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

Scientific Methods Document, Version 3

Acknowledgements

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Contents

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 3* (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 Wyoming Conservation 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, the HQT calculates a separate functional acre score 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. To function in Wyoming, the Exchange must work in tandem with federal and state mitigation regulations (e.g. Sage-Grouse Core Area Protection, Wyoming Exec. Order No. 2011-5). Appendix X describes the relationship of the Habitat Quantification Tool to the Wyoming Core Areas Strategy and Executive Order.

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 credits and debits are calculated in the same way (i.e. the HQT is symmetrical) 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 knows as “behavioral avoidance,” by accounting for distance-effects associated with anthropogenic infrastructure (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

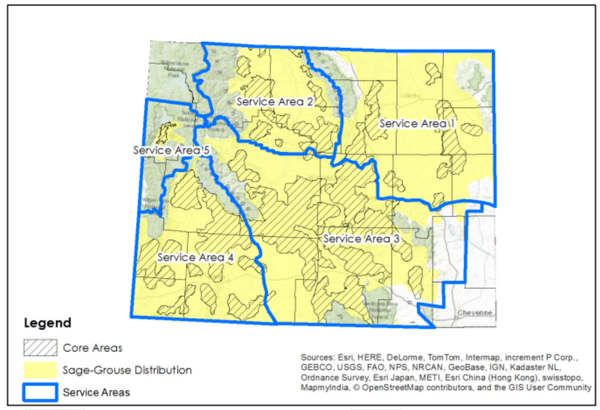
The HQT was developed to account for the habitat characteristics or attributes, both natural and anthropogenic, which influence GRSG habitat selection across multiple scales. These habitat characteristics were based on different orders of selection (Stiver et al. 2010), which represent four levels of 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 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:

- 1st order selection represents the geographic range of the GRSG population of interest—1st order habitat attributes are those necessary for the species to occur.
- Within this geographic range, 2nd order selection is based on habitats required by subpopulations; for example all habitats necessary to support the GRSG associated with that subpopulation.
- 3rd 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.
- 4th order selection establishes the food and cover attributes at particular sites.

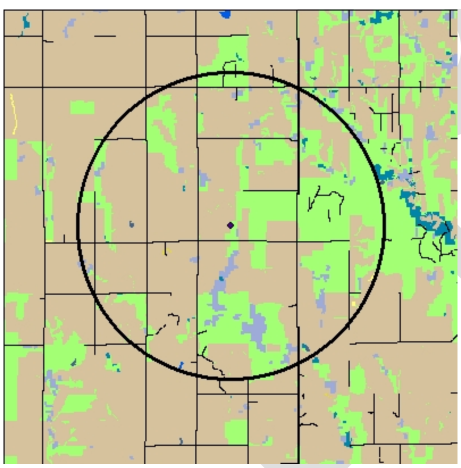
Although the orders of selection are described as stand-alone, these orders are inherently related and the value of a location for GRSG as quantified at a given order is only as good as the values measured at other orders. For example, the habitat conditions within a patch of sagebrush (4th order) may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

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

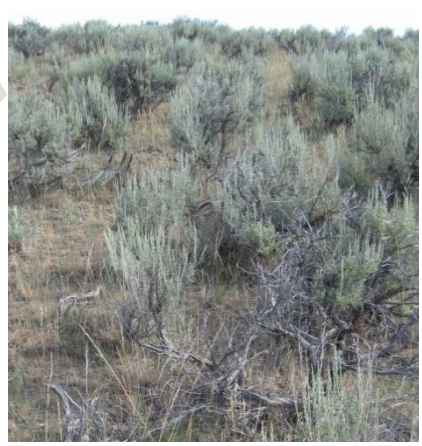


Figure 1. Orders of Selection Specific to the Wyoming Conservation Exchange for Greater Sage-Grouse

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 Wyoming 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 across the State (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 E) 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 the HQT considers specific vegetation features that are known to be particularly important to GRSG when evaluating habitat quality.

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, and the HQT does not consider transitional periods where habitat selection is less uniform (Connelly et al. 2000). 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) (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 Wyoming

The 1st order is the current estimated occupied range (EOR) of GRSG in Wyoming. The species' distribution is thought to have varied substantially over the species' history, and GRSG currently occupy 56% of their potential pre-settlement distribution (Schroeder et al. 2004). The reduction in distribution in North America appears to be a consequence of altered sagebrush habitat quality and quantity (Schroeder et al. 2004). Documented changes to the EOR will be tracked and incorporated into the HQT over time through the adaptive management process described in the Exchange Manual.

