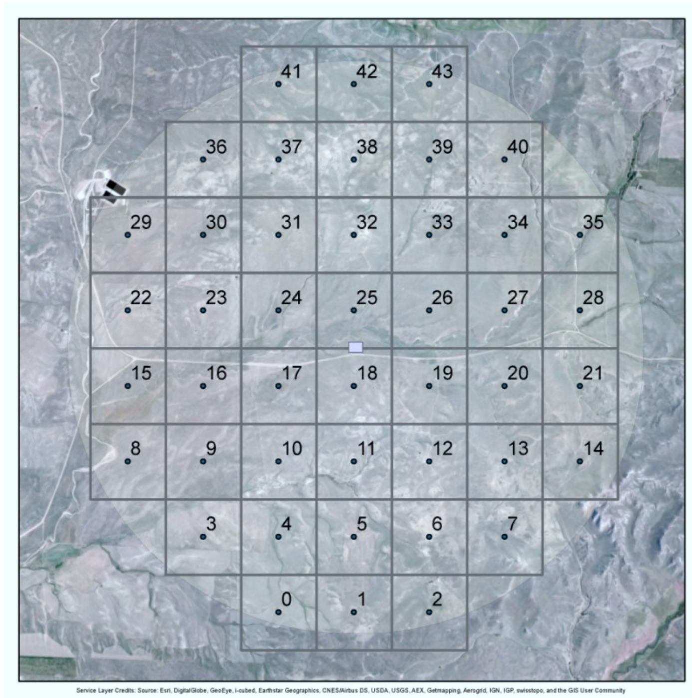


Figure 5. Systematic Grid Indicating Plot Sampling Locations Overlaid on Project Area

Vegetation Attributes

The height, structure, density, and cover of vegetation are important for providing cover and food resources adequate for productive seasonal habitat (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007, Greater Sage-grouse Steering Committee 2008, Connelly et al. 2011c). The rationale for vegetation attributes and scoring are established in Table 2. The attributes are repeatedly supported and justified by the aforementioned literature citations (and the citations within) that describe GRSG habitat (unless otherwise noted). Each habitat attribute is measured directly through vegetation plots (see Appendix F).

Table 2. Vegetation Characteristics Measured at Credit/Debit Project Sites

BREEDING		
Cover / Refugia	Sagebrush Height (quantitative measure)	This woody shrub overstory vertical attribute estimates the average height of a sample of sagebrush plants along a line transect.
	Sagebrush Canopy Cover (quantitative measure)	This woody shrub overstory horizontal attribute estimates the canopy (foliar) cover of sagebrush along a line-intercept or point-line intercept.
	Sagebrush Shape (qualitative measure)	This describes the growth-form of sagebrush. It is assumed that a columnar structure (Stiver et al. 2010) provides less horizontal structure (and less cover) at the ground level than more prostrate growth forms.
	Perennial Grass Height (quantitative measure)	This herbaceous vertical understory attribute estimates the average height of a sample of perennial grass heights along a line transect.
	Perennial Grass Cover (quantitative measure)	This herbaceous understory attribute estimates the percent grass horizontal cover structure along a line intercept or point-line intercept.
Foraging	Forb Cover (quantitative measure)	This herbaceous understory attribute estimates the percent horizontal forb cover. This attribute can be measured with line intercept or point-line intercept.
	Forb Species Richness (quantitative measure)	This is the simplest measure of forb diversity. The number of species detected is influenced by the size of the microplot sampled (Rosenzweig 1995). Sampling is conducted over 10 square meters with a1m^2 quadrat.
	Proportion of Forb Cover that is Noxious Weeds (quantitative measure)	A simple index to food availability (Appendix E)
SUMMER		
Cover / Refugia	Perennial Grass Height (quantitative measure)	See above
	Perennial Grass Cover (quantitative measure)	See above
Foraging	Forb Cover (quantitative measure)	See above
	Forb Species Richness (quantitative measure)	See above
	Proportion of Forb Cover that is Noxious Weeds (quantitative measure)	See above
WINTER		
Cover / Refugia and Foraging	Sagebrush Height (quantitative measure)	This woody shrub overstory vertical attribute estimates the average height of a sample of sagebrush plants along a line transect. It is a measure of food and cover.
	Sagebrush Canopy Cover (quantitative measure)	This woody shrub overstory horizontal attribute estimates the canopy (foliar) cover (and food) of sagebrush along a line-intercept of point-line intercept.

3.2.3 *Vegetation Attribute Weighting*

The score for each habitat attribute is then weighted as established in Table 3. The weights are based on expert opinion, are on a relative scale and add to 100. See also Connelly et al. 2011c for a review of habitat requirements for GRSG habitat, and aforementioned literature citations (and the citations within) that describe GRSG habitat. The scores are multiplied by the weight, and the weighted scores across all attributes for that season are then added to generate a seasonal vegetation score for a site. With respect to scoring, the weights are only applied to the site-level habitat attributes based on how much they each contribute to the total site score, as described in Table 3. The four orders of habitat selection are not weighted in any way; however the relative effect of each variable within the 2nd and 3rd orders (described in section 3.2.6 and section 3.3) depends on the number of variables used to generate that score.

Table 3. Vegetation Attribute Weighting Values

<table>
<tr><td colspan="7">BREEDING</td></tr>
<tr><td colspan="4">Cover / Refugia (50%)</td><td colspan="3">Forage (50%)[A]</td></tr>
<tr><td>Sagebrush Height 10%</td><td>Sagebrush Canopy Cover 15%</td><td>Grass Canopy Cover 12.5%</td><td>Grass Height 12.5%</td><td>Forb Cover 16.7%</td><td>Forb Species Richness 16.7%</td><td>Presence of Specific Forbs 16.7%[B]</td></tr>
<tr><td colspan="7">SUMMER [C]</td></tr>
<tr><td colspan="4">Cover / Refugia (30%)</td><td colspan="3">Forage (70%)</td></tr>
<tr><td colspan="2">Grass Canopy Cover 15%</td><td colspan="2">Grass Height 15%</td><td>Forb Cover 23.3%</td><td>Forb Species Richness 23.3%</td><td>Presence of Specific Forbs 23.3% [B]</td></tr>
<tr><td colspan="7">WINTER</td></tr>
<tr><td colspan="4">Sagebrush Height 50%</td><td colspan="3">Sagebrush Canopy Cover 50%</td></tr>
</table>

Reference: The weights are based on expert opinion. See also Connelly et al. 2011c for a review of habitat requirements for GRSG habitat, and aforementioned literature citations (and the citations within) that describe GRSG habitat.

[A] Cover / refugia is more important during the nesting portion of breeding season. However, during early brood-rearing the importance shifts as nutrient availability becomes equally as important. As a result both cover/refugia and foraging are weighted equally for breeding habitats.

[B] Forb cover 100% desirable (score 1.0); forb cover a mixture of non-native invasive/noxious weeds and desirable forbs (score 0.5); forb cover 100% non-native invasive/noxious weeds (score 0).

[C] During the summer, foraging is more important than cover/refugia. Barnett and Crawford (1994) found that diet of GRSG hens during the pre-laying period may influence reproductive success. Drut et al. (1994) found the protein-rich diet of forbs and insects of chicks enhanced the nutritional status of chicks and increased survival.

3.2.4 *Assessing Value of Vegetation at a Site – An Example*

A field team estimates the following vegetation measures on an arid location suitable for breeding (i.e., sagebrush canopy cover >5%): sagebrush height 28 cm; sagebrush canopy cover 22%; spreading sagebrush shape; perennial grass height 12 cm; perennial grass canopy cover 14%; forb cover 6%; forb species richness 4 species; and no noxious weeds (all the forbs present are desirable) (refer to Appendix

E and Appendix F for desirable forb list and field vegetation measurement protocol, respectively). Using the scoring curves presented in Appendix A, these measures result in the following scores as established in the tables associated with each scoring curve: sagebrush height 0.5; sagebrush canopy cover 1.0; spreading sagebrush shape 1.0; perennial grass height 0.8; perennial grass canopy cover 1.0; forb cover 0.8; forb species richness 0.75; and noxious weeds 1.0. Using these scores with the weights presented in Table 3, the following calculations are made (and depicted in the table below): sagebrush height (0.5*0.06) = 0.03; sagebrush canopy cover (1.0*0.15) = 0.15; spreading sagebrush shape (1.0*0.04) = 0.04; perennial grass height (0.8*0.13) = 0.1; perennial grass canopy cover (1.0*0.13) = 0.13; forb cover (0.8*0.17) = 0.14; forb species richness (0.75*0.17) = 0.13; and noxious weeds (1.0*0.17) = 0.17. The weighted scores are then summed across vegetation attributes to establish a *breeding season* vegetation score for the site of 0.88. The value of the vegetation at the location for other seasons (i.e., summer and winter) will use the triggers, scoring curves and weights specific to those seasons.

Table 4. Calculations for Assessing a Hypothetical Site Score

Attribute	Sage-brush height: 28 cm	Sage-brush cover: 22%	Sage-brush shape: spreading	Perennial grass height: 12 cm	Perennial grass cover: 14%	Forb cover: 6%	Forb species richness: 4	% Noxious weeds	
Scoring table values	0.50	1.00	1.00	0.80	1.00	0.80	0.75	1.00	
Weights	0.06	0.15	0.04	0.13	0.13	0.17	0.17	0.17	
Weighted scores	0.03	0.15	0.04	0.10	0.13	0.14	0.13	0.17	0.89

These scores are then "modified" based on the landscape context of the project area as described below.

3.2.5 Modifiers

A modifier is a habitat attribute that impairs the ability of the other attributes present on the site to provide suitable conditions for supporting GRSG. These habitat attributes reduce the ability of the site to function relative to optimal conditions. A modifier value from 0 (non-habitat) to 1 (optimal conditions) is multiplied by the site score and can result in a reduction in the value of the site (if the modifier value is less than 1). Table 5 shows the modifiers used in the HQT.

Table 5. Modifiers Used in the HQT

Modifier	Relevant Season	Order
Sagebrush shape	Breeding (sagebrush height)	4th
Invasive grass cover	Breeding, Summer	4th
Conifer cover	All	4th
Distance to anthropogenic features	All	4th
Distance to known lek	Breeding	3rd
Presence of sagebrush cover	Summer	3rd
Landscape Disturbance Index (LDI)	All	2nd

3.2.6 4th Order Modifiers

The following modifiers are utilized at the 4th order:

- Sagebrush shape;
- Invasive grass cover;
- Conifer cover;
- Distance to anthropogenic features.

Sagebrush Shape

Sagebrush shape only modifies sagebrush height for the calculation of breeding habitat. It is assumed that a columnar structure (Stiver et al. 2010) provides less horizontal structure (and less cover) at the ground level than more prostrate growth forms. In the HQT, if more than 50% of the sagebrush is spreading, there is no change to the sagebrush height measure; if more than 50% of sagebrush is columnar, then the value of the height measure is reduced by 50%.

Invasive Grass Cover

Invasive grass cover is a modifier for breeding and summer habitats, and is measured using field data collection methods (see Appendix F). Invasive grass measured in the field is *Bromus tectorum* (cheatgrass). Additional invasive grasses may be included as necessary. The influence of invasive grass cover on site-level condition scores is established in Table 6. Primary data from 12 locations in western Colorado at elevations ranging from 5,000 to 9,000 feet was used to inform the values in Table 6. Cheatgrass cover was compared to shrub cover, perennial forb cover, and perennial grass cover. Shrub cover, perennial forb cover, and perennial grass cover all declined with an increase in invasive grass cover.

Table 6. Modifications to Site-Level Condition Scores for Breeding and Summer Habitat Due to Invasive Grass Cover

Percent Cover of Invasive Grass	Percent Adjustment Multiplier
0 - 1%	100%[A]
>1 – 5%	80%
>5 - 10%	50%
>10 - 15%	10%
>15%	0%

[A] For example, 100% value indicates that the site-level condition score is multiplied by 1, or no change in value if invasive grass cover is less than 1%. In contrast, if invasive annual grass cover is between 5 and 10%, then the site-level condition score is multiplied by 0.5, so the value of that location is reduced.

Invasive plants, especially invasive non-native grasses (e.g., cheatgrass and smooth brome) in sagebrush-steppe habitats, alter plant community structure, composition and productivity and may competitively exclude native plants important as cover and forage for GRSG (Vitousek 1990, Mooney and Cleland 2001, Rowland et al. 2010). The most pronounced negative consequence of non-native grass invasion into sagebrush habitats is the resulting change in fire frequency and intensity (Balch et al. 2013). Ultimately, non-native grasses promote fires and fires promote non-native grasses. Fire also facilitates the conversion of rangelands from perennial-dominated to annual-dominated systems by eliminating fire-intolerant species (e.g. big sagebrush) from these systems, rendering them permanently unsuitable to GRSG (Connelly et al. 2004, Epanchin-Niell et al. 2009). In central Nevada, recruitment of male GRSG to leks was consistently low in areas with high proportions of non-native grasslands interspersed in the landscape within 5 km of a lek, even during years when climatic conditions resulted in substantial recruitment to leks in the region (Blomberg et al. 2012). When invasive grass cover within the project area surpasses 15%, then the breeding and summer habitat functionality scores are reduced to 0; scores are decreased according to a negative decay relationship for invasive grass cover values less than 15% (Table 6).

Conifer Cover[2]

Encroachment of conifers into upland sagebrush habitats – especially Utah Juniper (*Juniperus osteosperma)* and piñon (*Pinus edulis)*, which have expanded in recent years across most of the Colorado Plateau (Romme et al. 2009) – has the potential to transform sagebrush communities once suitable for GRSG into a less suitable state (Patten et al. 2005). Expansion of conifers into sagebrush communities can result in the elimination of the understory component important for GRSG and an increase in bare ground (Tausch and Tueller 1990, Miller et al. 2000, Petersen et al. 2009). Ongoing research in Colorado has found that in summer, GRSG use intact sagebrush habitats more frequently than similar areas which have encroaching piñon and juniper trees (Walker 2013). GRSG also strongly

[2] In this case “conifer” refers to piñon and juniper species. However if other species are encroaching on GRSG habitat they should be considered in a similar fashion as described here.

avoid conifer habitats in winter (Doherty et al. 2008) and during nesting (Doherty et al. 2010b). A study in Oregon found that the probability of lek activity declined with increasing conifer cover, with a 0% probability of activity with as little as 4 - 7% conifer cover within an area delineated by a 1-km buffer around a lek (Baruch-Mordo et al. 2013). Additionally, Miller et al. (2011) suggest that a negative relationship between sagebrush canopy cover and conifer cover exists; sagebrush canopy cover drops below 15% (Connelly et al. 2000) at between 10 and 15% juniper cover. Thus, all seasonal habitat types are modified based on conifer cover. To do this, a moving window with a radius of 1-km is applied to each pixel within the project area. For each pixel, the moving window calculates conifer cover using a conifer cover raster derived from the BASINWIDE dataset[3]. The conifer cover values for each pixel within a map unit are averaged for that map unit. Finally, the modifier is calculated according to Table 7. Habitats with <1% tree cover are assigned full value, followed by a linear decline in value with habitats containing >10% conifer cover receiving 0 value (Table 7).

Table 7. Modifications to Site-Level Condition Scores for all Seasonal Habitat Types due to Conifer Cover

Conifer Cover within 1km Radius of Map Unit	Percent Value
0 – 1%	100%[A]
>1 – 2%	85%
>2 – 3%	75%
>3 – 4%	65%
>4 – 7%	40%
>7 – 10%	20%
>10%	0%

[A] For example, 100% value indicates that the map unit score is multiplied by 1, or no change in value if conifer cover is ≤1%. In contrast, if conifer cover is between 1 and 2%, then the map unit score is multiplied by 0.85, so the value of that location is reduced.

A modifier which reduces GRSG habitat functionality according to conifer cover may provide incentive for piñon-juniper removal projects. Removal of the piñon-juniper cover can restore the productivity of shrubs and herbaceous vegetation in the understory, which is important for GRSG. However, not all piñon-juniper stands are suitable for this type of treatment. Miller et al. (2005) found that as juniper cover increases, sagebrush cover and the ability of the understory to respond positively to tree removal declines, with a threshold occurring at approximately 20% juniper cover (Miller et. al 2005). Beyond this threshold a positive response to tree removal should not be expected.

Therefore, a piñon-juniper project should only be eligible for credit generation if the pre-treatment piñon - juniper cover is 20% or lower. This criterion will help protect older piñon-juniper stands, and may aid in preventing unintended negative consequences of tree removal such as expansion of non-natives, such as cheatgrass (*Bromus tectorum*), which has been reported in several studies of piñon-juniper removal (Owen et al. 2009, Ross et al. 2012, Huffman et al. 2013).

[3] This is Colorado Parks & Wildlife's Colorado Vegetation Classification Project "basinwide" vegetation layer.

Distance to Anthropogenic Features

Anthropogenic features are defined as human-built features on the landscape that have influence on GRSG (see Appendix B for literature review), Research has established a “distance-effect” associated with anthropogenic features whereby GRSG are negatively influenced to a greater extent by infrastructure that is located nearby, with the response diminishing as distances from infrastructure increases (see Manier et al. 2013). In the HQT, the distance-effect is the influence that a given anthropogenic feature, in addition to its footprint, has on habitat function at the 4th order. Avoidance of anthropogenic features– including roads, power lines, and oil and gas well pads and other field-related infrastructure – has been documented during nesting, brood-rearing/summer, and winter seasons (see Naugle et al. 2011, Dzialak et al 2012 and 2013, Gillan et al. 2013, Dinkins et al. 2014, Fedy et al. 2014, Smith et al. 2014, Holloran et al. 2015). Impacts of anthropogenic features to vital rates (e.g., nesting propensity, nest success, chick and adult survival) have also been documented (see Naugle et al. 2011, Dzialak et al. 2011, Webb et al. 2012, LeBeau et al. 2014). The magnitude of these effects may be related to the levels of human activity associated with the anthropogenic features (Dzialak et al. 2012, Holloran et al. 2015). The suitability of a location is modified based on distance to anthropogenic features at the site level as shown in Table 8. These effects are quantified with decaying sigmoidal functions bounded between 0 and 1. Figure 6 shows a map of the site-level anthropogenic feature modifier.

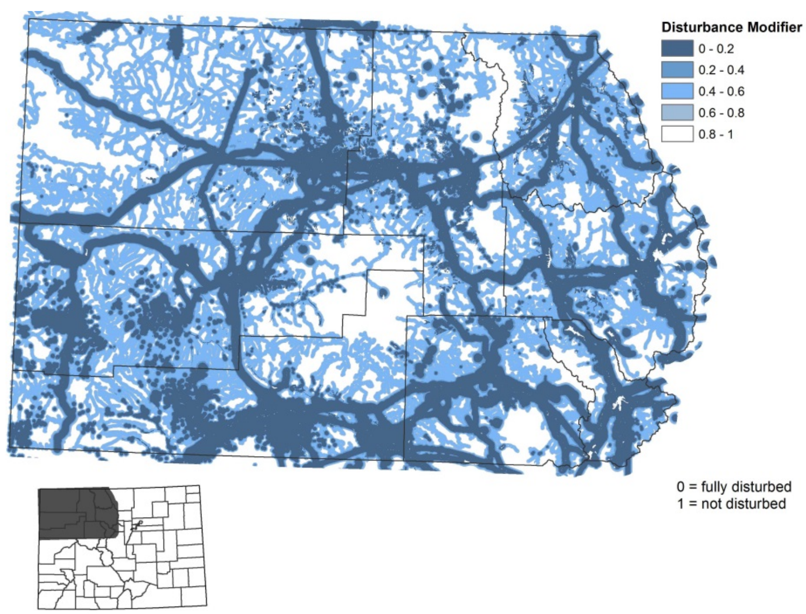


Figure 6. Map of site-level anthropogenic feature modifier where values of 0 represent fully disturbed locations and values of 1 represent no disturbance. County boundaries are shown in black.

Because distance effects influence GRSG grouse at a single point on the landscape (i.e., the distance from a given point to infrastructure is unique), we only considered individual-based literature (e.g., studies of radio-equipped GRSG) to establish the distance relationships. The distance relationships established, and the process and literature used to generate those relationships, are described in detail in Appendix B.

Table 8. Distance Effects and Weights for Anthropogenic Features Considered in the HQT*

Feature	Subtype	Weight	Distance (km)	Description
Oil & Gas Wells	Active	100	2.1	Point locations for individual oil and gas wells. Active wells represent those locations where activity is occurring at the well pads on a regular basis. Activity level was determined based on well descriptions. See Appendix B.
	Inactive	10	0	Point locations for individual oil and gas wells. Inactive wells represent locations where activity is not occurring regularly at the location. Activity level was determined based on well descriptions. See Appendix B.
Towers	Meteorological towers	50	0	As of April 2015 there are no data available for meteorological towers in Colorado. However, we include the weight and distance for future reference.
	Communication towers	50	0	Point locations for communication towers, which are tall structures designed to support antennas for telecommunications and broadcasting.
Transmission Lines		100	3	This line dataset represents major regional electrical power transmission lines that carry energy between electrical substations. On average, these lines carry 100 kV of power. It does not include minor transmission lines, such as those supplying individual developments or homes.
Wind turbines		100	3	As of April 2015 wind turbines do not occur in the study area indicated in Figure 6. However, we include the weight and distance for future reference.
Mines	Active – Large	100	2.1	Large mines have an area of 60 acres or more.
	Active – Small	100	0	Small mines have an area of less than 60 acres.
	Inactive – Large	50	0	Large mines have an area of 60 acres or more.
	Inactive – Small	10	0	Small mines have an area of less than 60 acres.
Agriculture	Tilled	100	0	Areas of land being actively tilled for agriculture. This includes annual row crops as well as orchards and both dryland and irrigated crops.
	Untilled	85*	0	Areas of land being used for hay or pasture. This includes both irrigated and dryland pastures.
Urban Development	Medium or High intensity	100	4.2	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units. Also includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.
	Low intensity	75	1.5	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
Roads	Major roads	100	4.2	This line dataset represents Interstate 70 in Colorado.

Feature	Subtype	Weight	Distance (km)	Description
	Secondary roads	50	1.5	This line dataset represents other highways and secondary roads, including ramps, local neighborhood roads, rural roads, city streets, vehicular trails (4WD), service drives along a limited access highway, private driveways, private roads for service vehicles (logging, oil fields, ranches, etc.), and parking lot roads.

* Note that these results do not reflect distances for siting anthropogenic features around leks, but rather represent spatial impacts of these features on a variety of components of GRSG ecology on the general landscape.

Accounting for Temporal Variation in Disturbance Levels

The Science Team recognizes the temporal variation in landscape disturbance (e.g. changes in activity level during different phases of well development or road traffic) with many anthropogenic features. However, there is a wide range of variation associated with the timing of activities among projects and companies, temporally and spatially—and this variation is not quantified on the site-by-site and day-by-day basis required to explicitly address this issue in the HQT. As such, the response of GRSG to activity levels most representative of type of feature over its lifetime is quantified in the HQT. For example, a well pad during the drilling phase of development will have a greater distance effect than that effect during the production phase of development (Holloran 2005). But, since a well pad is in production longer than there is a drilling rig present on the pad, the distance effect associated with a well pad was quantified based on literature investigating the response of GRSG to a producing well pad.

3.3 Assessment of Surrounding Habitat

Habitat condition surrounding a project area may affect GRSG seasonal habitat use, dispersal, local persistence, and overall population trend (Connelly et al. 2011a, Connelly et al. 2011c). Thus, site-level vegetation conditions are modified based on the context of the site within the surrounding landscape. These modifiers are considered measures of the quality of the habitat context, not the site itself. Each modifier is quantified as a value between 0 and 1 and each influences the vegetation condition score directly—i.e., the final vegetation score as described above is multiplied by each modifier score in succession to establish the final score of the project area. The following sections describe each modifier in more detail.

3.3.1 3rd Order Modifiers

There are two 3rd order modifiers:

- Distance to known lek;
- Presence of sagebrush cover.

Distance to Known Lek

Distance to known lek applies only to breeding habitat. GRSG breeding habitat is spatially tied to lek locations; the majority of females breeding on a given lek nest within 6-km of that lek (approximately 80% in Colorado; Colorado Greater Sage-grouse Steering Committee 2008). However, a portion of the female population will move farther than 6-km from a lek to nest (Holloran and Anderson 2005, and see Doherty et al. 2011), so suitable breeding habitat located beyond 6-km from a lek does not have 0 value for GRSG. Thus, habitats within 6-km of a lek receive full value followed by a linear decline in value between 6 and 10-km from a lek, and habitats farther than 10-km from a known lek receive 10% value as breeding habitat (Table 9).

Table 9. Modifications to Site-Level Condition Scores of Breeding Habitat Based on Distance to Lek

Distance to Known Lek (km)	Percent Value
0 – 6	100%[A]
>6 – 7	50%
>7 – 8	40%
>8 – 9	30%
>9 – 10	20%
>10	10%

[A] For example, 100% value indicates that the site-level condition score is multiplied by 1, or no change in value if the lek is located within 6km. In contrast, if a lek is located between 6 and 7km, then the site-level condition score is multiplied by 0.5, so the value of that location is reduced.

Presence of Sagebrush Cover

Presence of sagebrush cover applies only to summer habitat. In the summer season, GRSG use a variety of habitats and mesic conditions (meadows and high elevation mesic communities, agricultural fields, etc.) with a common factor that sagebrush is nearby as escape or roosting cover (Connelly et al. 2000). During this season, GRSG use habitat that does not have sagebrush directly present, but it is in close proximity. Meadows, riparian areas, or other moist areas adjacent to sagebrush habitat can provide foraging areas during this season (Fischer et al. 1996a, Fischer et al. 1996b, Connelly et al. 2000, Connelly et al. 2011c). Given the range of distances presented in the literature across which GRSG will travel between meadows and similar areas to sagebrush cover, the Science Team chose a conservative estimate. Thus, the Science Team's expert opinion is as long as at least 5% sagebrush canopy cover is located with 300-m of each sample point in a 30x30m patch size, it is considered summer habitat and there is no effect to the score. If sagebrush is located beyond 300-m of the sample point, the score is reduced to zero (Table 10).

Table 10. Modifications to Site-Level Condition Scores of Summer Habitat Based on Presence of Sagebrush Cover

Presence of Sagebrush Cover (m)	Percent Value
0 – 300	100%[A]
>300	0

[A] For example, 100% value indicates that the site-level condition score is multiplied by 1, or no change in value if the sample point is located within 300m of sagebrush cover.

3.3.2 2nd Order Modifier

There is one modifier at the 2nd order, the Landscape Disturbance Index.

Landscape Disturbance Index

Substantial amounts of research suggest that increased density of anthropogenic features in a landscape will negatively influence GRSG populations. Impacts to the number of males occupying leks are indiscernible at well pad densities at or below 1 pad/square mile (section) as quantified within 3 to 3.2-km of leks (Holloran 2005, Doherty et al. 2010). But, declines in the number of males on leks and lek loss (i.e., leks becoming inactive) increases at well densities exceeding this 1 pad/section threshold (Harju et al. 2010, see Naugle et al. 2011, Hess and Beck 2012, Taylor et al. 2013, Gregory and Beck 2014). We developed a Landscape Disturbance Index (LDI) to modify the value of a location based on anthropogenic feature densities quantified within a surrounding 12.4-square mile area (i.e., a 3.2-km radius moving window). To generate a common metric, all anthropogenic feature types (e.g., well pads, roads, towers, etc.) were converted to the amount of surface disturbance associated with each. A lower threshold was established at surface disturbance densities equating to 1 well pad and associated roads/section or less (i.e., landscapes are not degraded by anthropogenic feature densities at or below this threshold). Surface disturbance densities above this lower threshold resulted in declining value of a location based on the landscape context of that location. An upper threshold was established at disturbance densities equating to 6.5 well pads and associated roads/section or more (i.e., landscapes were non-functioning due to anthropogenic feature densities at or above this threshold). The LDI ranges in value from 0 to 1, where 0 corresponds to locations that are above the upper disturbance threshold, 1 corresponds to locations that are below the lower disturbance threshold, and values greater than 0 or less than 1 continuously represent intermediate levels of disturbance. See figure 7 for a map of the LDI.

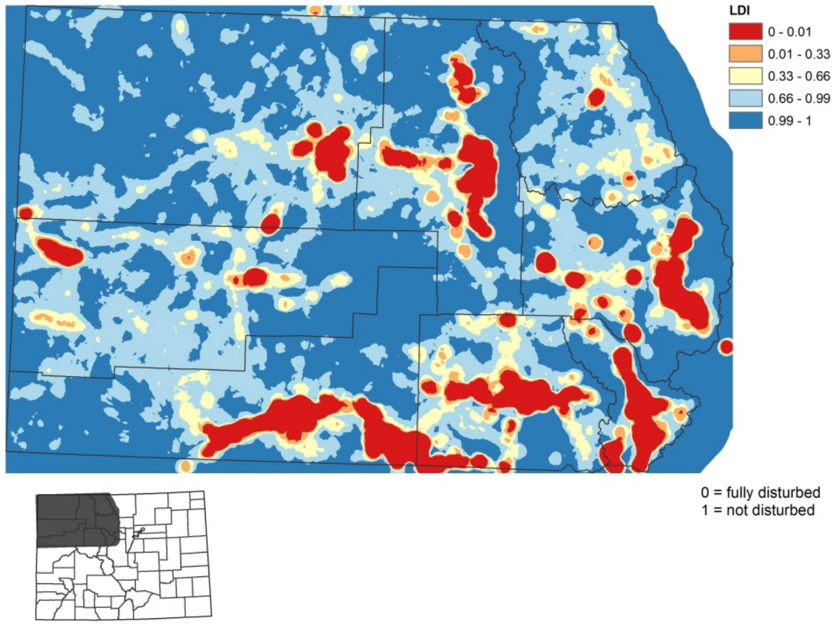


Figure 7. Map of the Landscape Disturbance Index, where values of 0 are above the upper disturbance threshold (i.e., fully disturbed) and values of 1 are below the lower disturbance threshold (i.e., not disturbed). County boundaries are shown in gray.

3.3.3 Final Value Assessment of a Site – Continuation of the Example

To continue the example from above, initial site-level vegetation measures have yielded a preliminary breeding season vegetation condition score of 0.89. Next, the score is modified based on the surrounding context of the project area. Site-level information establishes invasive grass cover on the project area of 4% and no conifer cover. The distance of the closest known lek to the site is 2.6 km, the site-level anthropogenic disturbance modifier is 0.93 and the LDI is 0.75. These measures result in the following scores as established in the tables associated with each scoring curve: invasive grass cover 0.8; conifer cover 1.0; and distance to lek 1.0. The actual values for the anthropogenic features disturbance modifier (0.93) and the LDI (0.75) are used in the scoring. By multiplying the vegetation score by these modifier scores, a breeding season score of 0.50 is calculated.

		Modifiers						
		4th			3rd		2nd	
Seasonal Habitat	Site Veg Condition Score (4th Order)	Cheat-grass	Conifer Cover	Site-Level Anthropogenic Feature Disturbance	Distance to Lek	Presence of Sagebrush	LDI*	Breeding Season Score
Breeding	0.89	0.80	1.00	0.93	1.00	N/A	0.75	0.50

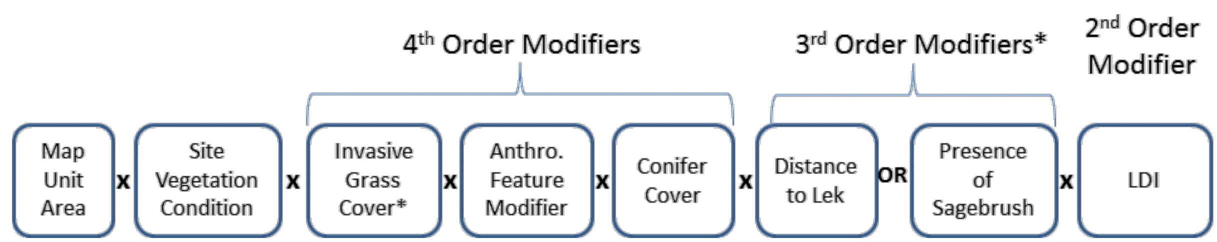
* Landscape Disturbance Index

4.0 Calculating Functional Acres

Functional acres are not the same as credits and debits. The role of the HQT is to calculate functional acres, which can then be used to calculate credits and debits. The calculation of credits and debits from functional acres is described in section 2.2.2 of the Exchange Manual.

To calculate functional acres, the project area is subdivided into map units. Vegetation attributes are measured within each map unit (4th order); translated to functional scores based on triggers, scoring curves and tables, and weighting; then modified to account for local context (3rd order) and landscape context (2nd order). For each map unit, habitat function (expressed as a percent) is multiplied by habitat area (expressed in acres) to calculate functional acres for the map unit. Functional acres for each map unit within the project are summed to calculate functional acres for the project. A functional acre value for each of the three seasonal habitat types is calculated. The basic formula for calculating functional acres:

Functional Acres =



* Not applied to winter habitat score

Table 11 shows the complete functional acre equation using hypothetical values for a single map unit. The site vegetation condition score is multiplied by each modifier value in succession to establish the final functional acre score for each map unit. Note that for each map unit a separate and unique functional acre score is calculated for each seasonal habitat type.

Table 11, Example Calculation of Functional Acres for One Map Unit

			Modifiers						
			4th			3rd		2nd	
Seasonal Habitat	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Conifer Cover	Site-Level Anthropogenic Feature	Distance to Lek	Presence of Sagebrush	LDI	Functional Acres
Breeding	160	0.50	0.80	1.00	0.75	1.00	N/A	0.92	44.16
Summer	160	0.60	1.00	1.00	0.75	N/A	1.00	0.92	66.24
Winter	160	0.80	N/A	1.00	0.75	N/A	N/A	0.92	88.32

Breeding Functional Acres = 160 * 0.50 * 0.80 * 1.00 * 0.75 * 1.00 * 0.92 = 44.16
Summer Functional Acres = 160 * 0.60 * 1.00 * 1.00 * 0.75 * 1.00 * 0.92 = 66.24
Winter Functional Acres = 160 * 0.80 * 1.00 * 0.75 * 0.92 = 88.32

4.1 Steps for Calculating Functional Acres

The purpose of this section is to describe the steps used to calculate functional acres. The calculations themselves are performed by the HQT Calculator once the data has been inputted. The example calculations shown utilize hypothetical data.

Calculating functional acres for a site requires a desktop and field analysis. The desktop analysis is described in detail in the *User's Guide.* The field analysis is described in detail in the *Field Data Collection Methods in* Appendix F. Table 12 shows which attributes are derived using the User's Guide (for GIS data) and attributes that are collected in the field.

Table 12. Attributes Derived with the User's Guide and Attributes Measured in the Field

GIS Data	Field Data
• Site-level anthropogenic feature modifier (pre-project and post-project) • Conifer cover • Distance to known lek • Presence of sagebrush within 300-m of sample point • LDI	• Sagebrush shape, height and percent cover • Grass height and percent cover • Forb percent cover, species richness and percent that are noxious weeds • Invasive grass percent cover

There are seven basic steps to calculating functional acres for a site (Table 13).

Table 13. Steps for Calculating Functional Acres

Steps	Detail
1. Delineate project area	• Credit projects: based on the area of uplift created or protection provided and distance effect(s) of existing structures within the area • Debit projects: based on the type of proposed anthropogenic disturbance and associated distance effect(s)
2. Set map units	Apply pre-existing grid of map units to project area.
3. Calculate 4th order modifiers	Modifier values for conifer cover and existing and proposed (or removed) anthropogenic features are calculated. See *User's Guide* for more information. Invasive grass cover is measured in the field. See *Field Data Collection Methods* (Appendix F) for more information.
4. Calculate 3rd order modifiers	Distance to lek and presence of sagebrush within 300-m of sample location are calculated. See *User's Guide* for more information.
5. Calculate 2nd order modifier	LDI values are calculated. See *User's Guide* for more information.
6. Complete field analysis	Vegetation data is collected for each map unit by field technicians. See *Field Data Collection Methods* (Appendix F) for more information.
7. Calculate functional acres using HQT Calculator	Vegetation data and outputs from the desktop analyses are input into the HQT Calculator. Pre-project and post-project functional acres are compared.

Step 1: Delineate Project Area

The project area is the area within which functional acres are assessed. Debit and credit project areas (or sites) are defined by the footprint of the project (i.e. for debit projects the land on which the development will occur, and for credit projects the area of land that is outlined in the participant's contract) plus the area of behavioral avoidance distance effect of any anthropogenic or natural feature (e.g. transmission line or conifer cover) that occurs on the site. For all projects, the behavioral avoidance distance associated with existing or proposed anthropogenic features must be included as part of the project area. Table 14 shows the behavioral avoidance distance from the outermost extent associated with anthropogenic features.

Table 14. Buffer Distances Associated with Anthropogenic Features*

Disturbance	Subtype	Distance (km)
Oil & Gas Wells	Active	2.1
	Inactive	0
Transmission Lines		3
Mines	Active – Large	2.1
	Active – Small	0
	Inactive – Large	0
	Inactive – Small	0
Agriculture	Tilled	0
	Untilled	0
Urban Development	Medium or High intensity	4.2
	Low intensity	1.5
Roads	Major roads	4.2
	Secondary roads	1.5

* Note that these results do not reflect distances for siting anthropogenic features around leks, but rather represent spatial impacts of these features on a variety of components of GRSG ecology on the general landscape.

Meteorological towers are removed from this table because as of April 2015 there are no data available for meteorological towers in Colorado. Wind turbines are removed from this table because as of April 2015 there are no wind turbines in CHE service areas.

Step 2: Set Map Units

Map units are predefined for all Exchange participants and are the basis for all credit and debit calculations. A systematic grid across the range in Colorado delineates map units and indicates plot sampling locations within each map unit. Vegetation attributes are measured at each plot sampling location for each map unit to calculate 4^{th} order habitat quality. Map units are assigned a unique identifier and inputted into the HQT Calculator spreadsheet.

Step 3: Calculate 4^{th} Order Modifiers

As noted in Table 12, conifer cover is measured with geospatial layers in a GIS. Invasive grass cover is measured in the field.

For all projects, existing anthropogenic features are digitized within a GIS and are used to calculate pre-project condition scores; proposed (or removed) features are used to calculate post-project condition scores. For debit projects, all proposed anthropogenic features are digitized within a GIS. The calculated 4^{th} order pre-project and post-project anthropogenic feature modifier values are inputted into the HQT Calculator. The pre- and post-project anthropogenic feature modifiers are calculated according to the steps outlined in the *User's Guide*.

Step 4: Calculate 3^{rd} Order Modifiers

Distance to lek and presence of sagebrush cover within 300-m of the sample point are calculated for each map unit according to the steps outlined in the *User's Guide*. Each 3^{rd} order modifier applies only to the appropriate seasonal habitat types, as shown in Table 15.

Table 15. 3rd Order Modifiers Applied to Breeding and Summer Scores

Seasonal Habitat Type	Local Context (3^{rd} Order) Modifier
Breeding	Distance to Lek
Summer	Presence of Sagebrush

Step 5: Calculate 2^{nd} Order Modifier

The LDI modifier value is calculated for each map unit according to the steps outlined in the *User's Guide.*

At the end of Step 5, all outputs from the desktop analysis for each map unit are inputted into the HQT Calculator (Table 16).

Table 16. Data Inputs from the Desktop Analyses for the Calculation of Functional Acres

Map Unit	Acres	Site Veg Condition Score (4th Order)	Modifiers						Functional Acres
			4th			3rd		2nd	
			Cheat-grass	Conifer cover	Site-Level Anthropogenic features	Distance to Lek	Presence of Sagebrush	LDI	
BREEDING									
1	160			1.00	0.82	1.00	N/A	0.89	
2	160			0.85	0.95	1.00	N/A	0.97	
3	160			0.85	0.78	1.00	N/A	0.81	
SUMMER									
1	160			1.00	0.82	N/A	1.00	0.89	
2	160			0.85	0.95	N/A	1.00	0.97	
3	160			0.85	0.78	N/A	1.00	0.81	
WINTER									
1	160		N/A	1.00	0.82	N/A	N/A	0.89	
2	160		N/A	0.85	0.95	N/A	N/A	0.97	
3	160		N/A	0.85	0.78	N/A	N/A	0.81	

Step 6: Complete Field Analysis

To complete the field analysis, field technicians will collect field data according to the sampling methodology at the locations provided by the Exchange within each map unit. Field technicians will note anthropogenic features and conifer encroachment and make adjustments to sampling location based on whether or not the sample point is located in non-habitat (e.g. parking lot or building). The process for completing the field analysis is described in Appendix F.

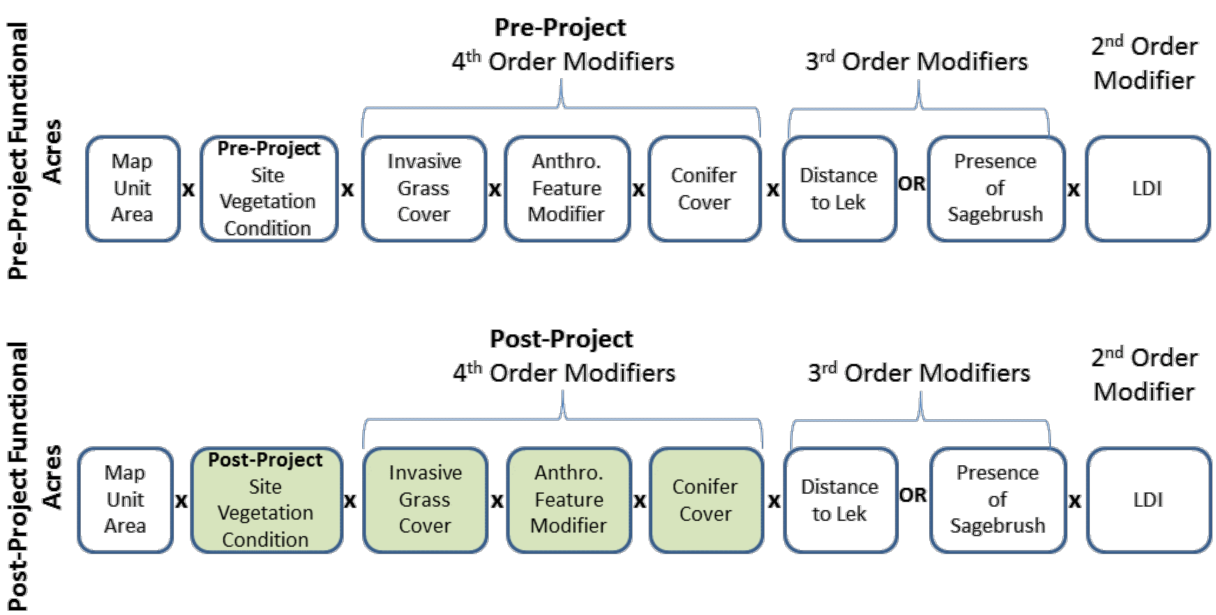
Step 7: Calculate Functional Acres Using HQT Calculator

At the end of Step 6, all of the data required to calculate functional acres have been obtained and can be inputted into the HQT Calculator spreadsheet, and functional acres are calculated automatically. In the Calculator, the vegetation condition score is multiplied by each modifier value in succession to calculate functional acres for each map unit (Table 17).

Table 17. GIS and Field Data Inputs for the Calculation of Functional Acres

Map Unit	Acres	Site Veg Condition Score (4^{th} Order)	Modifiers						Functional Acres
			4^{th}			3^{rd}		2^{nd}	
			Cheat-grass	Conifer cover	Site-Level Anthropogenic Disturbance	Distance to Lek	Presence of Sagebrush	LDI	
BREEDING									
1	160	0.54	0.80	1.00	0.82	1.00	N/A	0.89	**50.44**
2	160	0.80	1.00	0.85	0.95	1.00	N/A	0.97	**100.26**
3	160	0.68	0.80	0.85	0.78	1.00	N/A	0.81	**46.74**
SUMMER									
1	160	0.48	0.80	1.00	0.82	N/A	1.00	0.89	**44.84**
2	160	0.78	1.00	0.85	0.95	N/A	1.00	0.97	**97.75**
3	160	0.59	0.80	0.85	0.78	N/A	1.00	0.81	**40.56**
WINTER									
1	160	0.53	N/A	1.00	0.82	N/A	N/A	0.89	**61.89**
2	160	0.74	N/A	0.85	0.95	N/A	N/A	0.97	**92.74**
3	160	0.54	N/A	0.85	0.78	N/A	N/A	0.81	**46.40**

Pre-project conditions for the project area are compared to post-project conditions. In other words, the functional acre change from pre-project to post-project conditions is calculated. Only the site-level vegetation condition and 4^{th} order modifiers are changed by a landowner or developer. The 2^{nd} and 3^{rd} order modifiers do not change from pre-project to post-project condition.