Credits and debits are tracked, exchanged and reported within a distinct mapped geographic region called a service area. The Exchange's service areas are depicted in Figure 2. Service areas are mapped geographic sub-regions with unique ecological or political significance within which credits may be used to offset debits. Service areas protect species populations and sub-populations by ensuring that conservation benefits are located within an appropriate proximity to impacts to the species. Each credit is identified by the service area where it was created. Credits are eligible to offset debits within the same service area. An exception may be justified if the U.S. Fish & Wildlife Service (USFWS) and the Exchange Administrator agree the purchase of credits in service areas other than the one in which a debit is located produces an equivalent or preferable benefit to the species.

The service areas proposed for GRSG are based on the populations and subpopulations identified in the Conservation Objectives Team (COT) Final Report (USFWS 2013) and correspond to recommendations in the USFWS Greater Sage-grouse Range-wide Mitigation Framework (USFWS 2014). Delineations between service areas are drawn to avoid splitting GRSG local working groups (LWGs). The service areas are as follows Figure 2:

1. WAFWA Management Zone I: Powder River Basin population (includes Northeast WY LWG)
2. WAFWA Management Zone II: Wyoming Basin population, Big Horn Basin subpopulation (includes Big Horn Basin LWG)
3. WAFWA Management Zone II: Wyoming Basin population, Southcentral subpopulation & Laramie population (includes Wind River/Sweetwater River Basin LWG, Southcentral WY LWG, and Bates Hole/Shirley Basin LWG)
4. WAFWA Management Zone II: Wyoming Basin population, Southwest subpopulation (includes Southwest WY LWG and Upper Green River Basin LWG)
5. WAFWA Management Zone II: Jackson Hole population (includes Upper Snake River Basin WY LWG). See p. 22 here http://www.wyomingconservationexchange.org/wp-content/uploads/2015/01/Wyoming-Conservation-Exchange-Manual-