4.2 Calculation of Functional Acre Change for Anthropogenic Features

To account for the effect of anthropogenic features, 4th order modifiers based on existing and proposed (or removed) features are calculated. As noted above, pre-project condition scores are calculated based on existing features; proposed (or removed) features are used to calculate post-project condition scores. These values are generated using the raster data that was used to construct the site-level anthropogenic feature modifier. Table 18 shows the pre-project functional acre calculation using hypothetical values for single map unit. Table 19 shows the post-project functional acre calculation using hypothetical values for single map unit, where an additional anthropogenic feature was added to the project area.

Table 18. Pre-Project Condition Functional Acres

			Modifiers						
			4th			**3rd**		**2nd**	
Seasonal Habitat	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Conifer Cover	Pre-Project Site-Level Anthropogenic Feature	Distance to Lek	Presence of Sagebrush	LDI	Functional Acres
Breeding	160	0.50	0.80	1.00	0.75	1.00	N/A	0.92	44.16
Summer	160	0.60	1.00	1.00	0.75	N/A	1.00	0.92	66.24
Winter	160	0.80	N/A	1.00	0.75	N/A	N/A	0.92	88.32

Table 19. Post-Project Condition Functional Acres

			Modifiers						
			4th			**3rd**		**2nd**	
Seasonal Habitat	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Conifer Cover	Post-Project Site-Level Anthropogenic Feature	Distance to Lek	Presence of Sagebrush	LDI	Functional Acres
Breeding	160	0.50	0.80	1.00	**0.62**	1.00	N/A	0.92	**36.51**
Summer	160	0.60	1.00	1.00	**0.62**	N/A	1.00	0.92	**54.76**
Winter	160	0.80	N/A	1.00	**0.62**	N/A	N/A	0.92	**73.01**

Table 20 shows the comparison of post-project condition and pre-project condition functional acre scores.

Table 20. Comparison of Pre-Project and Post-Project Functional Acres for Debit Project

FUNCTIONAL ACRE CHANGE			
Seasonal Habitat	Post-Project Functional Acres	Pre-Project Functional Acres	Functional Acre Change
Breeding	36.51	44.16	**- 7.65**
Summer	54.76	66.24	**- 11.48**
Winter	73.01	88.32	**- 15.31**

4.3 Establishing a Standardized Scale of Measure

At the 4th order, vegetation attributes are measured and quantified using transects resulting in value estimates by map units. In contrast, some modifiers (those not measured in the field) are quantified in a GIS resulting in value estimates by 25×25-m pixels. To establish a standardized scale of measure such that estimates can be scored for each map unit, the 25×25-m raster grid used in the GIS calculations is laid over the project area. Each raster grid cell – or pixel – that falls within a given map unit is associated with that map unit. In situations where a single pixel includes multiple map units, if at least half of the pixel lands within a map unit, it is associated with that map unit. In Figure 8, pixels D, E and F are associated with map unit #37, and pixels A, B, and C are associated with map unit #36. Pixel G is associated with map unit #31. Conversely if less than half of a pixel lands within the project area, it is not populated with a value and therefore excluded from project area consideration. Pixels H, I and J are excluded from the project area.

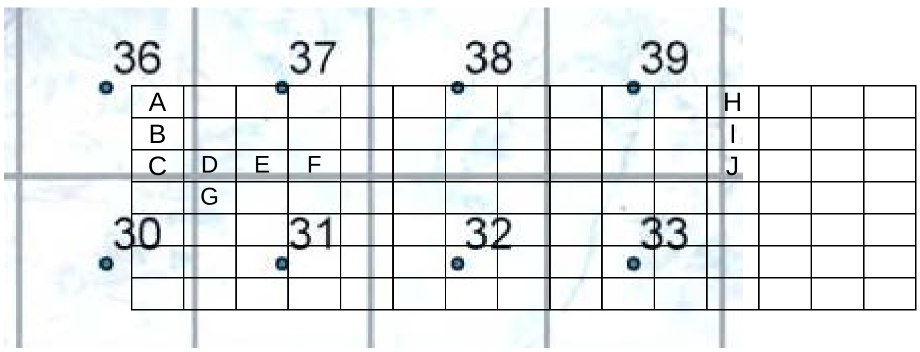


Figure 8. 25x25-m Raster Grid Cell Laid Over Project Area (figure is not drawn to scale)

5.0 Example Projects

Hypothetical data described below is used to demonstrate the calculation of functional acres. These hypothetical values are based on field data only (sagebrush cover, height and shape, grass cover and height, forb cover and species richness, percent of forb cover that is noxious weeds, and invasive grass). Because capturing the indirect effects of anthropogenic features is the most complex aspect of the calculation, this example focuses specifically on the footprint of the feature and its indirect effect. A complete debit calculation also uses the aforementioned field data collection to account for the change in site conditions associated with vegetation disturbance from activities outside of the well pad.

The first example in section 5.1 involves a proposed 10 acre well for a location in a relatively undisturbed area. The second example in section 5.2 involves a proposed 10 acre well pad for a location in a heavily disturbed area.

5.1 Debit Project, Example 1

5.1.1 Project Details

A proposed 10 acre well pad (that will contain two wells) is proposed in Moffatt County. The location reference for the facility is latitude 40.650089, longitude -107.780892 in service area 1, and is depicted in Figure 9.

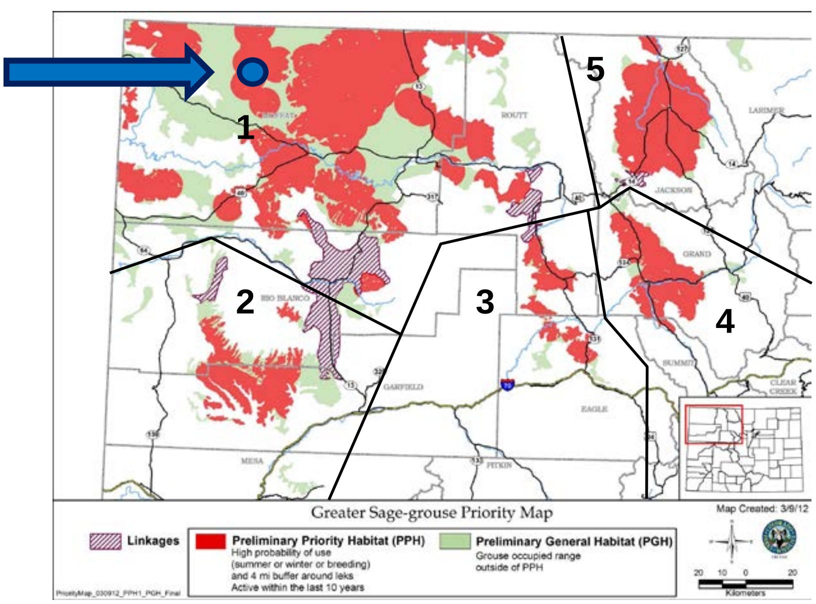


Figure 9. Location Reference for Proposed Well Pad in Example 1

The distance effect for an active oil & gas well pad is 2.1km, so a 2.1km buffer is delineated around the well pad. Figure 10 depicts the project area with the predefined grid of map units overlaid on the project area. Every map unit with a sample point that occurs within the project area is included within the overall project area. In this example, a total of 38 total map units, or 3849 acres, makes up the project area (Figure 10).

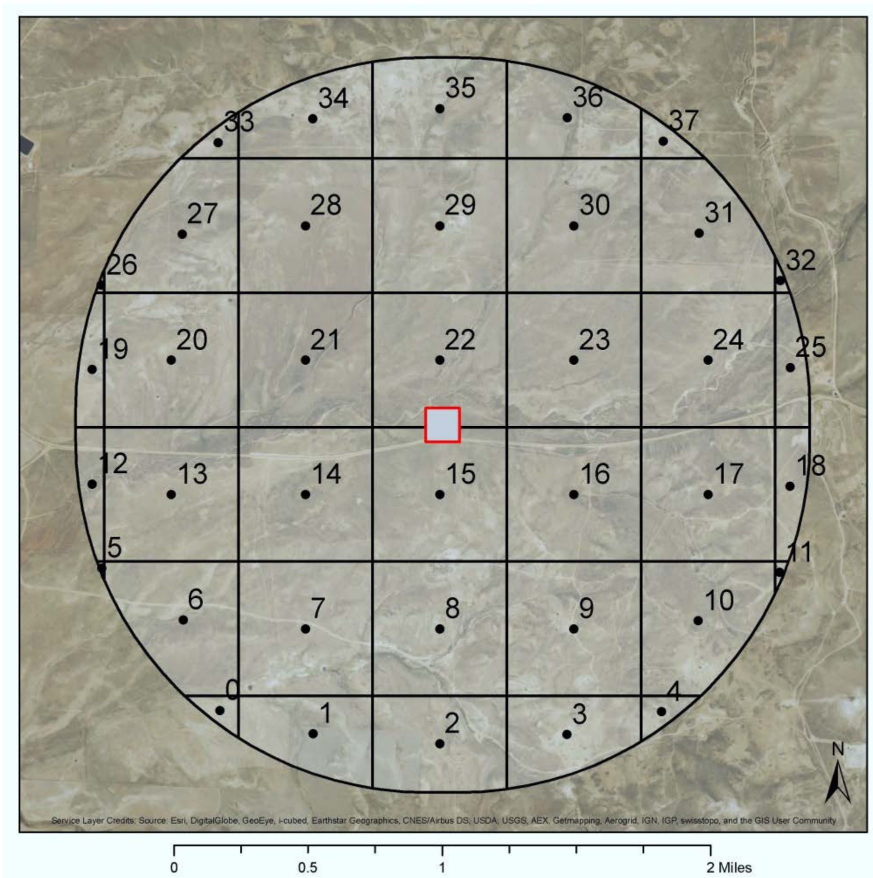


Figure 10. Predefined Map Unit Grid Overlaid on the Project Area

5.1.2 GIS and Field Data

GIS Data

GIS data for the project area is derived using the *User's Guide* and is input into the HQT Calculator, as shown in Table 22.

Table 21. GIS Data Input for the Project Example 1

Map Unit ID	Map Unit Area	LDI Modifier	Pre-project Site-Level Anthropogenic Disturbance Value	Post-project Site-Level Anthropogenic Disturbance Value	Distance to Known Lek (km) (rounded to nearest km)	Proportion Conifer Cover	Proportion of Sagebrush within 300 m
0	10.6	1.0000000	0.671503275	0.670556394	1	0.023575651	0.848073
1	86.2	1.0000000	0.755693171	0.746829874	1	0.038776191	0.712018
2	113.7	1.0000000	0.650926673	0.63694841	0	0.03537248	0.773243
3	88.7	1.0000000	0.461884614	0.455732318	0	0.026790424	0.820862
4	12.9	1.0000000	0.500431732	0.499519069	0	0.020020921	0.970522
5	0.6	1.0000000	0.199543201	0.199543201	2	0.000134328	0.800454
6	124.6	1.0000000	0.408140768	0.401770908	2	0.003162172	0.92517
7	160.0	1.0000000	0.546559577	0.474334293	1	0.012454952	0.920635
8	160.0	1.0000000	0.662864012	0.462668526	0	0.015174771	0.902494
9	160.0	1.0000000	0.63437208	0.525579939	0	0.010858972	0.886621
10	130.3	1.0000000	0.726230673	0.712171991	0	0.014393204	0.956916
11	1.9	1.0000000	0.856344076	0.856344076	1	0.023914428	0.965986
12	26.6	1.0000000	0.078104442	0.078012875	2	0.001081848	0.69161
13	160.0	1.0000000	0.110362216	0.102574135	2	0.000520124	0.943311
14	160.0	1.0000000	0.183801281	0.075860472	1	0.000770493	0.963719
15	160.0	1.0000000	0.30788559	0.034047289	1	0.004519969	0.984127
16	160.0	1.0000000	0.403742037	0.16840366	1	0.008403909	0.961451
17	160.0	1.0000000	0.525740682	0.488620762	1	0.006930873	0.984127
18	33.5	1.0000000	0.568945681	0.567615518	1	0.008046963	0.931973
19	27.4	1.0000000	0.031714438	0.03164975	3	0.001552931	0.945578
20	160.0	1.0000000	0.042581166	0.038963319	2	0.002075833	0.977324
21	160.0	1.0000000	0.103396411	0.035542058	2	0.001460303	0.45805
22	160.0	1.0000000	0.191543952	0.016262382	2	0.003138295	0.965986
23	160.0	1.0000000	0.247785486	0.09774805	1	0.006917698	0.99093
24	160.0	1.0000000	0.379760412	0.35029069	1	0.005459389	0.945578
25	34.3	1.0000000	0.349133613	0.348119657	2	0.004310945	0.761905
26	1.0	1.0000000	0.024199538	0.024199538	2	0.002497512	0.687075
27	127.7	1.0000000	0.036013931	0.035182525	2	0.004071174	0.764172
28	160.0	0.9952852	0.096793364	0.078620323	2	0.005597355	0.331066
29	160.0	0.9888903	0.229462359	0.150779739	2	0.004318505	0.8322
30	160.0	1.0000000	0.294781078	0.246854879	2	0.004236318	0.963719
31	133.2	1.0000000	0.479667823	0.470381087	2	0.003249801	0.9161
32	2.5	1.0000000	0.349860156	0.349860156	2	0.002828714	0.977324
33	12.9	1.0000000	0.041471955	0.041416208	2	0.007137768	0.938776
34	91.5	0.9822869	0.103789357	0.102523025	2	0.012305761	0.913832
35	119.1	0.9824620	0.257311888	0.252249824	2	0.013987373	0.904762
36	94.1	1.0000000	0.345334615	0.341663976	3	0.010126481	0.947846
37	15.4	1.0000000	0.50526595	0.504534114	3	0.005540558	0.943311

The average modifier values for the entire project area for each attribute are:

- LDI: 1.00
- Pre-Project Site-Level Anthropogenic Feature modifier: 0.35
- Post-Project Site-Level Anthropogenic Feature modifier: 0.31
- Distance to Known Lek: 1.0
- Presence of sagebrush within 300-m of sample point: 1.0 (actual average value 87%)
- Conifer cover: 1.0

Field Data

Hypothetical field data for two vegetation scenarios is used to calculate functional acres. In the first scenario for this project location, low-quality vegetation data and corresponding modifier values (based on mesic location, slope <5%), shown in Table 21, are entered into the HQT Calculator. In the second scenario for this same project location, project developers are not able to obtain field data at the project area. In this situation, the maximum values for field data are applied, which is an option available for debit projects when no field data is available.

Table 22. Average Field Data Scores for Hypothetical Low-Quality Habitat Scenario, Example 1

Attribute	Low-Quality Habitat Average Value for Project Area					
	Breeding		Summer		Winter	
	Field Data	Modifier Value	Field Data	Modifier Value	Field Data	Modifier Value
Sagebrush Cover	70-80%	0.25	N/A	N/A	70-80%	1.00
Sagebrush Height	18-29cm	0.50	N/A	N/A	18-29cm	0.50
Sagebrush Shape	spreading	No change in height	N/A	N/A	N/A	N/A
Grass Cover	2%	0.10	1%	0.50	N/A	N/A
Grass Height	3cm	0.05	1cm	0.50	N/A	N/A
Forb Cover	1-4%	0.05	1-4%	0.50	N/A	N/A
Forb Species Richness	2	0.40	2	0.40	N/A	N/A
% Forb that is Noxious Weeds	1-50%	0.50	1-50%	0.50	N/A	N/A
Presence of Facultative Forbs	N/A	N/A	Yes	1.00	N/A	N/A
BRTE	10-15%	0.10	10-15%	0.10	N/A	N/A

5.1.3 Comparison of Final Functional Acre Scores

Table 23 shows the comparison of pre-project condition and post-project condition functional acre scores for the two scenarios:

Table 23. Comparison of Pre- and Post-Project Functional Acre Scores for the Example Debit Project

FUNCTIONAL ACRE CHANGE				
Scenario	**Seasonal Habitat**	**Post-Project**	**Pre-Project**	**Change**
Low-quality habitat	Breeding	28.98	37.05	- 8.08
	Summer	40.68	52.02	- 11.34
	Winter	640.70	819.34	- 178.64
Maximum Values for Field Data	Breeding	1054.23	1317.94	- 263.72
	Summer	1054.23	1317.94	- 263.72
	Winter	1054.23	1317.94	- 263.72

5.2 Debit Project, Example 2

5.2.1 Project Details

A proposed 10 acre well pad (that will contain two wells) is proposed in Garfield County. The location reference for the facility is latitude 39.652012, longitude -108.121399 in service area 2, and is depicted in Figure 11.

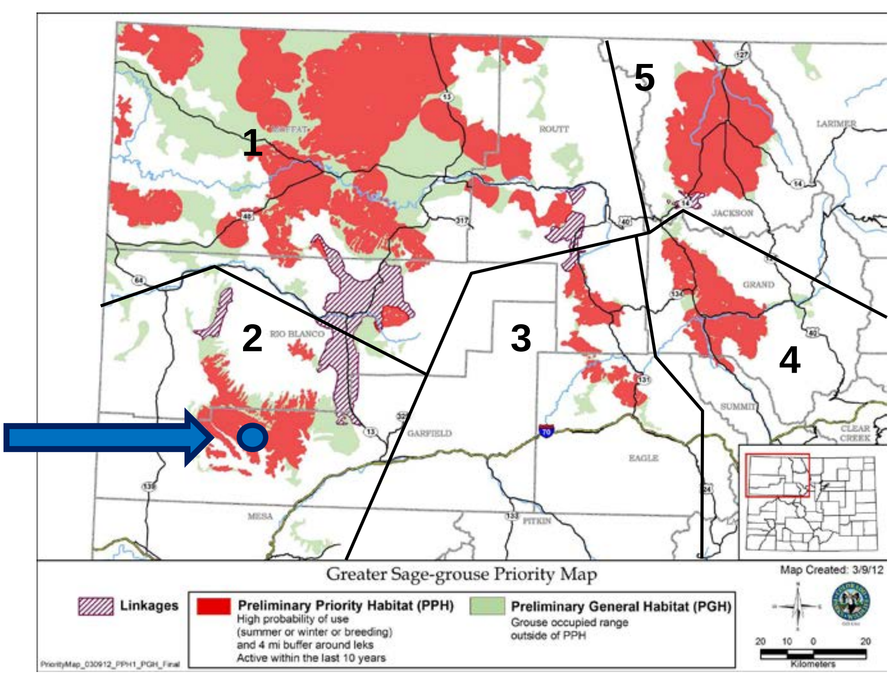


Figure 11. Location Reference for Proposed Well Pad in Example 2

The distance effect for an active oil & gas well pad is 2.1km, so a 2.1km buffer is delineated around the well pad. Figure 12 depicts the project area with the predefined grid of map units overlaid on the project area. Every map unit with a sample point that occurs within the project area is included within the overall project area. In this example, a total of 38 total map units, or 3849 acres, makes up the project area (Figure 12).

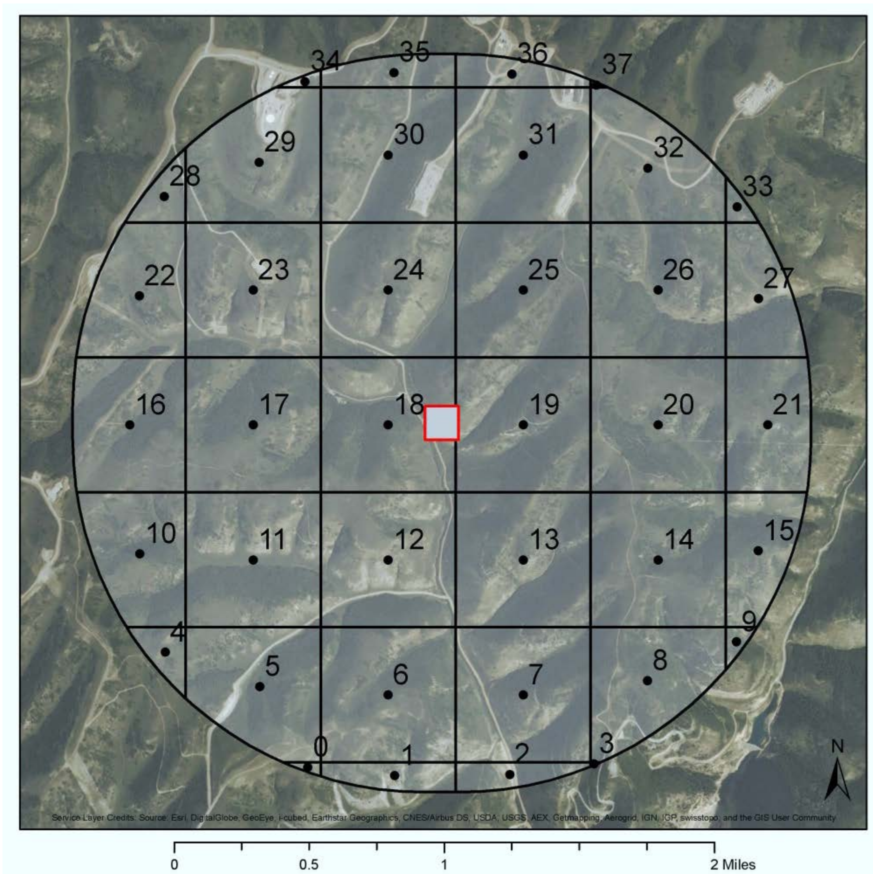


Figure 12. Predefined Map Unit Grid Overlaid on the Project Area for Example 2

5.2.2 GIS and Field Data

GIS Data

GIS data for the project area is derived using the *User's Guide* and is input into the HQT Calculator, as shown in Table 24.