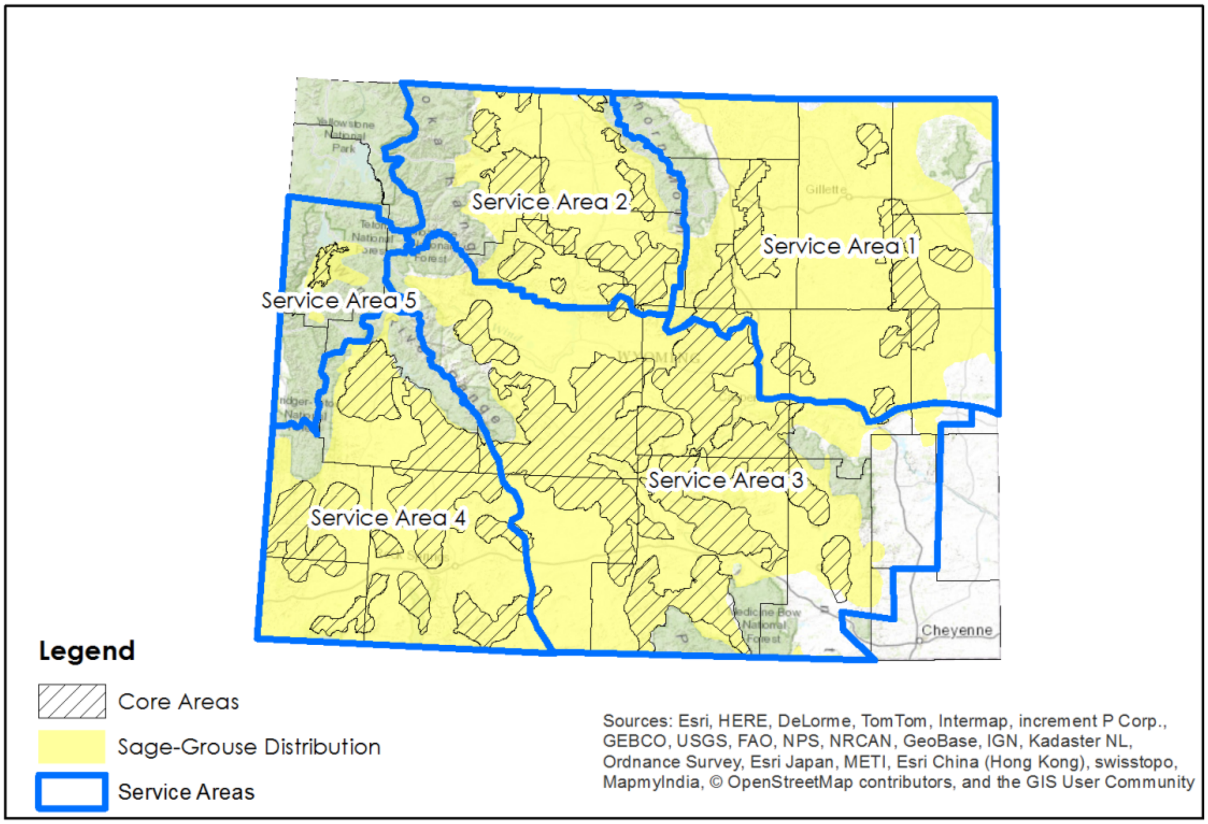


Figure 2. Service Areas in Wyoming

3.2 Assessment of Site Condition

When a project area is within the occupied range of GRSG in Wyoming, 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 debits 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 effect of any anthropogenic or natural feature (e.g. transmission line or conifer cover) that occurs on the site. The HQT 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 and are important in GRSG habitat selection (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007). The functional acre score resulting from these 4^{th} order measures is then adjusted based on quality of the surrounding habitat context. The concept model presented in Figure 3 illustrates the attributes being measured and the role they play in providing suitable breeding, summer, and winter habitat for GRSG.

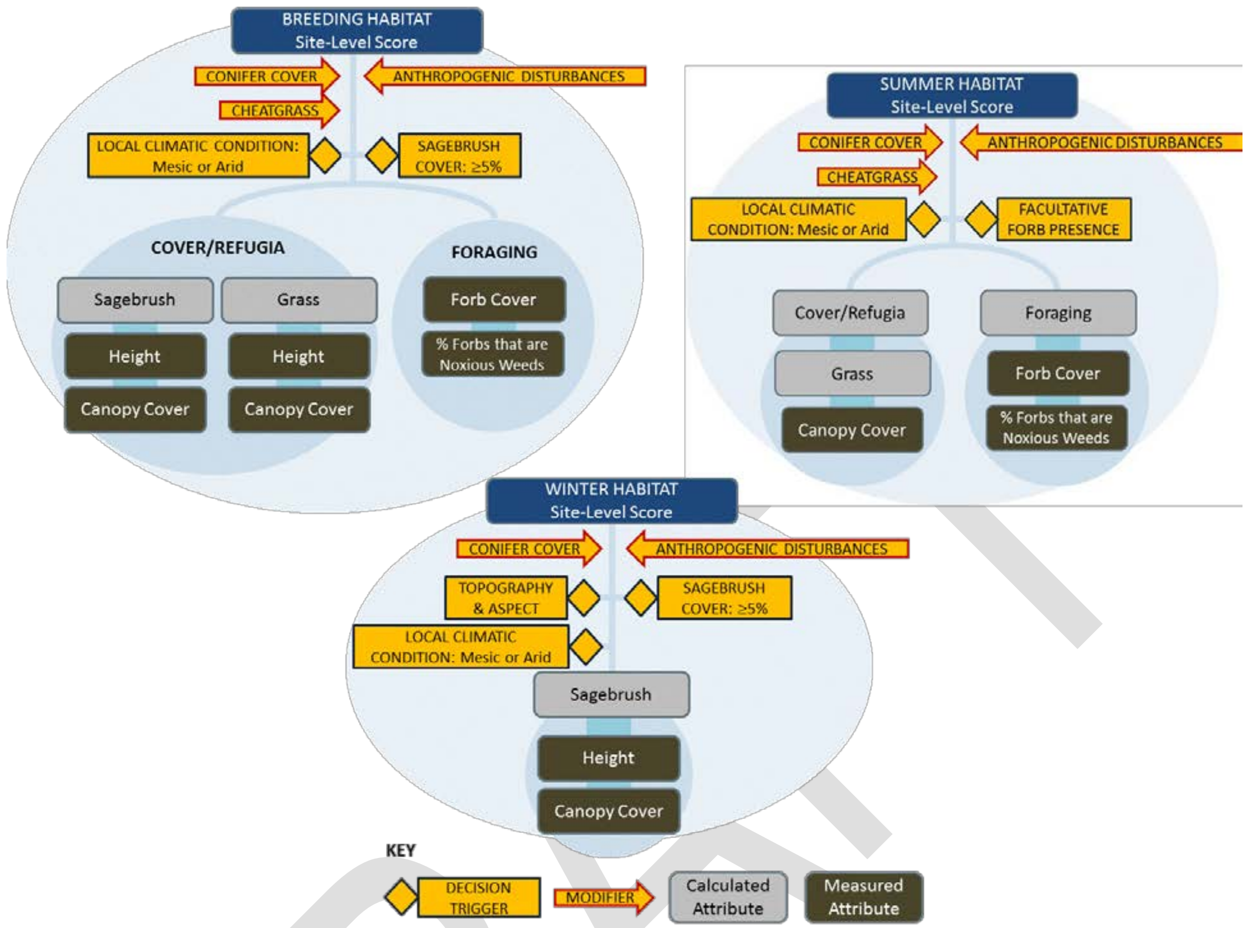


Figure 3. Conceptual Model Depicting GRSG Life History Requirements

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 is not scored for breeding habitat value; that value is 0. In addition, a set of decision triggers also determines whether scoring curves 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. For Service Area