Table 24. GIS Data Input for the Project Example 2

Map Unit ID	Map Unit Area	LDI Modifier	Pre-project Site-Level Anthropogenic Disturbance Value	Post-project Site-Level Anthropogenic Disturbance Value	Distance to Known Lek (km) (rounded to nearest km)	Proportion Conifer Cover	Proportion of Sagebrush within 300 m
0	2.5	0.6817232	0.228881796	0.228881796	5	0.007785359	0.514739
1	30.6	0.6800953	0.171570163	0.171278487	5	0.00760529	0.408163
2	25.5	0.6923010	0.079983977	0.079849902	6	0.017928418	0.278912
3	0.2	0.6993212	0.075631645	0.075631645	6	0.01022317	0.365079
4	20.1	0.6740148	0.320346196	0.319766362	4	0.006124791	0.360544
5	136.0	0.6515004	0.2586445	0.253538128	5	0.012245472	0.174603
6	160.0	0.6788096	0.225457412	0.206958606	5	0.027591097	0.31746
7	160.0	0.7056820	0.142833194	0.131196369	6	0.05074283	0.514739
8	116.9	0.7560028	0.144166289	0.141729838	6	0.067467235	0.244898
9	6.0	0.6612921	0.268283459	0.268283459	6	0.003088162	0.414966
10	106.0	0.6273727	0.183294845	0.183007498	4	0.003638003	0.126984
11	160.0	0.5877350	0.155921173	0.136445281	4	0.015932139	0.353741
12	160.0	0.6030829	0.151839024	0.063804392	5	0.032144	0.517007
13	160.0	0.7097203	0.232287848	0.106369026	5	0.030484679	0.356009
14	160.0	0.7418302	0.262965255	0.231934473	6	0.033469908	0.181406
15	72.8	0.6290377	0.310725722	0.308415367	6	0.001816674	0.192744
16	133.0	0.6011742	0.05419101	0.05419101	3	0.003731188	0.0634921
17	160.0	0.5783687	0.025300483	0.021701761	3	0.014644473	0.154195
18	160.0	0.5951742	0.043463417	0.003965948	4	0.024386759	0.147392
19	160.0	0.6540018	0.09872244	0.016193995	5	0.015662877	0.31746
20	160.0	0.6986101	0.16515169	0.144002617	5	0.017889637	0.349206
21	99.8	0.5769453	0.357591156	0.35714836	6	0.001991634	0.342404
22	107.5	0.5824528	0.009139573	0.009139573	2	0.004389187	0.387755
23	160.0	0.5940253	0.000693758	0.000693758	3	0.013911886	0.54195
24	160.0	0.6411478	0.003813506	0.002120923	3	0.01540372	0.575964
25	160.0	0.6418095	0.009482985	0.006701084	4	0.008704874	0.147392
26	160.0	0.6419870	0.055101987	0.055101987	5	0.00627256	0.244898
27	74.3	0.5608905	0.283151033	0.283151033	6	0.000729922	0.37415
28	22.0	0.5686346	0.002396399	0.002396399	2	0.002116049	0.335601
29	138.9	0.6237878	0.000746072	0.000746072	2	0.006767432	0.365079
30	160.0	0.6625171	0.000426885	0.000426885	3	0.007314432	0.287982
31	160.0	0.6475232	0.001455789	0.001455789	4	0.003427074	0.256236
32	120.7	0.6455931	0.013169187	0.013169187	5	0.005007818	0.621315
33	7.0	0.5699114	0.092954011	0.092954011	5	0.003001658	0.285714
34	3.8	0.6246407	0.000556274	0.000556274	2	0.003705473	0.292517
35	34.8	0.6509529	0.00120823	0.00120823	3	0.003488115	0.356009
36	29.7	0.6574197	0.004225871	0.004225871	4	0.002512438	0.301587
37	0.6	0.6574197	0.009473205	0.009473205	4	0.002512438	0.310658

The average modifier values for the entire project area for each attribute are:

- LDI: 0.64
- Pre-Project Site-Level Anthropogenic Feature modifier: 0.12
- Post-Project Site-Level Anthropogenic Feature modifier: 0.10
- Distance to Known Lek: 0.88
- Presence of sagebrush within 300-m of sample point: 1.0 (actual average value 33%)
- Conifer cover: 1.0

In the second vegetation scenario, project developers are not able to obtain field data at the project area. In this situation, the maximum values for field data are applied, which is an option available for debit projects when no field data is available.

Field Data

Hypothetical field data for two vegetation scenarios is used to calculate functional acres. In the first scenario for this project location, low-quality vegetation data and corresponding modifier values (based on mesic location, slope <5%), shown in Table 25, are entered into the HQT Calculator. In the second scenario for this same project location, project developers are not able to obtain field data at the project area. In this situation, the maximum values for field data are applied, which is an option available for debit projects when no field data is available.

Table 25. Average Field Data Scores for Hypothetical Low-Quality Habitat Scenarios, Example 2

Attribute	Low-Quality Habitat Average Value for Project Area					
	Breeding		Summer		Winter	
	Field Data	Modifier Value	Field Data	Modifier Value	Field Data	Modifier Value
Sagebrush Cover	30-39%	1.00	N/A	N/A	30-39%	1.00
Sagebrush Height	18-29cm	0.50	N/A	N/A	18-29cm	0.50
Sagebrush Shape	spreading	No change in height	N/A	N/A	N/A	N/A
Grass Cover	2%	0.10	1%	0.50	N/A	N/A
Grass Height	3cm	0.05	1cm	0.50	N/A	N/A
Forb Cover	1-4%	0.05	1-4%	0.50	N/A	N/A
Forb Species Richness	2	0.40	2	0.40	N/A	N/A
% Forb that is Noxious Weeds	1-50%	0.50	1-50%	0.50	N/A	N/A
Presence of Facultative Forbs	N/A	N/A	Yes	1.00	N/A	N/A
BRTE	10-15%	0.10	10-15%	0.10	N/A	N/A

5.2.3 Comparison of Final Functional Acre Scores

Table 26 shows the comparison of pre-project condition and post-project condition functional acre scores for the two scenarios:

Table 26. Comparison of Pre- and Post-Project Functional Acre Scores for Example 2

FUNCTIONAL ACRE CHANGE				
Scenario	**Seasonal Habitat**	**Post-Project**	**Pre-Project**	**Change**
Low-quality habitat	Breeding	6.31	7.75	- 1.44
	Summer	8.50	10.08	- 1.58
	Winter	133.86	158.80	- 24.94
Maximum Values for Field Data	Breeding	181.03	227.04	- 46.01
	Summer	232.84	281.20	- 48.36
	Winter	232.84	281.20	- 48.36

5.3 Example Credit Project

The pre-project site-level condition for an example credit project with 3 map units is depicted in the table below. The Exchange participant's activities affect site-level conditions only; 2nd and 3rd order modifiers do not change. Table 26 depicts 4th order scores for pre-production condition; Table 27 depicts 4th order scores for post-project condition. **This example is for illustrative purposes only to demonstrate the scoring.**

5.2.1 Results for Pre-Project Condition

Table 27. Pre-Project 4th Order Vegetation Condition Scores

BREEDING Pre-Project 4th Order Vegetation Condition												
		Sagebrush			Grass		Forbs			Modifier		
Map Unit	Acres	Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass	4th Order Habitat Function	Functional Acres
1	25	18-29	20-29	Spreading	5	10	<2	15-20	No	0-1	0.59	14.75
2	30	18-29	20-29	Spreading	11	>20	5	1-4	No	5-9	0.38	11.40
3	45	10-17	<5	Spreading	4	6	<2	0	No	>15	0	0
											Total Functional Acres	26.15

SUMMER Pre-Project 4th Order Vegetation Condition												
		Sagebrush			Grass		Forbs			Modifier		
Map Unit	Acres	Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass	4th Order Habitat Function	Functional Acres
1	25	18-29	20-29	Spreading	5	10	<2	15-20	No	0-1	0.73	18.25
2	30	18-29	20-29	Spreading	11	>20	5	1-4	No	5-9	0.40	12.00
3	45	10-17	<5	Spreading	4	6	<2	0	No	>15	0	0
											Total Functional Acres	30.25

WINTER Pre-Project 4th Order Vegetation Condition												
		Sagebrush			Grass		Forbs			Modifier		
Map Unit	Acres	Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass	4th Order Habitat Function	Functional Acres
1	25	18-29	20-29	Spreading	5	10	<2	15-20	N/A	0-1	0.75	18.75
2	30	18-29	20-29	Spreading	11	>20	5	1-4	N/A	5-9	0.75	22.50
3	45	10-17	<5	Spreading	4	6	<2	0	N/A	>15	0.25	11.25
											Total Functional Acres	52.50

5.2.2 Results for Post-Project Condition

It is **expected** that the landowner's activities will increase forb cover, increase the number of forb species, and decrease cheatgrass cover for some map units. Table 27 depicts 4th order scores for post-project condition.

Table 28. Post-Project 4th Order Vegetation Condition Scores

BREEDING Post-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass		
1	25	18-29	20-29	Spreading	5	10	*4*	15-20	No	0-1	0.69	17.25
2	30	18-29	20-29	Spreading	11	>20	*6*	*10-14*	No	*2-4*	0.65	19.50
3	45	10-17	<5	Spreading	4	6	*6*	*10-14*	No	*2-4*	0.37	16.65
											Total Functional Acres	53.40

SUMMER Post-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass		
1	25	18-29	20-29	Spreading	5	10	*4*	15-20	No	0-1	0.87	21.75
2	30	18-29	20-29	Spreading	11	>20	*6*	*10-14*	No	*2-4*	0.74	22.20
3	45	10-17	<5	Spreading	4	6	*6*	*10-14*	No	*2-4*	0.65	29.25
											Total Functional Acres	73.20

WINTER Post-Project 4th Order Vegetation Condition												
Map Unit	Acres	Sagebrush			Grass		Forbs			Modifier	4th Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Shape	Height	% Cover	# of Species	% Cover	100% Noxious weed cover	Cheatgrass		
1	25	18-29	20-29	Spreading	5	10	*4*	15-20	N/A	0-1	0.75	18.75
2	30	18-29	20-29	Spreading	11	>20	*6*	*10-14*	N/A	*2-4*	0.75	22.50
3	45	10-17	<5	Spreading	4	6	*6*	*10-10*	N/A	*2-4*	0.25	11.25
											Total Functional Acres	52.50

5.2.3 Comparison of Final Functional Acre Scores

Pre-project condition is subtracted from post-project condition to calculate the functional acre change by season (Table 28).

Table 29. Comparison of Pre- and Post-Project Functional Acre Scores for the Example Credit Project

FUNCTIONAL ACRE CHANGE BY SEASON			
Seasonal Habitat	**Post-Project**	**Pre-Project**	**Difference**
Breeding	53.40 functional acres	26.15 functional acres	+27.25 functional acres
Summer	73.20 functional acres	30.25 functional acres	+42.95 functional acres
Winter	52.50 functional acres	52.50 functional acres	No change in functional acres

6.0 Adaptive Management

Adaptive management is a fundamental principle of the HQT and it is vital to the proper functioning of the Exchange overall. When it comes to managing GRSG populations or improving sagebrush habitats, quite a bit is known about the species' habitat preferences, but less is known about the effectiveness of habitat restoration and management techniques in creating positive habitat conditions. For this reason and others, it is necessary that the Exchange is implemented in an adaptive manner that evaluates the effectiveness of practices in meeting desired outcomes. An adaptive approach to the management and monitoring plan will be developed that addresses these issues.

Adaptive management is defined as the structured dynamic process of addressing uncertainty in management through the incorporation of procedures that seek to periodically revise and update tools, strategies and approaches to management in response to changing conditions or new information. Adaptive management strategies allow for changes to the overall conservation strategy to occur in response to changing conditions or new information, including those identified during monitoring. Adaptive approaches to management recognize that not all of the answers to management questions are known and some management is a process of trial and error. Adaptive management also includes, by definition, a commitment to change management approaches when appropriate for attaining biological goals and objectives of a conservation strategy. The goal of adaptive management for the HQT is to make periodic changes that keep it up to date with the current state of ecological knowledge and apparent functioning of the tool.

Adaptive management is not just one component of the Exchange, but is the foundation of implementation of the Exchange itself. There needs to be an explicit, straightforward process in place for the incorporation of monitoring data into the models (HQT) and Exchange framework – within which management decisions are informed. And, the process by which those management decisions are informed in the adaptive context also needs to be explicitly established. These approaches have not yet been formulated for the Exchange.

The development of an adaptive implementation approach would address the following questions:

1) What criteria/metrics/data need to be collected over time?
2) How is this information incorporated into the Exchange? What is the model framework within which these data are used to inform and adapt the Exchange through time?
3) What are the steps and methods for implementing the Exchange? Explicitly establish the steps along with cost estimates for implementing the Exchange in a scientifically-rigorous manner.

Until a more explicit adaptive management and monitoring approach is developed, the following will serve adaptive management needs. The Science Advisory Team will meet periodically to review and evaluate new information including: monitoring data, research on the species biology or ecology, additional or changing threats to the species, recent substantial gains or losses of habitat for the species, the establishment of new protected areas, etc. During the first three years of the Exchange, the Team will meet at least bi-annually. Beyond that, the Team will meet every year. These reviews will additionally be used to iteratively evaluate the HQT, specifically: 1) tool functions (scoring tools, GIS applications, etc.); 2) accuracy of the scores in measuring real and expected outcomes; 3) utility (ease of use, efficiency, and cost) across end-users, 4) repeatability of scores from one user to the next and across habitat types, and 5) reliability of scores over time. Previously identified knowledge gaps will be re-evaluated and addressed, as data allows. Modifications to the HQT and the processes by which habitat condition is quantified will be made based on the conclusions the Science Advisory Team reaches during these reviews. The Exchange Manual further describes the role of the Science Advisory Team in implementing and adapting the Exchange.

The Exchange will focus on habitat outcomes, as described by the HQT, while bird population data will remain the purview of state and federal agencies. It will be possible, however, to evaluate regional population status and trends over time and relate them to landscape-scale habitat conditions to get an idea of how habitat exchanges are performing in combination with other conservation efforts and to determine whether management practices are yielding net benefits for the species. The approach for establishing these connections will be explored as a component of the adaptive implementation processes developed for the Exchange.

In the adaptive management and monitoring plan, we will develop a link between habitat as quantified through the Exchange and GRSG populations. This connection would be established in a 2-tiered approach by first tying the approaches to quantifying habitat "value" as outlined in the Exchange with extant geospatial data, and then analyzing GRSG population metrics with these geospatial covariates. Developed models would be used to inform the potential associated with the Exchange in terms of GRSG population sustainability through build-out scenarios – basically investigating the population-level response to different debit/credit generation scenarios. The models would also be used to assess trends toward goals established as a result of the implementation of the Exchange, and to assess different aspects of the implementation of the Exchange. For example, the analysis could address questions such as: what habitat quality thresholds are required for a site to be considered for credit; how well do landscape-scale modifiers associated with the HQT work; what are the consequences of considering conservation/preservation as a credit; etc.

There will always be uncertainty about the exact vegetation and bird population responses to habitat manipulations. While much is known about the habitat needs of GRSG, the long-term effects of most available habitat management options are unknown (Sage and Columbian Sharp-tailed Grouse Technical Committee 2009). Caution and discretion must be exercised when proposing habitat treatments, especially on drier sites, sites where cheatgrass may invade, or sites with limited potential to produce sagebrush (e.g., the interface between the Wyoming Basin and the Great Plains). An interdisciplinary group developing grazing management objectives in Wyoming's GRSG habitats (Wyoming Interagency Grazing Management Committee 2009) recommends a small-scale, case-by-case disturbance regime conducted over the long-term. We caution that the Colorado Habitat Exchange should **NOT** be used as justification for wide-scale modification of sagebrush ecosystems as a GRSG management tool. Over time, the adaptive process by which the Exchange is implemented should inform habitat treatments that result in the most beneficial outcomes for the species.

7.0 Limitations of the HQT

The HQT is based on the best available science and best professional judgment. However, there are aspects of its content and potential uses that can be improved as it is adaptively managed over time.

First, most of the literature used to estimate the density effects associated with anthropogenic features is derived from analyses of the response of GRSG on leks (i.e., number of males occupying leks) to those features (see Appendix C). Since the HQT seeks to quantify vegetation that supports seasonal needs of GRSG (i.e., breeding, summer and winter), and credits and debits are based on these assessments of seasonal habitat value, the LDI will be updated as more information pertaining to GRSG seasonal response to anthropogenic activity becomes available.

Second, the HQT currently relies on a standardized, site-specific vegetation sampling protocol to establish vegetation conditions and monitor vegetation changes. However, standardizing vegetation sampling protocols over space and time has its challenges, which could be problematic in situations where quantifying vegetation change is the objective of monitoring (Seefeldt and Booth 2006). Aerial imagery and other remotely-sensed information offer the opportunity for objective measurement of vegetation across space and time, but in most instances the products derived from these data are too coarse to effectively detect small-scale changes in the vegetation (Seefeldt and Booth 2006). As remote-sensing platforms and sensors mature, spatial and temporal resolution are expected to improve and costs decrease, making it easier to effectively quantify change in relevant vegetation attributes. The Science Advisory Team will stay abreast of advances in remote-sensing and image analysis software so that GIS-based monitoring protocols can be incorporated into the HQT as suitable to address the HQT objectives.

Third, the HQT alone is not an effective tool for assessing how changes in habitat condition contribute to population viability. As described in the adaptive management section (section 6), the HQT is focused on actions that occur at the site level, and the methods required to accurately measure conditions at that scale (e.g., vegetation plots) are not conducive to large-scale assessments. However, additional research could contribute to a greater understanding of how cumulative habitat changes contribute to population viability. Furthermore, as long as debits are offset by credits, and as credits accumulate beyond debits, the Exchange will contribute to net increases in high quality habitat that we believe to be likely to sustain resilient GRSG populations over time.

Fourth, the Science Team developed an approach to quantifying the conditions of the surrounding landscape as the proportion of each seasonal range available to GRSG on that landscape. This modifier was meant to establish that habitats suitable for GRSG during all seasonal periods (breeding, summer and winter) were present on the landscape and available to an individual in sufficient quantities.

However, extant information – primarily the seasonal habitat suitability maps presented in Rice et al. (2013) – was not conducive to accurately establishing these relationships. This was due to a difference in objectives associated with the metric we were attempting to develop and the metrics Rice et al. (2013) were modeling. Further, the Science Team recognizes that the interspersion and juxtaposition of the differing cover types used by GRSG during an annual cycle influence the effectiveness of a given landscape to provide GRSG with useable and high quality habitat (Connelly et al. 2011c); and that these metrics, along with availability, are not quantified in the HQT. Future iterations of the HQT would explore how to integrate availability, interspersion and juxtaposition of seasonal ranges on the landscape as modifiers.

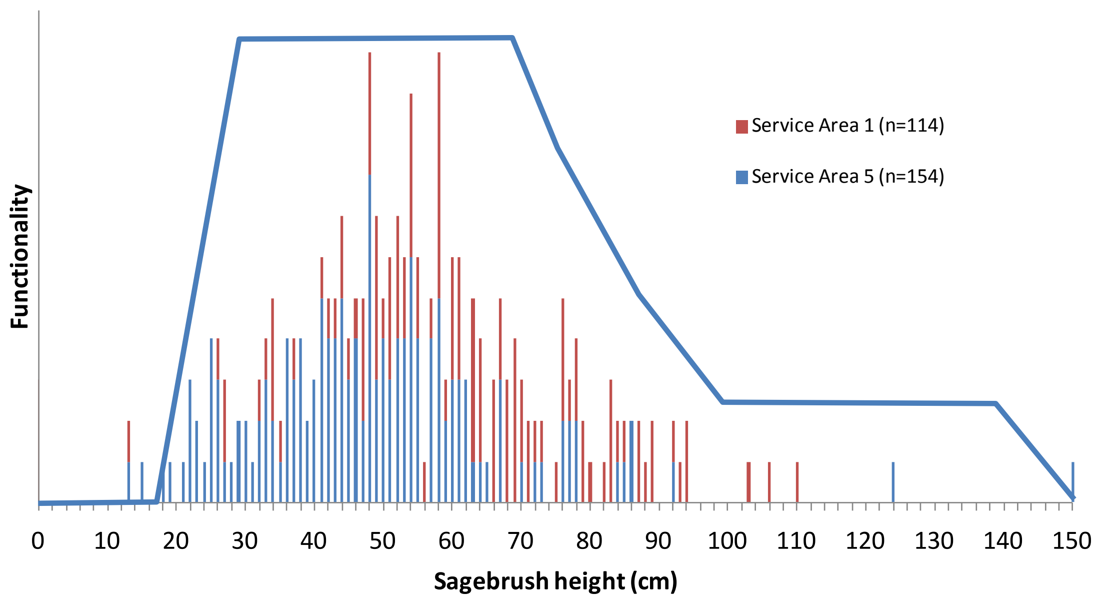
Finally, the scoring approach used in the HQT does not include a short-term temporal aspect. Thus, it cannot detect short-term changes in impacts resulting from anthropogenic features. For example, a drilling rig may have more impact than an active producing well. Due to this limitation, it scores the impact based on the primary level of activity the majority of the time the disturbance is present. In this example, it scores based on the impact of the active production phase, rather than the drilling rig phase, which may only last 60 days.

Appendix A. Scoring Curves and Tables

Scoring response curves for each attribute were developed by the Science Team. Data used to develop and/or inform the relationship were from actual breeding (nesting and early-brood-rearing; n = 402), summer (brood-rearing and unsuccessful; n=148), and winter (male and female; n = 63) use sites of GRSG collected from 2001 – 2010. Actual sample sizes used by attribute varied based upon site and the year data was collected. Data for the attributes were extracted from GRSG use sites in Service Areas 1, 2, 3, and 5 (see service areas in Figure 2 on page 14). Thus, the data were collected from a range of environmental conditions (xeric to mesic). If data were not available, the CCP was the default, but the Science Team did not use habitat measurements from outside Colorado.

Guidance for inflection points on the response curves is generally consistent with the CCP (Greater Sage-grouse Rangewide Steering Committee 2008). Minor adjustments and deviations to the inflection points may be different from the CCP because additional data have been collected post CCP publication (CPW, unpublished data; A.D. Apa personal communication).

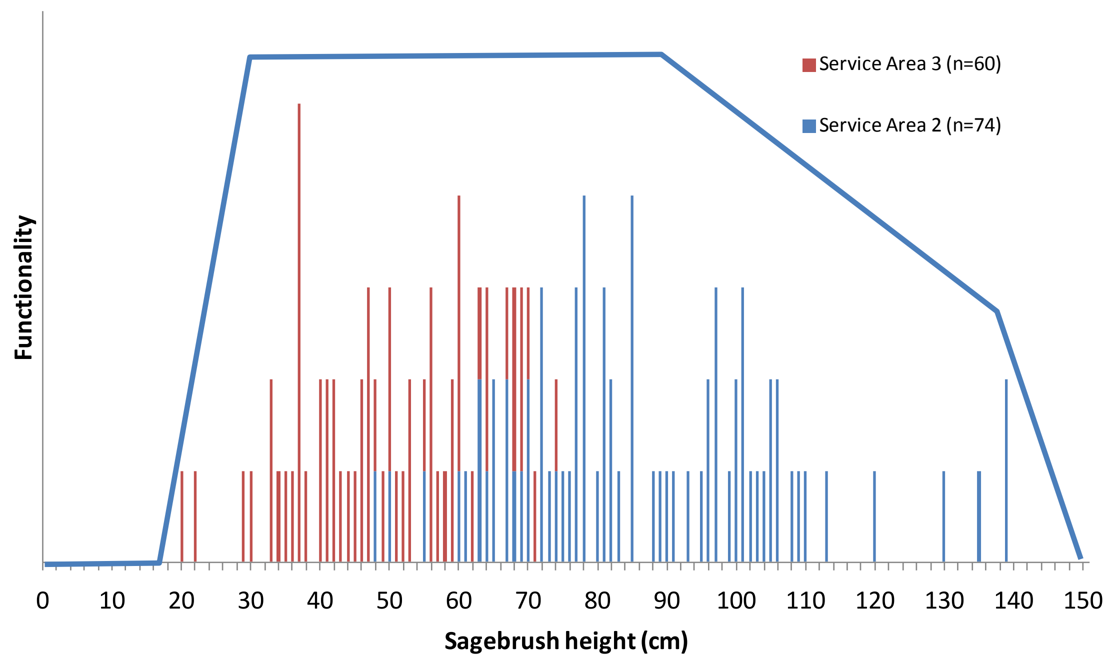
Breeding Habitat: Sagebrush Height, Arid Sites



<18	18-29	30-39	40-49	50-59	60-69	70-79
0	0.5	1	1	1	1	0.7
80-89	**90-99**	**100-119**	**120-140**	**>140**		
0.7	0.25	0.25	0.25	0		

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

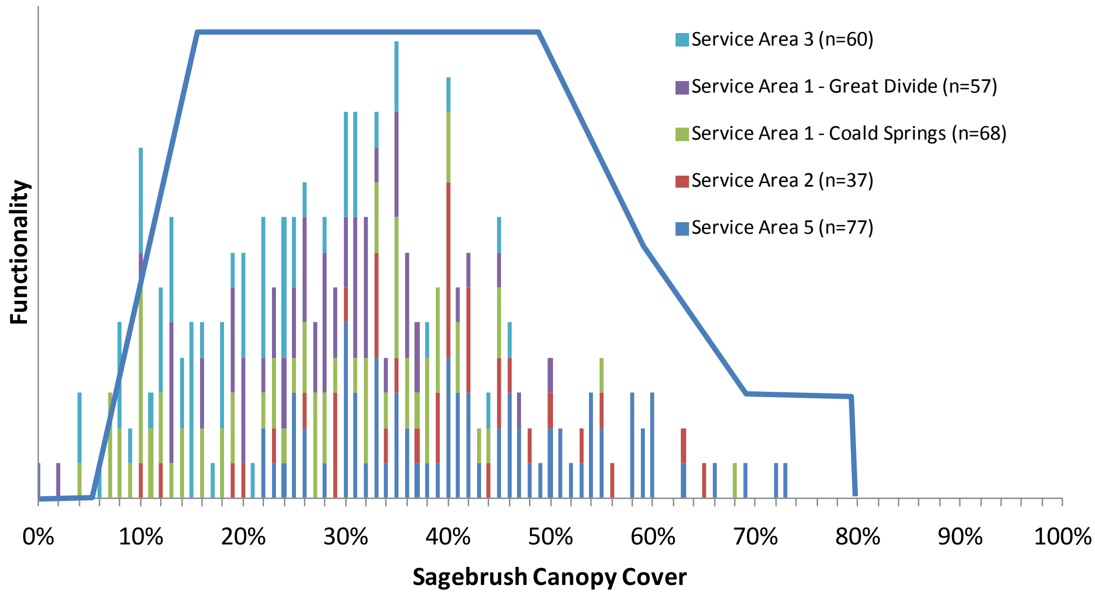
Breeding Habitat: Sagebrush Height, Mesic Sites



<18	18-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-119	120-139	>140
0	0.5	1	1	1	1	1	1	0.7	0.6	0.5	0

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

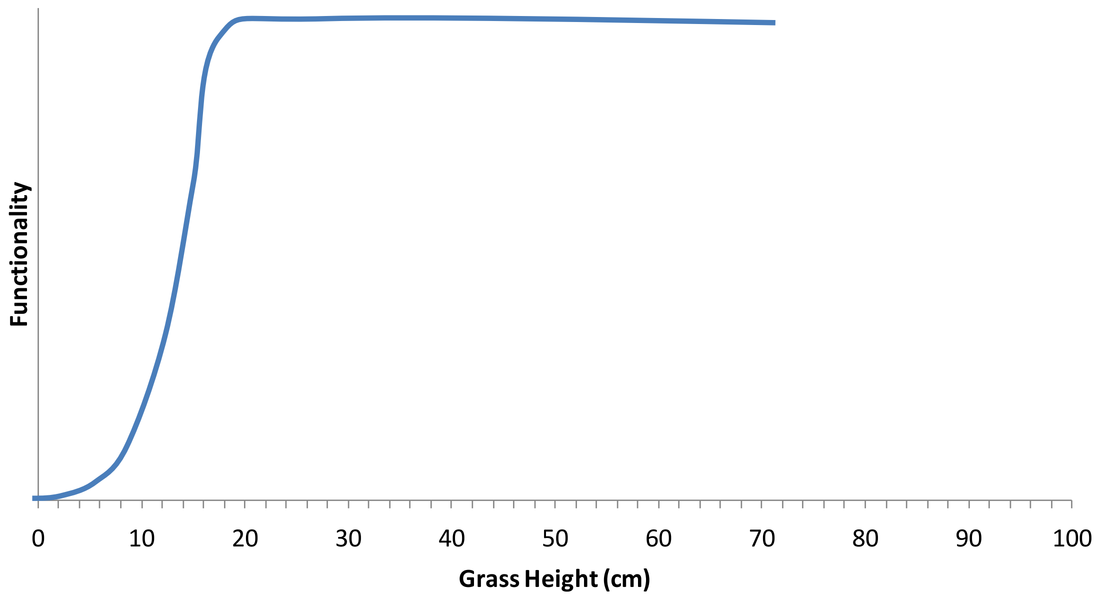
Breeding Habitat: Sagebrush Canopy Cover



<5	5-14	15-19	20-29	30-39	40-49	50-59	60-69	70-79	>80
0	0.5	1	1	1	1	0.5	0.25	0.25	0

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

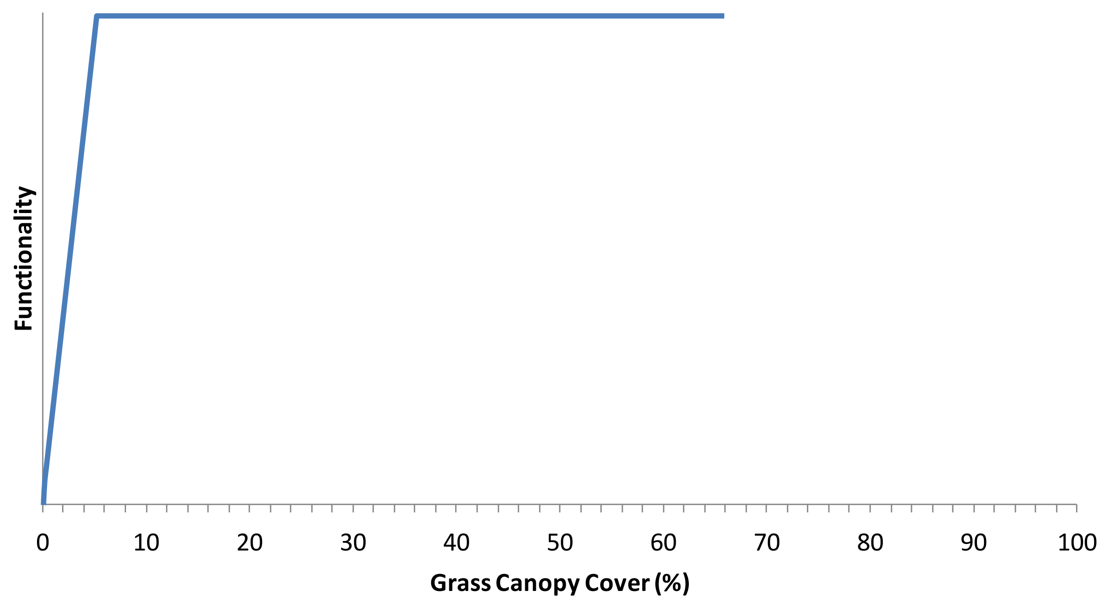
Breeding Habitat: Grass Height



1	2	3	4	5	6	7	8	9	10
0	0.0125	0.05	0.05	0.075	0.075	0.1	0.2	0.3	0.5
11	**12**	**13**	**14**	**15**	**>15**				
0.7	0.8	0.9	0.95	1	1				

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

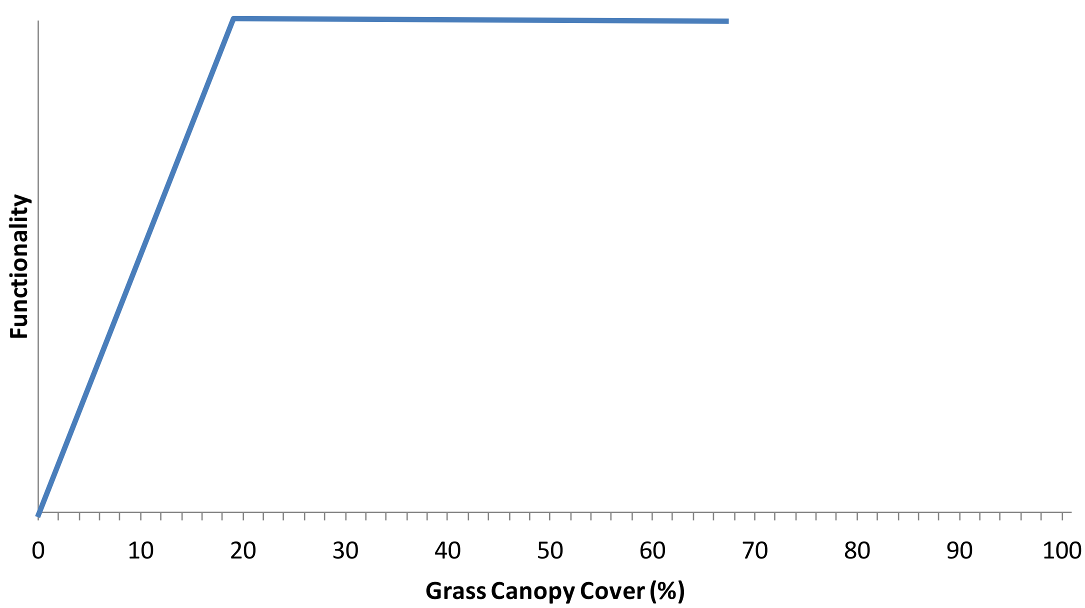
Breeding Habitat: Grass Canopy Cover, Arid Sites



1	2	3	4	5	>5
0.1	0.3	0.4	0.5	1	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

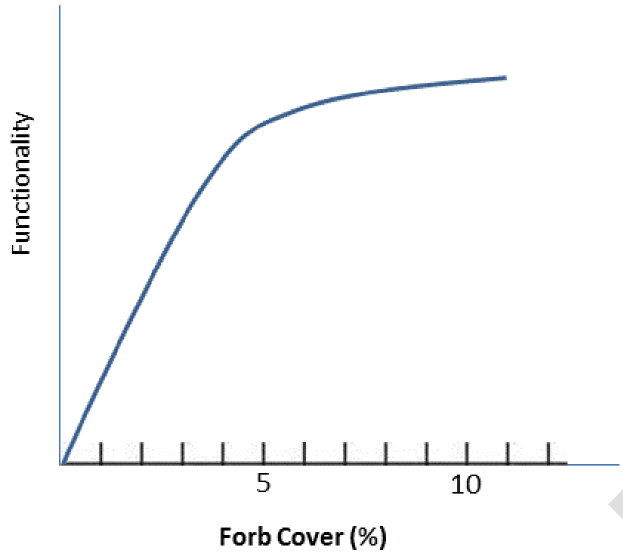
Breeding Habitat: Grass Canopy Cover, Mesic Sites



1	2	3	4	5	6	7	8	9	10	
0	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**>20**
0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

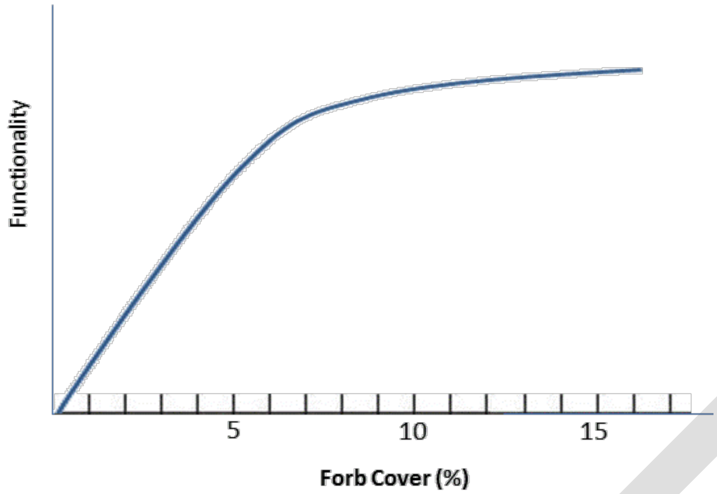
Breeding Habitat: Forb Cover, Arid Site



0	1-5	5-7	7-10	>10
0	0.5	0.8	0.8	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

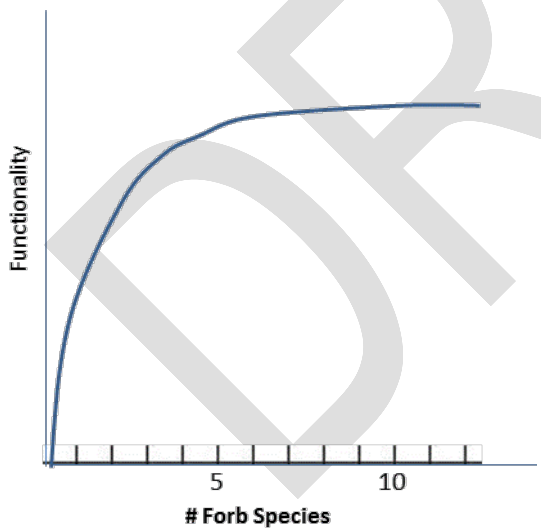
Breeding Habitat: Forb Cover, Mesic Site



0	1-5	5-7	7-10	10-15	>15
0	0.5	0.5	0.8	0.8	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

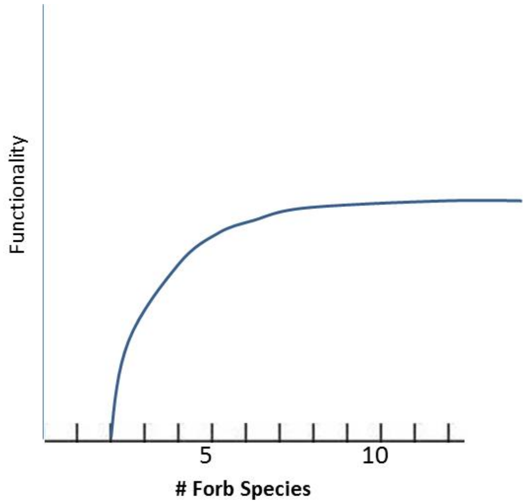
Breeding Habitat: Forb Species Richness, Arid Site



<2	2	3	4	5	6	>7
0	0.4	0.6	.075	0.85	0.95	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

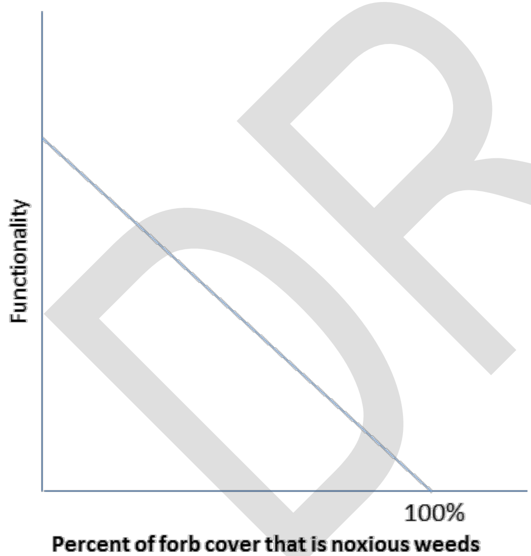
Breeding Habitat: Forb Species Richness, Mesic Site



<2	2	3	4	5	6	7	8	9	10	>11
0	0.4	0.5	0.6	0.65	0.7	0.8	0.85	0.9	0.95	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

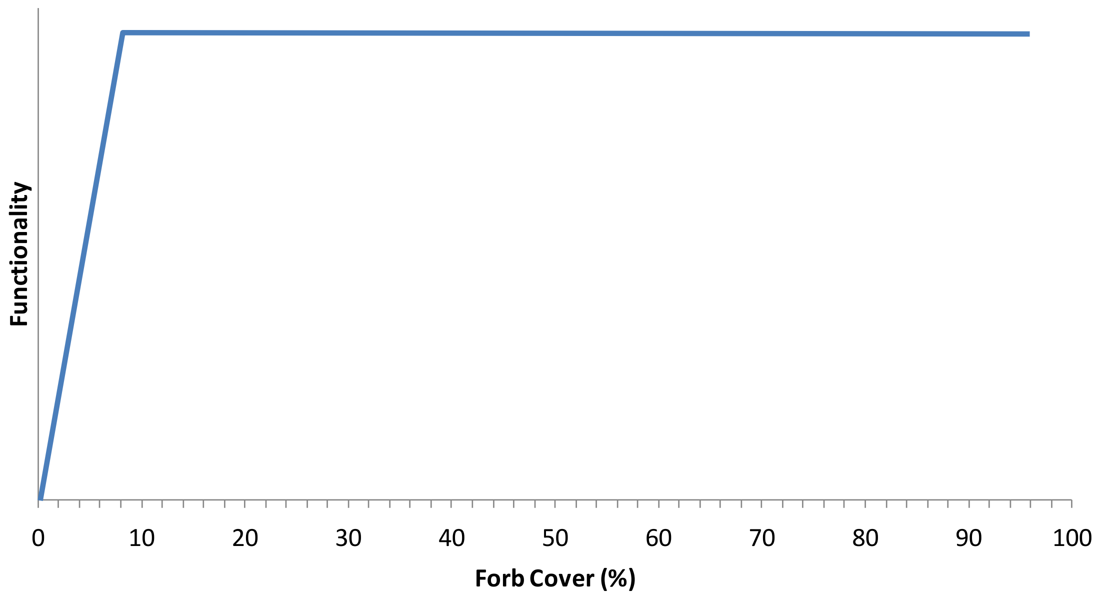
Breeding Habitat: Presence of Specific Forb Species (Noxious weeds)



0	50	100
1	0.5	0

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

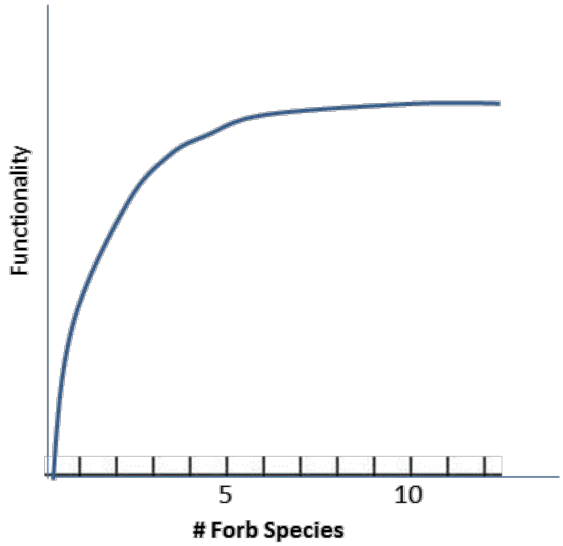
Summer Habitat: Forb Cover



0	1-4	5-6	7-9	10-14	15-20	>20
0	0.5	0.7	0.9	1	1	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

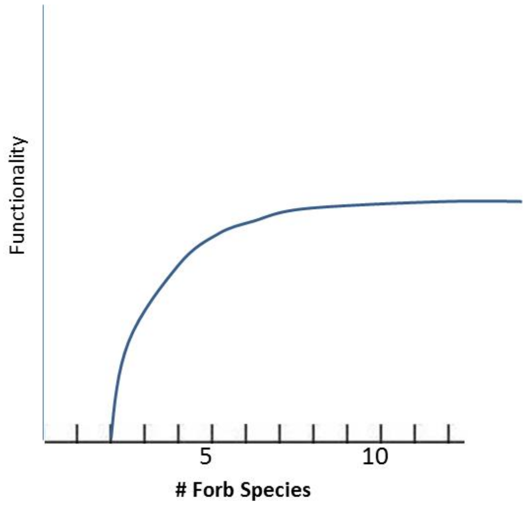
Summer Habitat: Forb Species Richness, Arid Site



<2	2	3	4	5	6	>7
0	0.4	0.6	0.75	0.85	0.95	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

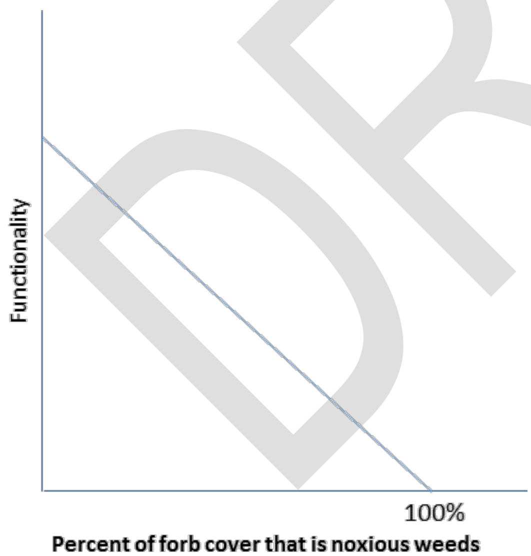
Summer Habitat: Forb Species Richness, Mesic Site