4, one set of scoring curves is used for both mesic and arid conditions (see scoring curves in Appendix A).

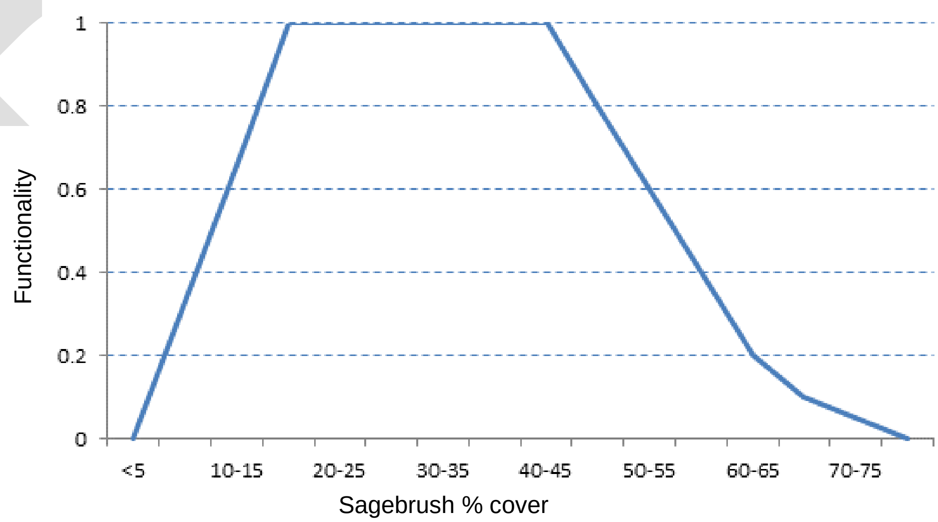
Table 1. Decision Triggers Used in the HQT

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 the GRSG results in different vegetation potentials regionally in Wyoming 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 have different potential than sites in mesic conditions. These conditions influence plant community composition, productivity and presence (Winward 2004). The HQT addresses this site variability 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%.

Attribute		Trigger	Definition
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.
	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, the HQT classifies summer habitat 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. 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	5-10	10-15	15-45	45-50	50-55	55-60	60-65	65-70	70-75	>75
Functionality	0	0.33	0.66	1	0.8	0.6	0.4	0.2	0.1	0.05	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 and each service area were developed by the Science Team. More detailed information on how the scoring curves are used to calculate scores is available in Section 4.1.

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 at the center of each map unit (Figure 5). Vegetation attributes are measured at the sampling location within each map unit to calculate 4th order habitat quality.

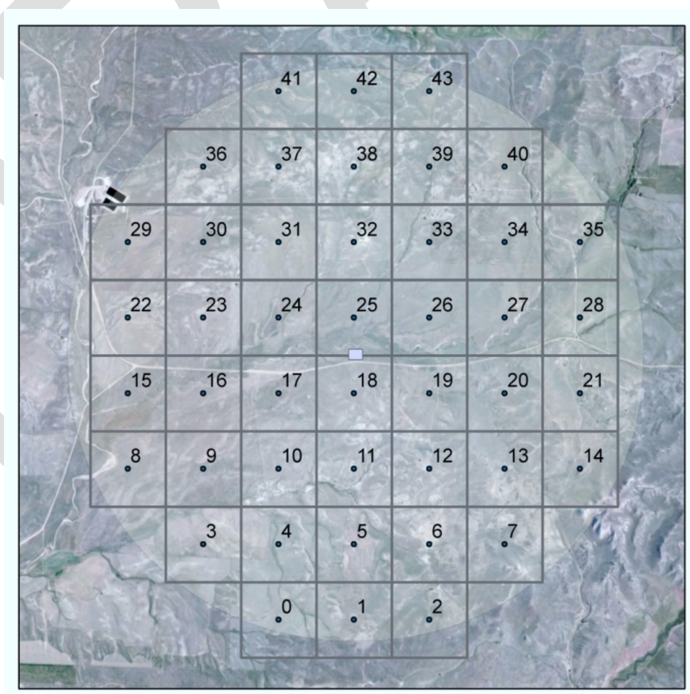


Figure 5. Systematic Grid Indicating Plot Sampling Locations Overlaid on Project Area

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, 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 E).