<2	2	3	4	5	6	7	8	9	10	>11
0	0.4	0.5	0.6	0.65	0.7	0.8	0.85	0.9	0.95	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

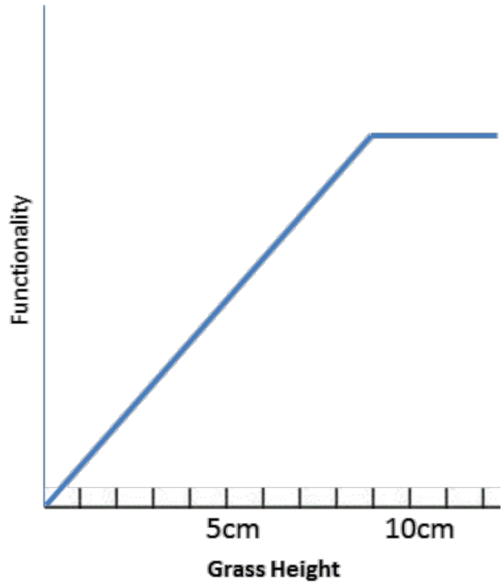
Summer Habitat: Presence of Specific Forb Species



0	50	100
1	0.5	0

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

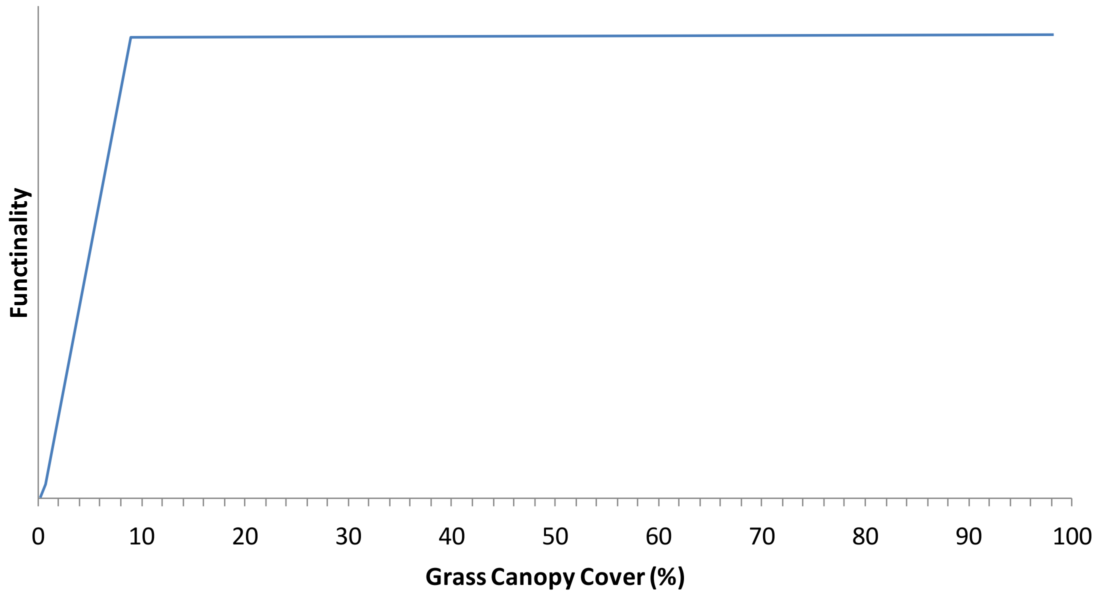
Summer Habitat: Grass Height



0	1-4	5-10	>10
0	0.5	.75	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

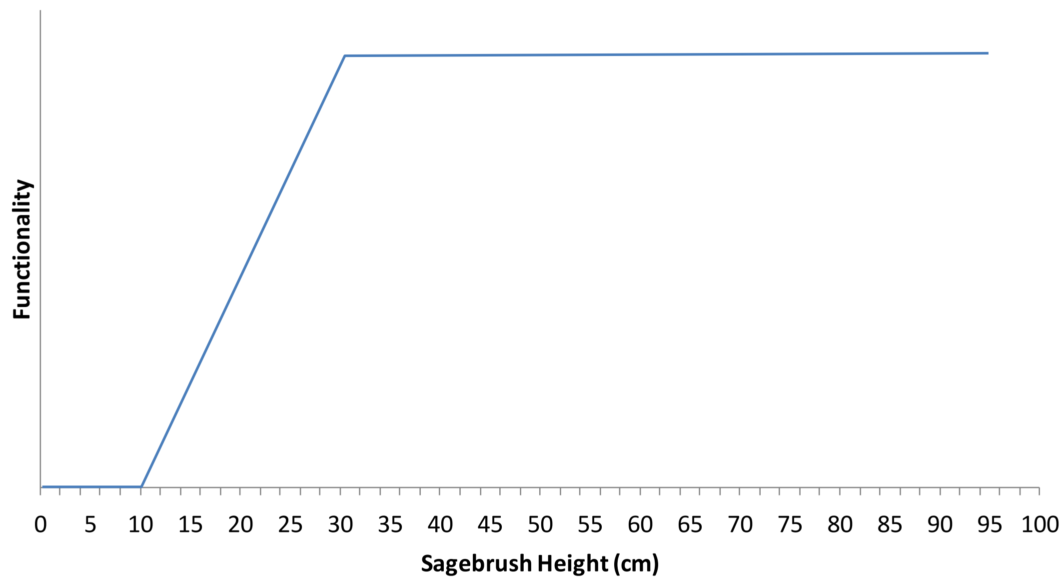
Summer Habitat: Grass Canopy Cover



0	1-4	5-10	>10
0	0.5	.75	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

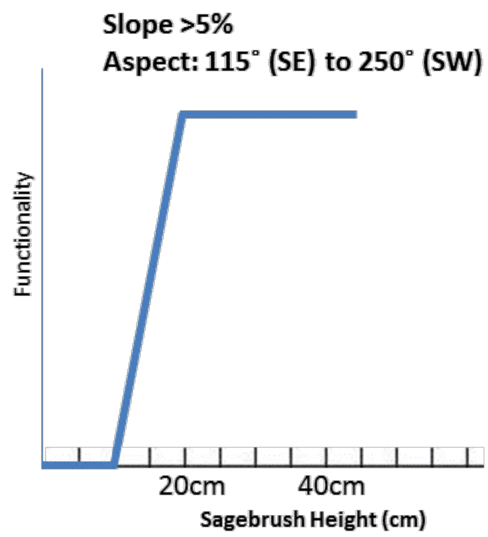
Winter Habitat: Sagebrush Height, Slope <5%



0-9	10-30	>30
0	0.5	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

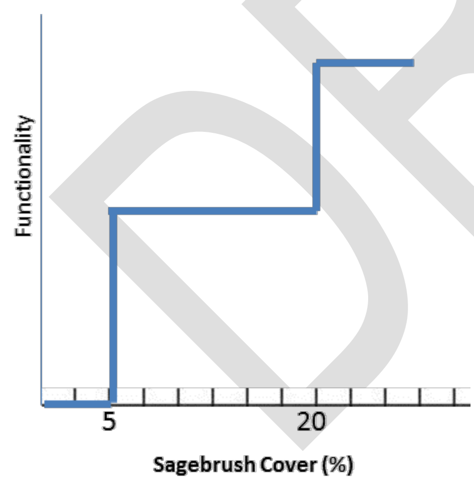
Winter Habitat: Sagebrush Height, Slope >5%



0-9	10-20	>20
0	0.5	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

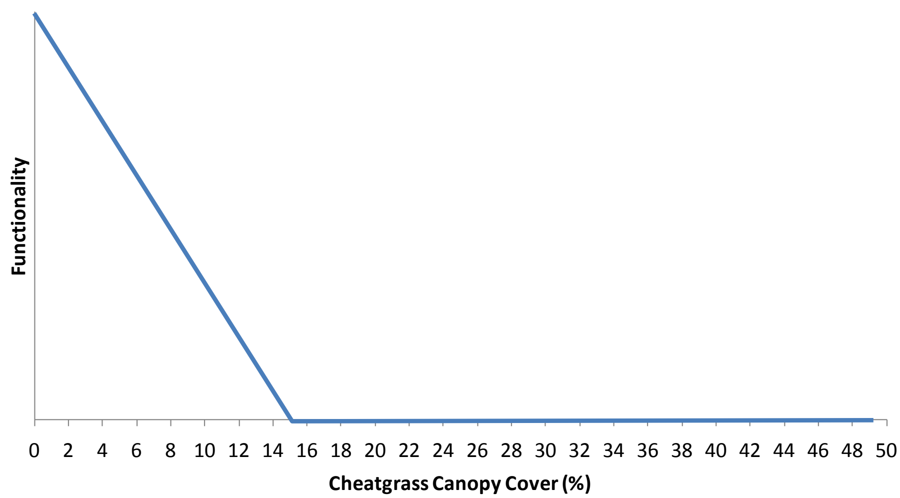
Winter Habitat: Sagebrush Canopy Cover



<5	5-15	15-20	>20
0	0.5	0.5	1

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

Invasive Grass



0-1	2-4	5-9	10-15	>15
1	0.8	0.5	0.1	0

Reference: Greater Sage-grouse Rangewide Steering Committee 2008; CPW, unpublished data; A.D. Apa personal communication

Appendix B. Distance Effects of Anthropogenic Features: Literature Review and Analysis

Introduction and Rationale

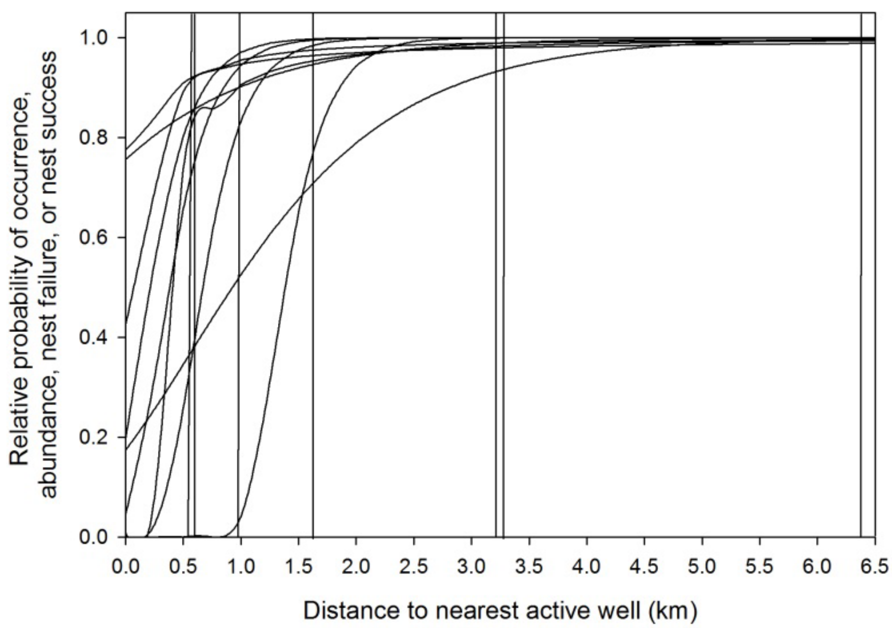
The HQT contains a 4th order or site-level anthropogenic feature modifier to represent the local impacts of anthropogenic features on individual GRSG. Literature results describing the ecology of individual GRSG birds in relation to distance-to-feature were used to inform the modifier values in the site-level anthropogenic feature modifier. We note that these results do not reflect distances for siting anthropogenic features around leks, but rather represent spatial impacts of these features on a variety of components of GRSG ecology on the general landscape.

A large body of literature explores the impact of anthropogenic features on GRSG ecology, such as individual bird occurrence, nest placement, and adult survival. We conducted a thorough literature review of peer-reviewed publications, theses/dissertations, book chapters, and publicly-available reports and found several studies that contained original data analysis on spatial impacts of four anthropogenic feature types: transmission lines, highways, secondary roads, and producing natural gas/oil wells. The results from these analyses can be used to identify non-linear, continuous relationships documenting the decline of impacts over increasing distances or to identify distance values beyond which impacts were minimal or non-existent.

We used a simple criterion for inclusion of literature results in this analysis. To be included, a study had to either address distance-to-feature as a continuous non-linear curve (to allow for a decline in the magnitude of the relationship at greater distances) or assess the presence/absence of an impact within ≥ 4 buffer distances (i.e., treat distance as quasi-continuous). Studies that treated distance as continuous but linear were not relevant because they modeled selection as monotonically increasing or decreasing indefinitely. A monotonic impact whose magnitude is constant does not provide any information as to how impacts decline at greater distances. Studies that treated distance as quasi-continuous, but with ≤ 3 potential distances, had limited information content as to the true scale of impacts, were considered insufficiently relevant to this analysis, and were therefore also excluded.

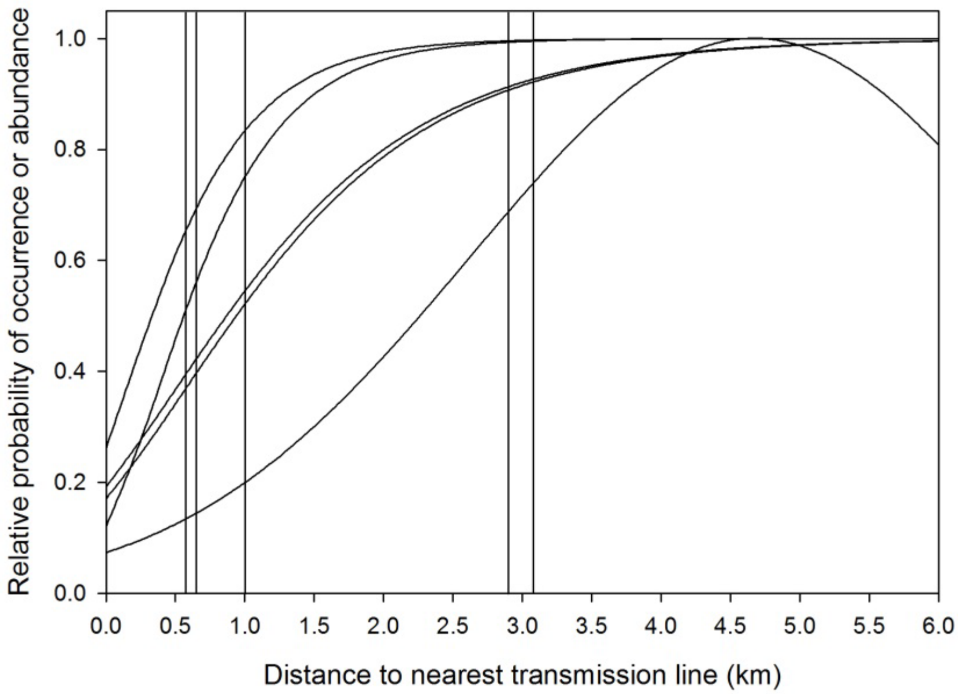
All non-linear curves were obtained by back-transforming the coefficient estimate to a continuous line along the range of the distance-to-feature according to the specific model used in each study (e.g., decay curve, broken-stick models, curvilinear regression, etc.; y = exp(coeff. * distance)). If necessary, curves were normalized to a scale of 0 – 1 for comparison across model and variable types. To determine the specific values that informed the analysis of indirect impact distances for curves, we used the distance (km) at which curves reached 90% value (e.g., 90% probability of survival, relative probability of occurrence, etc.). All buffer bars were obtained directly from each study as the best scale among those considered for identifying impacts. Two studies also reported sufficient data to detect inflection points, which was the distance from a feature where the magnitude of impacts declined sharply, even though impacts were present at further distances. Inflection points were symbolized as dashed bars. Each bar indicates a cessation of spatial impacts at greater distances from the feature for that particular study/analysis. Each curve or bar represents a single independent analysis/result.

A total of 65 analysis results from 13 separate studies fit the criteria for inclusion as a relevant finding. Measured GRSG responses to distance-to-feature included seasonal occurrence (e.g., brood-rearing, summer, and winter), nest site selection, nest fate, adult or chick survival, and pellet group abundance. Figures 13-16 depict the results of the analysis described above.



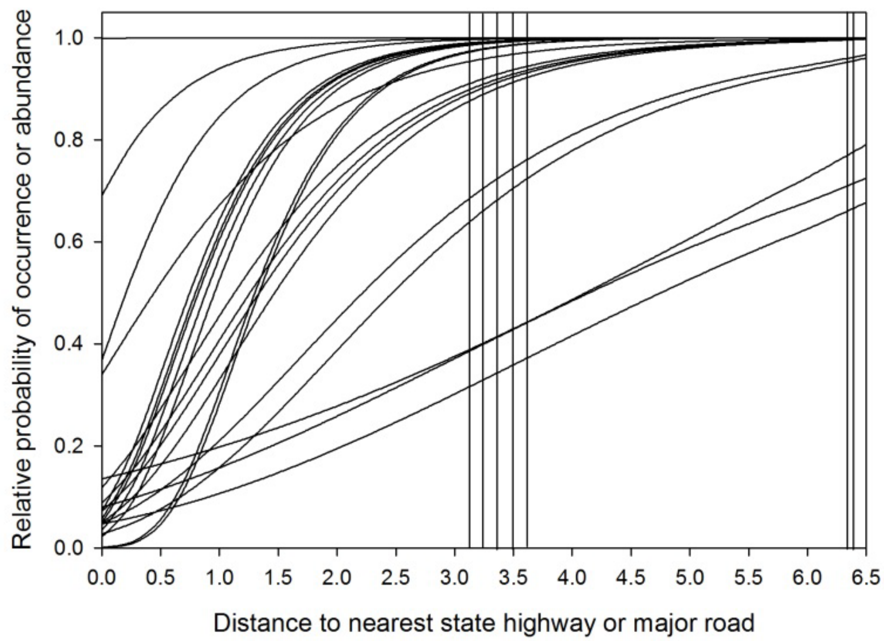
Distance relationships between the nearest active well and sage-grouse brood and winter occurrence, nest site selection, general abundance, and nest failure/success. Each curve or vertical bar is from a separate analysis (n=16). Curves relate to both y- and x-axis; bars relate only to x-axis. Vertical bars and curve shoulders identify distances at which impacts of active wells became negligible or absent.

Figure 13. Distance to Nearest Active Well (km)



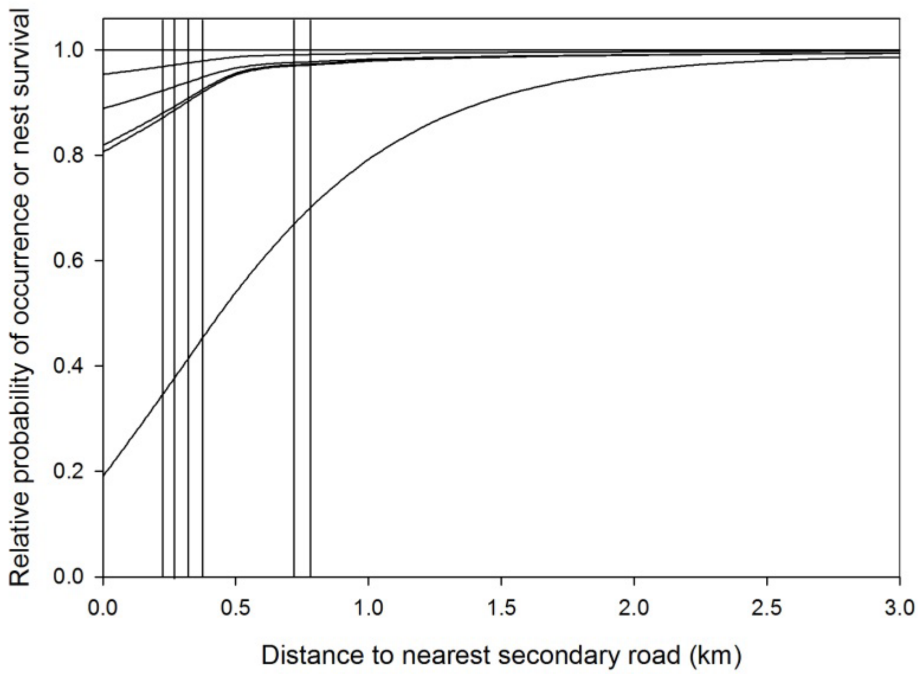
Distance relationships between the nearest transmission line and sage-grouse brood occurrence, adult general occurrence, pellet abundance, and adult survival. Each curve or vertical bar is from a separate analysis (n=10). Curves relate to both y- and x-axis; bars relate only to x-axis. Vertical bars and curve shoulders identify distances at which impacts of transmission lines became negligible or absent.

Figure 14. Distance to Nearest Transmission Line (km)



Distance relationships between the nearest state highway or major road and sage-grouse brood, summer, and winter occurrence, nest site selection, and general abundance. Each curve or vertical bar is from a separate analysis (n=27). Curves relate to both y- and x-axis; bars relate only to x-axis. Vertical bars and curve shoulders identify distances at which impacts of state highways or major roads became negligible or absent.

Figure 15. Distance to Nearest State Highway or Major Road



Distance relationships between the nearest secondary road and sage-grouse brood, summer, and winter occurrence, nest site selection, nest survival, and adult survival. Each curve or vertical bar is from a separate analysis (n=12). Curves relate to both y- and x-axis; bars relate only to x-axis. Vertical bars and curve shoulders identify distances at which impacts of secondary roads became negligible or absent.

Figure 16. Distance to Nearest Secondary Road (km)

We recognize that the information we relied on to establish decay curves in the HQT suggests substantial variability in the response of GRSG to the different disturbance classes, which made identifying a single distance of effect around those disturbance classes subjective at some level. For example, the distance effect of a producing well of the studies we considered ranged from 0.5 km to 6.4 km. Because of this inconsistency, we established a distance effect as the distance incorporating 75% of the results considered. This interpretation assumes that each of the studies considered accurately established the scale of effect, and that the range of actual effect distances is captured in the literature referenced—meaning GRSG are responding negatively to infrastructure within 0.5 km in a given situation whereas in another situation the species was responding negatively at 6.4 km. So the distance effect identified establishes that, given the range of impact distances reported, 75% of the time we will be over-estimating the actual distance, and 25% of the time we will be underestimating the actual distance. The inconsistency among studies is likely related to site-specific conditions influencing the scale of effect, for example human activity levels, line-of-site, noise, etc. As information relating to the mechanisms underlying the response of GRSG to anthropogenic features accumulates, we will be in a position to modify distance effects to more accurately estimate response on a site-by-site basis.

Disturbance types included in the site-level anthropogenic feature modifier were limited to those for which spatial data were available consistently across the study area. Literature was available with which to establish indirect distance effects for transmission lines, highways, unpaved roads, and producing natural gas/oil wells (Table 29). For other anthropogenic features, we applied literature-derived distances established for what we considered the most similar feature type (Table 29).

Table 30. Distance Effects and Weights for Anthropogenic Structures Considered in the HQT

Disturbance	Subtype	Weight	Distance (km)
Oil & Gas Wells	Active	100	2.1
	Inactive	10	0
Towers	Met towers	50	0
	Communication towers	50	0
Transmission Lines		100	3
Wind turbines		100	3
Mines	Active – Large	100	2.1
	Active – Small	100	0
	Inactive – Large	50	0
	Inactive – Small	10	0
Agriculture	Tilled	100	0
	Untilled	85*	0
Urban Development	Medium or High intensity	100	4.2
	Low intensity	75	1.5
Roads	Major roads	100	4.2
	Secondary roads	50	1.5

*The weight for untilled agriculture was reduced within 60 m of the edge of each field. A weight of 33 was assigned from the edge to 30 m, and a weight of 66 was assigned from 30 to 60 m into the field.

By identifying the anthropogenic features believed to represent the greatest degree of impact among those considered, we determined the upper end of the modifier scale (representing 100% disturbance). For all other, lesser, disturbances of anthropogenic features, we assigned a ***relative*** weight that was intended to represent the assumed proportion of disturbance in comparison with a disturbance with a weight of 100%. For example, we considered a major road to have no value to GRSG on that road itself, but that a secondary road provided some value (50% more) as compared to a major road. It is important to note that the weights are unitless and represent the comparative contribution of each disturbance to GRSG avoidance of an area.

Each digital map of an anthropogenic feature subtype was converted to a raster with cell size of 25 x 25-m. A point became a single cell, line data became a series of individual cells that approximated the line, and polygons became a group of contiguous cells approximating the extent of the original shape. The actual extent, or footprint, of each anthropogenic feature subtype was assigned the weight value for that feature type. For anthropogenic features with distance effects specified, the weight value decreased from the location of the feature out until it reached zero at the distance specified in the table above. This distance decay was applied as a sigmoid curve, using the following sigmoid function:

$$y = \frac{1}{1 + \exp(b(\frac{x}{c} - a))} \times w$$

where:

a - shifts curve to right or left
b - determines spread of curve, or slope of the rapidly decreasing part of curve.
c - scalar to adjust total distance of interest
x - distance in meters from impact
w - weight of impact (maximum value at 0 distance)

In this instance, a = 1, b = 5, c = half the full distance. Weight and full distance are provided in the table above. The distance decay was implemented in Python by first calculating Euclidean Distance for the disturbance raster and then applying the sigmoid curve equation to the Euclidean Distance output.

Methods for the effects of agriculture were slightly different than described above. GRSG may use the edges of untilled agricultural fields, based on their patterns of use in burned sagebrush habitats (Slater 2003); therefore we reduced the disturbance impact near untilled field edges. Slater (2003) found that 85% of GRSG observations in burned habitats were within 60-m of the edge those burns shared with sagebrush habitat. No brood-rearing observations occurred beyond 60-m in burned habitat, and three times more birds were observed at the edge, within sagebrush habitat, as were observed 30-m inside the disturbed habitat. Numbers of birds observed decreased by the same magnitude (3x) between 30 and 60-m inside the disturbed habitat. Only 15% of birds used areas further than 60-m into non sagebrush habitats (Slater 2003); therefore the interiors of untilled agricultural fields were assigned a weight of 85 (where 100 is the most disturbed).

The disturbance rasters as originally calculated were scaled from the maximum weight for that category (e.g., 10, 50, 75, 100) representing maximum disturbance, down to 0, representing no disturbance. Subtypes of anthropogenic features were combined first, by taking the maximum value at each raster cell from among the subtypes (e.g., active and inactive oil and gas wells). Next the raster for each anthropogenic features type was inverted and normalized to a scale of 0 (full impact) to 1 (no impact).

These rescaled rasters were multiplied together to produce the final disturbance modifier, where values also ranged from 0 (full impact) to 1 (no impact).

Table 31. Datasets Used to Represent Disturbance Features for the Site-level Anthropogenic Feature Modifier

Disturbance	Subtype	Description	Data source
Oil & Gas Wells	Active	Point locations for individual oil and gas wells. Active wells represent those locations where activity is occurring at the well pads on a regular basis. Activity level was determined based on well descriptions (see Table 31).	Colorado Oil and Gas Conservation Commission (2015). Oil and gas well locations. http://oil-gas.state.co,.us Source date: February 2015
	Inactive	Inactive wells represent locations where wells are recorded by activity is not occurring regularly at the location.	
Communication Towers		Point locations for communication towers. No met tower data were available in Colorado.	Federal Communications Commission (2012) http://wireless.fcc.gov/geographic/index.htm?job=licensing_database_extracts
Transmission Lines		This line dataset represents major electrical power transmission lines. It does not include minor transmission lines, such as those supplying individual developments or homes.	Hanser, S. 2004. Powerlines in the western United States. *.in* Sagemap, editor., http://sagemap.wr.usgs.gov/ftp/regional/usgs/powerlines_hf.shp.
Mines	Active – Large	Large mines have an area of 60 acres or more. Mines were only available as point locations with a reported size class and some mines had reported sizes. Each point was buffered by a circular radius resulting in a polygon corresponding to average sizes for small (80 m), medium (240 m), or large mines (1000 m), based on mines in that size category for which actual sizes were provided. Activity level was active according to status code of “A”.	Mine permit dataset. Colorado Division of Reclamation, Mining and Safety (2014) http://mining.state.co.us/Reports/Pages/GISData.aspx
	Active – Small	Small mines have an area of less than 60 acres. Activity level was active according to status code of “A”.	
	Inactive – Large	Large mines have an area of 60 acres or more. Activity level was inactive according to status code of “I”.	
	Inactive – Small	Small mines have an area of less than 60 acres. Activity level was inactive according to status code of “I”.	

Disturbance	Subtype	Description	Data source
Agriculture	Tilled	Polygons representing agriculture were identified from the referenced CDOW and GAP datasets. CDOW dataset categories included: Agriculture Land (Class 4), Dryland Ag (Class 5), Irrigated Ag (Class 6), Orchard (Class 7), and Soil (Class 93, bare soil and fallow ag fields). GAP categories included Agriculture (Class N80). Colorado Natural Heritage Program staff reviewed these agriculture boundaries against 2013 NAIP imagery and determined whether agriculture polygons were tilled or untilled. In some instances boundaries were modified.	Colorado Natural Heritage Program (2014). Updated agriculture and urban land cover for northwest Colorado. Colorado Division of Wildlife [CDOW]. 2003. Colorado Vegetation Classification Project (CVCP), land use/land cover. Raster digital data. Colorado Division of Wildlife, Department of Natural Resources, Denver, Colorado. http://ndis.nrel.colostate.edu/ftp/index.html USGS National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.
	Untilled	See description above for tilled agriculture.	
Urban Development	Medium or High intensity	Polygons representing urban development were identified from the referenced CDOW and GAP datasets. CDOW dataset categories included: Urban/Built Up (Class 1), Residential (Class 2) and Commercial (Class 3). GAP categories included Developed, Open Space-Low Intensity (Class N21) and Developed, Medium-High Intensity (Class N22). Colorado Natural Heritage Program staff reviewed these urban area boundaries against 2013 NAIP imagery and categorized high-density urban and commercial areas as medium or high intensity urban development. In some instances boundaries were modified.	Colorado Natural Heritage Program (2014). Updated agriculture and urban land cover for northwest Colorado. Colorado Division of Wildlife [CDOW]. 2003. Colorado Vegetation Classification Project (CVCP), land use/land cover. Raster digital data. Colorado Division of Wildlife, Department of Natural Resources, Denver, Colorado. http://ndis.nrel.colostate.edu/ftp/index.html USGS National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.
	Low intensity	See description above. Colorado Natural Heritage Program staff reviewed these urban area boundaries against 2013 NAIP imagery and categorized low density suburban and exurban development as low intensity urban development. In some instances boundaries were modified.	
Roads	Major roads	This line dataset represents Interstates, state highways and other major roads. Data codes included from the referenced dataset: S1100, S1200, S1630.	Census Bureau (2013). TIGER/Line shapefiles.https://www.census.gov/geo/maps-data/data/tiger-line.html
	Secondary roads	This line dataset represents narrower roads that may be unpaved and smaller streets and driveways. Data codes included: S1400, S1500, S1640, S1730, S1740, S1750, S1780.	

Table 32. Colorado Well Status Codes Present in the Oil and Gas Well Dataset used to Construct the Site-Level Anthropogenic Feature Index

Well status code	Well Description	Assigned activity level
AC	Active	Active
CM	Commingled (none present)	Active
DG	Drilling	Active
IJ	Injecting	Active
PR	Producing	Active
WO	Waiting on completion	Active
AB	Abandoned wellbore or completion	Inactive
AL	Abandoned location	Inactive
CL	Closed	Inactive
DA	Dry and abandoned	Inactive
PA	Plugged and abandoned	Inactive
SI	Shut in	Inactive
TA	Temporarily abandoned	Inactive
DM	Domestic well	Omitted
UN	Unknown??	Omitted
XX	Location	Omitted

Literature Used to Establish Anthropogenic Distance Effects

A list of all sources that contained data or statistical analysis directly assessing the spatial extent and decline of impacts of distance to major road, unpaved road, power line, or oil/natural gas well pad on GRSG ecology and demography is provided below. This list does not contain citations that we assessed that did not address our question of spatial extent of impacts, assessed the question but had statistically non-significant findings, presented insufficient information for us to derive specific values for distance-to-feature, or were classified as low quality / relevance because they assessed a minimal number of potential distances.

Braun, C. E. 1998. Sage-grouse declines in western North America: what are the problems? Proceedings of the Western Association of State Fish and Wildlife Agencies 78: 139-156.

Carpenter, J., C. Aldridge, and M. S. Boyce. 2010. Sage-grouse habitat selection during winter in Alberta. Journal of Wildlife Management 74(8): 1806-1814.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2014. Greater sage-grouse (*Centrocercus urophasianus*) select habitat based on avian predators, landscape composition, and anthropogenic features. The Condor: Ornithological Applications 116: 629-642.

Dzialak, M. R., C. V. Olson, S. M. Harju, S. L. Webb, J. P. Mudd, J. B. Winstead, and L. D. Hayden-Wing. 2011. Identifying and prioritizing greater sage-grouse nesting and brood-rearing habitat for conservation in human-modified landscapes. PLoS ONE 6(10): e26273.

Dzialak, M. R., C. V. Olson, S. M. Harju, S. L. Webb, and J. B. Winstead. 2012. Temporal and hierarchical spatial components of animal occurrence: conserving seasonal habitat for greater sage-grouse. Ecosphere 3(4): 30.

Fedy, B. C., K. E. Doherty, C. L. Aldridge, M. O'Donnel, J. L. Beck, B. Bedrosian, D. Gummer, M. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A. Mandich, D. Marshall, W. McKee, C. Olson, A. C. Pratt, C. C. Swanson, and B. L. Walker. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: an example using greater sage-grouse in Wyoming. Wildlife Monographs 190: 1-39.

Gillan, J. K., E. K. Strand, J. W. Karl, K. P. Reese, and T. Laninga. 2013. Using spatial statistics and point-pattern simulations to assess the spatial dependency between greater sage-grouse and anthropogenic features. Wildlife Society Bulletin 37: 301-310.

Gregory, A. J. and J. L. Beck. 2014. Spatial heterogeneity in response of male greater sage-grouse lek attendance to energy development. PLoS ONE 9(6): e97132.

Hanser, S. E., C. L. Aldridge, M. Leu, M. M. Rowland, S. E. Nielsen, and S. T. Knick. 2011. Greater sage-grouse: general use and roost site occurrence with pellet counts as a measure of relative abundance. *In* Hanser, S. E., M. Leu, S. T. Knick, and C. L. Aldridge (eds). Sagebrush ecosystem conservation and management: ecoregional assessment tools and models for the Wyoming Basins. Allen Press, Lawrence, Kansas.

Harju, S. M., M. R. Dzialak, R. C. Taylor, L. D. Hayden-Wing, and J. B. Winstead. 2010. Thresholds and time lags in effects of energy development on greater sage-grouse populations. Journal of Wildlife Management 74(3): 437-448.

Hess, J. E. and J. L. Beck. 2012. Disturbance factors influencing greater sage-grouse lek abandonment in north-central Wyoming. Journal of Wildlife Management 76: 1625-1634.

Holloran, M. J. 2005. Greater sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. Ph.D. dissertation, University of Wyoming, Laramie, Wyoming.

Holloran, M. J., R. C. Kaiser, and W. A. Hubert. 2010. Yearling greater sage-grouse response to energy development in Wyoming. Journal of Wildlife Management 74(1): 65-72.

LeBeau, C. W. 2012. Evaluation of greater sage-grouse reproductive habitat and response to wind energy development in south-central Wyoming.

Slater, S. J. 2003. Sage-grouse (*Centrocercus urophasianus*) use of different-aged burns and the effects of coyote control in southwestern Wyoming. MS Thesis, University of Wyoming, Laramie, USA.

Tack, J. D. 2009. Sage-grouse and the human footprint: implications for conservation of small and declining populations. M.S. Thesis, University of Montana, Missoula, Montana.

Taylor, R. L., J. D. Tack, D. E. Naugle, and L. Scott Mills. 2013. Combined effects of energy development and disease on greater sage-grouse. PLoS ONE 8(8): e71256.

Webb, S. L., C. V. Olson, M. R. Dzialak, S. M. Harju, J. B. Winstead, and D. Lockman. 2012. Landscape features and weather influence nest survival of a ground-nesting bird of conservation concern, the greater sage-grouse, in human-altered environments. Ecological Processes 1:1.

Appendix D. Landscape Disturbance Index: Methods for HQT Disturbance Calculations

The Landscape Disturbance Index (LDI) represents the density of anthropogenic features or disturbance at a landscape scale (3.2-km radius surrounding a location) and is applied as a 2nd order modifier in the HQT. This landscape scale represents the response of GRSG populations to disturbance and is based on literature associated with leks. The modifier ranges in value from 0 to 1, where 0 corresponds to locations that are highly disturbed and likely no longer provide suitable GRSG habitat (i.e., above an upper disturbance threshold), 1 corresponds to locations that have no or minimal disturbance (i.e., below a lower disturbance threshold), and values greater than 0 or less than 1 continuously represent intermediate levels of disturbance.

Upper and lower disturbance thresholds were identified through a literature review of GRSG lek response to roads and oil and gas wells. These thresholds were applied across all disturbance types, because literature is lacking to describe responses of GRSG to densities of other disturbance types, such as wind turbines or mines. Therefore, we assumed that GRSG subpopulation response to any anthropogenic feature would be the same as the response to roads and oil and gas wells. The LDI could be updated in the future as information becomes available regarding GRSG response to density of other types of anthropogenic feature.

We used a simple criterion for inclusion of literature results in this analysis. To be considered pertinent, a study had to either address density of disturbance (e.g., number of oil and gas wells, linear distance of roads, etc.) as a continuous non-linear curve (to allow for identifying points at which impacts on GRSG leks began to occur and at which impacts come high and pronounced) or assess the impact of disturbance density within multiple buffer distances (i.e., treat density impacts as quasi-continuous). Studies that treated density as continuous but linear, or did not present results on density relationships, were not considered here. Six studies met our criteria; two of these studies had several independent analyses that informed our assessment of disturbance density (Holloran 2005, Tack 2009, Harju et al. 2010, Hess and Beck 2012, Taylor et al. 2013, Gregory and Beck 2014).

The LDI is intended to represent the cumulative impact of disturbance from anthropogenic features across the landscape on GRSG populations. Therefore we relied on the lek-based literature because GRSG responses, as measured via facets of lek ecology (e.g., peak attendance, lek activity status, etc.), represent long term and large-scale population responses to cumulative impacts on the surrounding landscape. For each study that met our inclusion criteria, we identified the density of disturbances at which point impacts became apparent. We then identified the density of disturbances at which point impacts became pronounced and/or remained constant at higher levels of disturbance density. The median value across all analyses for each of these two points represents the lower and upper thresholds for cumulative landscape disturbance within the LDI. All results were standardized to a common density metric (i.e., number of wells / km^2 or km of roads / km^2). Results from the LDI literature analyses are presented in Table 32.

Each upper or lower threshold was represented by an amount of anthropogenic feature per unit area (Table 32). These areas were based on numbers of well pads and length of road. The studies consulted typically used a well pad as a surrogate for that well pad plus associated roads and power lines. Rather than attempt to define a typical area of roads associated with a well pad, we represented a well pad as only the pad itself and combined that well density threshold with a separate road density threshold, both identified from the literature described above. We assigned an area per well pad and a road width in order to spatially represent the thresholds (Table 32). These areas were assigned to be consistent with the 25-m raster resolution of infrastructure GIS datasets used to construct the LDI. For example, roads were assigned a width of 30 m, even though actual widths are more typically 10 m. This was done to avoid overestimating disturbance thresholds in the LDI.

To calculate the LDI, first we mapped the cumulative disturbance footprint associated with anthropogenic features (Tables 33, 34). Footprints of individual anthropogenic feature types were combined so that presence of one or more anthropogenic feature types within a raster cell equaled a footprint value of present, or 1. Representation of disturbance footprints was constrained by the 25-m raster resolution associated with statewide land cover datasets for Colorado (i.e., the smallest footprint possible for any point feature was 25-m by 25-m.

Second, we calculated disturbance density from the cumulative disturbance footprint for a 3.2-km radius surrounding each raster cell, which is median best distance from studies that evaluated disturbance density effects over multiple window sizes (Walker et al. 2007, Tack 2009, Hess and Beck 2012, Taylor et al. 2013, Gregory and Beck 2014). For each raster cell, we calculated the sum of all cells with a disturbance footprint that occurred within a 3.2-km radius of the focal cell, using the Focal Sum tool in Arc Map 10.1 (ESRI, 2015). Raster cells beyond the state boundary were assigned a value of “No Data” so that edge calculations only included the values available within the study extent. Sums were converted to areas of disturbance per km^2 and thresholds were applied (Table 32). Disturbance densities below the lower threshold were assigned a value of 1, densities above the upper threshold were assigned a value of 0, and intermediate values were scaled to range between 0.01 and 0.99.

Table 33. Disturbance density thresholds applied for the Landscape Disturbance Index in Colorado

	Lower density threshold	**Upper density threshold**
Median well density [A]	0.39 wells/km^2 (1.01 wells/mi^2)	2.54 wells/km^2 (6.58 wells/mi^2)
Median road density [B]	0.94 km road/km^2	3.73 km road/km^2
Combined road and well density	0.03 km^2/ km^2	0.10 km^2/km^2
Density threshold applied to 3.2 km radius	0.82 km^2/ 32.2 km^2 (203 acres/12.4 mi^2)	3.07 km^2/ 32.2 km^2 (759 acres/12.4 mi^2)
Area associated with density threshold at 3.2-km radius	203 acres; equivalent to 2.5% disturbance	759 acres; equivalent to 9.5% disturbance

[A] 5666 m^2 (1.4 acre) was used to represent the footprint per well pad.
[B] 0.025 km^2 (1 km, 25-m wide) was used to represent the footprint per kilometer of road.

Table 34. Disturbance footprint determination for the Landscape Disturbance Index in Colorado

Disturbance feature	**Feature type**	**Footprint per feature**	**How disturbance footprint was determined**
Active Oil & Gas Wells	point	75 m x 75 m	Average well pad size was 0.5 ha (1.2 acre). A 75-m x 75-m footprint equates to 0.56 ha (1.4 acre). Multiple well pads were measured throughout development fields using high-resolution aerial imagery. For pads with multiple wells, pad size was divided by number of wells. Only active wells were included due to associated levels of activity.
Towers	point	25 m x 25 m	Towers typically range in size from 5x 5 m to 30 x 30 m.
Transmission Lines	line	25 m width	Transmission lines are typically 10 – 20 m wide.
Urban	polygon	Polygon extent	The polygons include low, medium and high intensity development categories.
Roads – Interstate Highways	line	50 m width	The width of Interstate 70, including the medians, ranges from 40 m to 60 m. Measurements were made using high-resolution aerial imagery.
Roads – State Highways and Secondary Roads	line	25 m width	State highways are ~10 m wide, and secondary roads are typically 10 m wide or less. Measurements were made using high-resolution aerial imagery.
Active Mines	point	Variable, based on mine size	Only active mines were included due to associated levels of activity. Each point was buffered by a circular radius resulting in a polygon corresponding to average sizes for small (80 m), medium (240 m), or large mines (1000 m), based on mines in that size category for which actual sizes were provided. Size categories were defined in the original dataset.

Table 35. Datasets used to represent disturbance features in the Landscape Disturbance Index

Disturbance feature	Description	Data source
Active Oil & Gas Wells	Point locations for individual oil and gas wells. Active wells represent those locations where activity is occurring at the well pads on a regular basis. Activity level was determined based on well descriptions (see Table 35).	Colorado Oil and Gas Conservation Commission (2015). Oil and gas well locations. http://oil-gas.state.co,.us Source date: February 2015
Towers	Point locations for communication towers.	Federal Communications Commission (2012) http://wireless.fcc.gov/geographic/index.htm?job=licensing_database_extracts
Transmission Lines	This line dataset represents major electrical power transmission lines. It does not include minor transmission lines, such as those supplying individual developments or homes.	Hanser, S. 2004. Powerlines in the western United States. *.in* Sagemap, editor., http://sagemap.wr.usgs.gov/ftp/regional/usgs/powerlines_hf.shp.
Urban	This polygon dataset represents areas of low to high intensity urban development. Polygons representing urban development were identified from the referenced CDOW and GAP datasets. CDOW dataset categories included: Urban/Built Up (Class 1), Residential (Class 2) and Commercial (Class 3). GAP categories included Developed, Open Space-Low Intensity (Class N21) and Developed, Medium-High Intensity (Class N22). Colorado Natural Heritage Program staff reviewed these urban area boundaries against 2013 NAIP imagery and in some instances boundaries were modified to better reflect development patterns.	Colorado Natural Heritage Program (2014). Updated agriculture and urban land cover for northwest Colorado. Colorado Division of Wildlife [CDOW]. 2003. Colorado Vegetation Classification Project (CVCP), land use/land cover. Raster digital data. Colorado Division of Wildlife, Department of Natural Resources, Denver, Colorado. http://ndis.nrel.colostate.edu/ftp/index.html USGS National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.
Roads – Interstate Highways	This line dataset represents Interstate 70 in Colorado, subset from data code S1100.	Census Bureau (2013). TIGER/Line shapefiles.https://www.census.gov/geo/maps-data/data/tiger-line.html
Roads – State Highways and Secondary Roads	This line dataset represents other highways and secondary roads. Data codes included from the referenced dataset: S1200, S1630, S1400, S1500, S1640, S1730, S1740, S1750, S1780	Census Bureau (2013). TIGER/Line shapefiles.https://www.census.gov/geo/maps-data/data/tiger-line.html
Active Mines	Point locations for active mine permits Active mines (code =A) were selected from this dataset. Size representation of mines of these mines is described in Table 33.	Mine permit dataset. Colorado Division of Reclamation, Mining and Safety (2014) http://mining.state.co.us/Reports/Pages/GISData.aspx

Table 36. Colorado Well Status Codes Present in the Oil and Gas Well Dataset used to Construct the Landscape Disturbance Index

Well status code	Well Description	Assigned activity level
AC	Active	Active
CM	Commingled (none present)	Active
DG	Drilling	Active
IJ	Injecting	Active
PR	Producing	Active
WO	Waiting on completion	Active
AB	Abandoned wellbore or completion	Inactive
AL	Abandoned location	Inactive
CL	Closed	Inactive
DA	Dry and abandoned	Inactive
PA	Plugged and abandoned	Inactive
SI	Shut in	Inactive
TA	Temporarily abandoned	Inactive
DM	Domestic well	Omitted
UN	Unknown??	Omitted
XX	Location	Omitted

Appendix E. Forb and Grass Species List

Monson, S.B. 2005. Restoration manual for Colorado sagebrush and associated shrubland communities. Colorado Division of Wildlife, Colorado, USA.

(See this document for the value of each species for food and cover.)

Species Name	Common Name
Forbs	
Achillea millefolium	Western yarrow
Agoseris glauca	False dandelion
Antennaria spp.	Everlasting
Aster chilensis	Pacific aster
A. glaucodes	Blueleaf aster
Balsamorhiza hookeri	Hairy balsamroot
B. macrophylla	Cutleaf balsamroot
B. sagittata	Arrowleaf balsamroot
Calochortus spp.	Sego lily
Castilleja spp.	Indian paintbrush
Collomia linearis	Tiny trumpet
Crepis spp.	Hawksbeard
Erigeron spp.	Fleabane
E. umbellatum	Sulfur buckwheat
Eriogonum heracleoides	Wyeth buckwheat
Gayophytum spp.	Groundsmoke
Grindelia squarrosa	Curlycup gumweed
Hedysarum boreale	Utah sweetvetch
Lactuca serriola	Prickley lettuce
Lathyrus spp.	Pea
Lepidium spp.	Pepperweed
Linanthus spp.	Gilia
Linum perenne	Blue flax
Lomatium spp.	Desertparsley
Lupinus spp.	Lupine
Medicago sativa	Alfalfa
Mimulus spp.	Monkey flower
Orobanche spp.	Broomrape
Penstemon eatonii	Firecracker penstemon
P. palmeri	Palmer penstemon
Phlox spp.	Phlox
Potentilla spp.	Cinquefoil
Sanguisorba minor	Small burnet
Senecio spp.	Groundsel
Sphaeralcea spp.	Globemallow
Taraxacum officinale	Common dandelion
Tragopogon spp.	Salsify
Trifolium spp.	Clover

Species Name	Common Name
Grasses	
Agropyron Dasytachyum	Thickspike wheatgrass
A. desertorum	Std/desert wheatgrass
A. intermedium	Intermediate wheatgrass
A. cristatum	Crested wheatgrass
A. fragile	Siberian wheatgrass
A. smithii	Western wheatgrass
A. spicatum	Bluebunch wheatgrass
A. trachycaulum	Slender wheatgrass
Bouteloua gracilis	Blue grama
Bromus carinatus	Mountain brome
B. inermis	Smooth brome
Dactylis glomerata	Orchardgrass
Elymus cinereus	Great Basin wildrye
E. junceus	Russian wildrye
Koeleria macrantha	Junegrass
Oryzopsis hymenoides	Indian ricegrass
Poa fendleriana	Muttongrass
P. secunda	Sandberg bluegrass
Sitanion hystrix	Squirreltail
Sporobolus cryptandrus	Sand dropseed
Stipa comata	Needle-and-thread grass
S. lettermanii	Letterman's needlegrass

Appendix F. Field Data Collection Methods

The methods outlined below are for field data collection of attributes associated with the 4^{th} order scale, which defines habitat conditions at the site of proposed activities. The attributes in Table 36 collected for the habitat model result in functional acre scores for specified habitat areas.

Table 37. Methods for Data Collection of Field Attributes

<table>
<tr><th>ATTRIBUTE</th><th>RESOURCE</th><th>GRSG SEASON</th><th>ATTRIBUTE DATA COLLECTION SUMMARY</th></tr>
<tr><td>Sagebrush Height</td><td rowspan="5">Cover / Refugia</td><td>Breeding</td><td>The sagebrush height is measured for plants intersecting the transect line (see also sagebrush canopy cover).</td></tr>
<tr><td>Sagebrush Canopy Cover</td><td>Breeding</td><td>The percent canopy cover is estimated with line intercept (% of shrub canopy intersecting transect line).</td></tr>
<tr><td>Sagebrush Shape</td><td>Breeding</td><td>This measures the growth-form of sagebrush for plants intersecting the transect line.</td></tr>
<tr><td>Perennial Grass Height</td><td>Breeding, Summer</td><td>The grass height is measured for plants intersecting the transect line (see also grass canopy cover).</td></tr>
<tr><td>Perennial Grass Cover</td><td>Breeding, Summer</td><td>Percent cover of perennial grasses is determined from sampling over a standard-sized area of 1 m^2. Percent cover of perennial grasses is estimated within 1 m^2 quadrats at 10 meter increments along a 50 m transect.</td></tr>
<tr><td>Forb Cover</td><td rowspan="3">Foraging</td><td>Breeding, Summer</td><td>Percent cover of forbs is determined from sampling over a standard-sized area of 1 m^2. Percent cover of forbs is estimated within 1 m^2 quadrats at 10 meter increments along a 50 m transect.</td></tr>
<tr><td>Forb Species Richness</td><td>Breeding, Summer</td><td>Presence of forbs is determined from sampling over a standard-sized area of $1m^2$. Species are tallied using a 1 m^2 quadrat at 10 meter increments along a 50 m transect.</td></tr>
<tr><td>Specific Forb Species Presence</td><td>Breeding, Summer</td><td>Presence of forbs is determined from sampling over a standard-sized area of $1m^2$. Species are tallied using a 1 m^2 quadrat at 10 meter increments along a 50 m transect.</td></tr>
<tr><td>Sagebrush Height</td><td rowspan="2">Cover / Refugia and Foraging</td><td>Winter</td><td>The sagebrush height is measured for plants intersecting the transect line (see also sagebrush canopy cover).</td></tr>
<tr><td>Sagebrush Canopy Cover</td><td>Winter</td><td>The percent canopy cover is estimated with line intercept (% of shrub canopy intersecting transect line).</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="3">Invasive Grass Canopy Cover</td><td>Percent cover of invasive grasses is determined from sampling over a standard-sized area of 1 m^2. Percent cover of invasive grasses is estimated within 1 m^2 quadrats at 10 meter increments along a 50 m transect.</td></tr>
<tr><td colspan="3">Presence of Facultative Forb Species</td><td>Presence of facultative forbs is measured for plants intersecting the transect line.</td></tr>
</table>

Materials Needed

Hand-held GPS unit, preloaded with sample points
Field maps, using aerial photos as background
Tripod-mounted laser pointer (or pin flag if laser not available)
Two 50-meter tapes or one 100-meter tape
PVC or wooden 1 m^2 quadrat
1 meter ruler
Plant field guides for the area
1 meter tape

Map Unit Delineation and Sampling Intensity

In order to properly assess functional acreage, the site and its map units must be clearly defined. This step is essential because the “currency” of this evaluation, functional acres, is tied to a unit of area. The project area is the area within which functional acres are assessed. Debit and credit project areas (or sites) are defined by the footprint of the project (i.e. for debit projects the land on which the development will occur, and for credit projects the area of land that is outlined in the participant’s contract) plus the area of behavioral avoidance distance effect of any anthropogenic or natural feature (e.g. transmission line or conifer cover) that occurs on the site.

Map units are predefined for all Exchange participants using a systematic grid with each grid cell measuring 160 acres. Within each map unit, a specific plot sampling location in the map unit is also predesignated. Vegetation attributes are measured at each plot sampling location within each map unit.

Modifying Sampling Location Based on Field Observations

As noted above, plot sampling locations are predesignated for all habitats within the Exchange. However, if it is determined during field work that the sampling location is located in non-habitat such as a building or road, the field technician should generate a random sampling location. The field technician should move at least 200 feet from the area, throw a Frisbee or other identifiable object a short distance and use that as the center stake of the transect line.

Although seasonal habitat use by GRSG is described in the HQT, by no means is the HQT a comprehensive review of the available literature on GRSG habitat use. Practitioners of the HQT should have a working knowledge of GRSG ecology and habitat use. This can be accomplished by conducting a comprehensive review of the literature or consulting closely with GRSG experts or local agency biologists.

Timing of Transect Data Collection

To best equate and compare data collection in map units with breeding, summer, and winter habitat attributes, every effort should be made to collect data during those seasons (with the exception of winter; winter data can be collected any time of year). Data collection should be season specific because of the temporal changes that occur in herbaceous heights and plant species presence and identification. However, it may not be possible to conduct more than one visit to a given project. Thus, data collection for the vegetation attributes for the breeding season may occur in May through mid-July. Because vegetation phenology varies during this time period, for repeated measurements at a given site, if possible field data should be collected within the same three week period or under similar phonological conditions. Data collection for the summer season vegetation attributes may occur June through mid-September. Data collection for the winter season vegetation attributes can occur anytime of the year because sagebrush height does not vary significantly. Topographic measurements can occur at any time. A useful manuscript to consult that describes how GRSG habitat measurements are collected is Connelly et al. (2003) or Appendix C-1 (Greater Sage-grouse Rangewide Steering Committee 2008).

In some cases Exchange participants may have very limited or no access to habitats within the project area or they may not be able to collect field data during the appropriate seasons. In these situations, Exchange participants would input all data from desktop analyses (Steps 1-5 as described in section 4.1), and field data inputs would be assigned maximum habitat value (1.0). This is similar to the high quality habitat scenario from the debit project example in section 5.1. The HQT Calculator includes this option to maximize values for all field measurements for debit projects only.

Sampling Location Quality Check / Site Reconnaissance

Upon arrival at the site, field crews should walk the site together to confirm that the predesignated plot sampling locations are not located in non-habitat areas. Crews should be prepared to modify the plot sampling location in the field based on observations, and should also come to a common understanding of the plants present, and the protocol that follows. The sampling location should be recorded once it becomes final.

The locations of anthropogenic features should be compared against aerial imagery so that features can be added or removed as necessary via desktop processing.

Transect Layout and Initial Measurements

The core layout for the measurements that follow will be a 50-m transect. Field crews should navigate to the sample point via hand-held GPS. Select a random direction by blindly spinning a compass wheel, flipping a pen in the air, or other commonly used method. Insert a stake in the ground, and lay out a 50-m transect along the direction chosen, taking care to lay it over any shrubs and under or through trees along the transect.

Fill in all fields at the top of the data sheet, with the date, observer initials, site name (a unique identifier assigned by the workers), the site UTMs (including UTM Zone and Datum), and whether the site is arid or mesic. Be sure to record all photo numbers and the camera used throughout data collection. At the midpoint of the transect (25-m) record the slope and aspect of the map unit.

NOTE: During the course of sampling, a 1 m^2 quadrat and tripod-mounted laser may be used to sample cover, vegetation composition, and other attributes. (If a laser is not available or is difficult to use because of the thickness and/or height of sagebrush, crews should use standard point intercept methods, e.g. with a pin flag or using the thin metal edge of a meter stick. It should be decided *a-priori* on which side of the transect the sampling will occur (e.g. the right side as seen from 0 to 50 meters), and all unnecessary foot traffic should occur on the other (e.g. left) side of the transect line so as not to trample vegetation.

Grass, Forb, and Shrub Measurements with Quadrat

Using a 1m^2 quadrat, take the following measurements on the right side of the transect line, by placing the quadrat every 10 meters from 10 to 50 (five measurements total).

- Grass height. Height is the estimate of the height above the ground at which the preponderance of grass biomass is present (this is important for both forage and hiding cover for GRSG) (Connelly et al. 2003). It is NOT necessarily the total height of the grass. Grasses with different morphologies will have different bulk heights. For example, grasses with large and diffuse seed heads (such as Indian ricegrass) will likely have the bulk height near the top of the plant; bunch grasses with small seed heads will likely have it near the bottom. Measure this in centimeters with a ruler.
- Grass Cover. Estimate the percent cover of perennial grass species present inside the quadrat; grass cover should be measured by overall grass cover (aerial cover), as opposed to the basal cover only.
- Invasive Grass Cover. Estimate the percent cover of cheatgrass (*Bromus tectorum*) present inside the quadrat.
- Number of Forb Species Present. Tally the number of different annual and perennial forb species present inside the quadrat.
- Forb Cover. Estimate the percent cover of perennial forbs species present inside the quadrat.

- Height of Sagebrush. Measure the height (excluding the flower inflorescence) of the nearest sagebrush plant within one meter of the meter mark where the quadrat is located (5, 10, 15, etc.). If there is NO sagebrush plant within one meter of the mark, put a dash in this field.

Sagebrush Cover via Line-Intercept

Record the start and stop points of the sagebrush intersections along the 50-m tape. Consider a length of sagebrush unbroken if there is no more than a 5.0 cm. gap. Measure intersections of sagebrush overstory. The total of all the lengths over the 50 meters will enable an easy calculation of percent canopy cover of sagebrush.

- Each unique sagebrush shrub is counted, even if the transect crosses multiple shrubs in a cluster.
- Completely dead shrubs do not get counted.
- Cover lengths of live shrubs are measured along a 50m transect for every span of live vegetation less than 5 cm. Spans that are less than 5cm between live vegetation are not measured. Multiple measurements may be taken for single clusters.

Food and Cover Abundance

On the data sheet, record the abundance of the plants listed. A pre-study analysis of the study area will determine if all of these species listed in Appendix D are applicable. Without taking too much time, record a qualitative estimate of the relative abundance of the plants over the entire map unit, not just what may or may not have fallen in the quads or along the transect.

Appendix G. Field Datasheet

EcoMetrix

SAGE-GROUSE Attribute Measurements

Revised 12-07-14 (JKo)

Site Name:			
Map Unit ID:	Date:		Observers:
Transect #:	Transect UTM E:		Transect UTM N:
Transect Sample Bearing (°):	Camera / Photo #'s:		
Site is: ARID or MESIC (circle one)	% Slope: <5% or >5% (Circle one)		Aspect (°):

LINE INTERCEPT (SHRUB COVER)

Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading	Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading
1					11				
2					12				
3					13				
4					14				
5					15				
6					16				
7					17				
8					18				
9					19				
10					20				

Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading	Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading
21					31				
22					32				
23					33				
24					34				
25					35				
26					36				
27					37				
28					38				
29					39				
30					40				

Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading	Sagebrush Spp. Plant #	Start	Stop	Shrub Height (cm)	Columnar / Spreading
41					51				
42					52				
43					53				
44					54				
45					55				
46					56				
47					57				
48					58				
49					59				
50					60				

Notes for Line Transect:

DAUBENMIRE PLOTS (HERBACEOUS COVER)

Record percent cover

Plot #	Presence of Facultative Species*	Grass Height (cm)	% Grass Cover	% BROTEC Cover	# of Forb Species	% Forb Cover	100% Noxious Weed Cover? (Y/N)	Comments
1								
2								
3								
4								
5								

Total number of unique forb species along transect:

Sum total number of unique forb species found across all plots within this transect:

Notes for Daubenmire plots and unknown species codes/descriptions:

Appendix H. Evaluating the HQT Calculator and Quantification Model

The HQT Calculator is a spreadsheet that performs the functional acre calculations using field data and the information contained in this HQT Methods document. It contains the scoring curves and scoring tables in Appendix A and combines performance scores for the attributes in weighted scoring algorithms based on the relationships identified in the concept model (see Section 4.0 for a detailed description of the scoring approach).

EcoMetrix Solutions Group (ESG) conducted two distinct analyses to evaluate the accuracy of the HQT Calculator and sensitivity-to-findings of the quantification model. To evaluate the accuracy of the Calculator, Colorado Parks & Wildlife (CPW) vegetation data from GRSG use and non-use sites in Colorado was input into the Calculator and the outputs were compared against CPW staff knowledge about those sites. To evaluate the sensitivity-to-findings within the model, an analysis was conducted using a Bayesian Belief Network, which identifies the level of significance associated with each input attribute. Each analysis is explained in greater detail below.

Analysis Using CPW Data

CPW shared vegetation data from approximately 125 use and non-use sites from the North Park and Parachute-Piceance-Roan (PPR) populations in Colorado. The PPR data included nest (breeding habitat) sites and brood-rearing (summer habitat) sites; the North Park data included nest sites (breeding habitat), random sites, brood sites (summer habitat), unsuccessful female sites (summer habitat), and use and random sites for winter habitat.

The vegetation data for all sites was input directly into the Calculator. Because some data were missing, the following assumptions were made and approved by CPW staff:

- All sites were mesic (thus the "Arid" portion of the model is not represented in this analysis);
- Each map unit area is 1 acre;
- At least 5% sagebrush was present within 300 meters of the sample;
- Sagebrush shape is "spreading" Big Mountain sage;
- No sites with 100% noxious weed cover;
- No anthropogenic structures or disturbances;

The functional acre outputs for the sites closely matched CPW staff knowledge and expectations about the sites. Specified winter sites at North Park scored better on average than random sites (20% for random sites and 40% for winter sites). North Park sites defined as breeding had an average score of

60% and the average score for random sites was 50%. North Park sites defined as brood rearing (summer) had an average score of 80% and the average score for random sites was 70%. Sites at PPR scored evenly on average against random sites (70% for breeding and 80% for brood rearing). While scores for all seasons for successful and unsuccessful nesting and brood-rearing events were very similar, comparisons were determined to be inconclusive since disturbance variables were not recorded.

Sensitivity-to-Findings Analysis

A Bayesian Belief Network (BBN) is a graphical representation of a probabilistic dependency model which, as applied here, depicts the causal relations between ecological factors and habitat suitability for conditions related to breeding, summer and winter conditions for GRSG. A BBN consists of a set of interconnected nodes, where each node represents a variable in the dependency model, and connecting arcs represent the causal relationships between these variables. In this case, each node represents a vegetation attribute. A BBN was developed using the HQT concept model to represent the causal web of attributes that influence breeding, summer, and winter habitat quality.

Because BBN analysis allows for the propagation and reporting of uncertainty throughout the models, one of the most effective methods to identify the level of significance associated with each input attribute is the sensitivity-to-findings analysis, which is based on this uncertainty. The sensitivity-to-findings analysis measures the reduction in uncertainty associated with findings in each of the input attributes. This analysis is particularly significant as a model development tool because it helps a development team determine whether or not the model is performing as expected in terms of input weighting. As such the analysis was conducted on the vegetation attributes only; it did not include the LDI and LQI modifiers. It is important to note that in this case, these sensitivity values represent the potential contribution that a single finding may have from a single attribute in the model.

In the tables below, variance reduction is the expected reduction of variance between the predicted real value from the output node and the expected real value as a result of a finding in one of the input nodes. This assessment can be used as a measure of relative input variable importance to the final score's reduction in uncertainty. An associated percentage is reported which represents the percent reduction in variance that can be expected in the output node values from a finding in the input node. Because different findings in a node will result in different levels of variance reduction, and the percentage value is a representation of the node as a whole, the percentage values for all nodes will not sum to 100, which is to be expected.

The results illustrate that the algorithms for combining attributes and the weightings assigned to the individual attributes appropriately characterize the habitat conditions required by GRSG for each seasonal habitat type. Some attributes have very little impact on the functional scores. However, the Science Team is cautious about focusing on only one specific component of the model for potential adjustments or even removal. As part of the adaptive management process, the Science Team will assess the algorithms, weights, and actual attributes within the context of the entire quantification approach and knowledge of the species prior to making adjustments to the models.

Winter Habitat Model

Sensitivity of Winter 'Score' to a finding at another node:		
Node	**Variance Reduction**	**Percent**
Conifer Cover	0.03021	44.9%
Aspect	0.01102	16.4%
Sage Brush % Cover	0.008427	12.5%
Sage Brush <5% Modifier	0.007987	11.9%
Sage Brush Height (cm)	0.004655	6.92%
Topography Percent	0.00000103	0.00153%

Summer Habitat Model

Sensitivity of Summer 'Score' to a finding at another node:		
Node	**Variance Reduction**	**Percent**
Presence of Mesic Forbs	0.00538	14.5%
Presence of Sagebrush	0.00538	14.5%
Grass % BRTE	0.004334	11.7%
100% Noxious Weed Cover	0.0001627	0.44%
Forbs Percent Cover	0.0000777	0.21%
Forbs Number of Species	0.00004697	0.13%
Grass Height (cm)	0.00003599	0.1%
Grass (%) Canopy Cover	0.00003244	0.09%
Is site Arid or Mesic?	0.0000009515	0.003%

Breeding Habitat Model

Sensitivity of Breeding 'Score' to a finding at another node:		
Node	**Variance Reduction**	**Percent**
Grass % BRTE	0.002264	19.7%
Conifer Cover	0.001405	12.2%
Distance to Lek (km)	0.001208	10.5%
Sage Brush % Cover	0.000309	2.69%

Sage Brush <5% Modifier	0.000247	2.15%
100% Noxious Weed Cover	0.000104	0.9%
Forbs Percent Cover	0.000039	0.34%
Grass Height (cm)	0.000038	0.33%
Forbs Number of Species	0.000033	0.29%
Grass (%) Canopy Cover	0.000021	0.18%
Is site Arid or Mesic?	0.000012	0.1%
Sage Brush Height (cm)	0.000009	0.08%
Sage Brush Shape	0.0000000063	0.00006%

Appendix I. Literature Cited

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