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

BREEDING		
Function	**Attribute**	**Description**
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.
	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.
	Percent of Forb Species that is Noxious Weeds	A simple index to food availability (Appendix D)
SUMMER		
Cover / Refugia	Perennial Grass Cover (quantitative measure)	See above
Foraging	Forb Cover (quantitative measure)	See above
	Percent of Forb Species that is Noxious Weeds	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.

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 final 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 2^{nd} and 3^{rd} orders (described in section 3.2.5 and section 3.3) depends on the number of variables used to generate that score.

Table 3. Vegetation Attribute Weighting Values

BREEDING					
Cover / Refugia (66.7%)				Forage (33.3%)[A]	
Sagebrush Height 10%	Sagebrush Canopy Cover 25%	Grass Canopy Cover 16.68%	Grass Height 16.68%	Forb Cover 16.7%	Percent Forbs that are Noxious Weeds 16.7%[B]
SUMMER [C]					
Cover / Refugia (33.3%)		Forage (66.7%)			
Grass Canopy Cover 33.3%		Forb Cover 33.4%		Percent Forbs that are Noxious Weeds 33.4% [B]	
WINTER					
Sagebrush Height 50%			Sagebrush Canopy Cover 50%		

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 – A Hypothetical Example

Using the field data collection methods (Appendix E) a technician collects vegetation data on an arid location suitable for breeding (i.e., sagebrush canopy cover >5%). Based on the project area's annual precipitation zone, the project area is located in arid conditions. The mesic location triggers the use of scoring curves associated with mesic conditions (note that for Service Area 4 there is only one set of scoring curves used for all projects located in that Service Area). The following measurements are collected: sagebrush height 18 cm; sagebrush canopy cover 22%; perennial grass height 10 cm; perennial grass canopy cover 14%; forb cover 6%; and none of the forbs present are noxious weeds (refer to Appendix D and Appendix E 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 0.66; sagebrush canopy cover 1.0; perennial grass height 0.7; perennial grass canopy cover 1.0; forb cover 1.0; and all forbs present desirable 1.0. Using these scores with the weights presented in Table 3, the following calculations are made (and depicted in Table 4): sagebrush height (0.66*0.10) = 0.07; sagebrush canopy cover (1.0*0.25) = 0.25; perennial grass height (0.7*0.17) = 0.12; perennial grass canopy cover (1.0*0.17) = 0.17; forb cover (1.0*0.17) = 0.17; and desirable forbs present (1.0*0.17) = 0.17. The weighted scores are then summed across vegetation attributes to establish a final *breeding season* vegetation score for the site of 0.95. 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: 18 cm	Sage-brush cover: 22%	Perennial grass height: 10 cm	Perennial grass cover: 14%	Forb cover: 6%	Percent Noxious Weeds: 0	
Scoring table values	0.66	1.00	0.70	1.00	1.00	1.00	
Weights	0.10	0.25	0.17	0.17	0.17	0.17	
Weighted scores	0.07	0.25	0.12	0.17	0.17	0.17	0.95

These scores are then "modified" based on the context of the site 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
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:

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

Invasive Grass Cover

Invasive grass cover is a modifier for breeding and summer habitats, and is measured using field data collection methods (see Appendix E). 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 shown in Table 6.

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

Percent Cover of Invasive Grass	Percent Adjustment Multiplier
0 - 10%	100%[A]
>10 – 20%	80%
>20 – 30%	60%
>30 – 40%	40%
>40 – 50%	20%
>50%	0

* There may be unique scoring tables for each service area. This table should be used for service area 4.

[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 10%. In contrast, if invasive annual grass cover is between 20 and 30%, then the site-level condition score is multiplied by 0.6, 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 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[1]

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 Intermountain West (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 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. The HQT therefore modifies all seasonal habitat types based on conifer cover. To do this, a moving window with a radius of 1-km is applied to the project area. For each pixel, the moving window calculates conifer cover using a conifer cover raster derived from the LANDFIRE dataset. 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.

[1] 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.

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).

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 the footprint, has on habitat function at the 4^{th} order. Avoidance of anthropogenic features– including roads, power lines, and oil and gas well pads and other field related infrastructure – have 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 HQT modifies the suitability of a location 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.

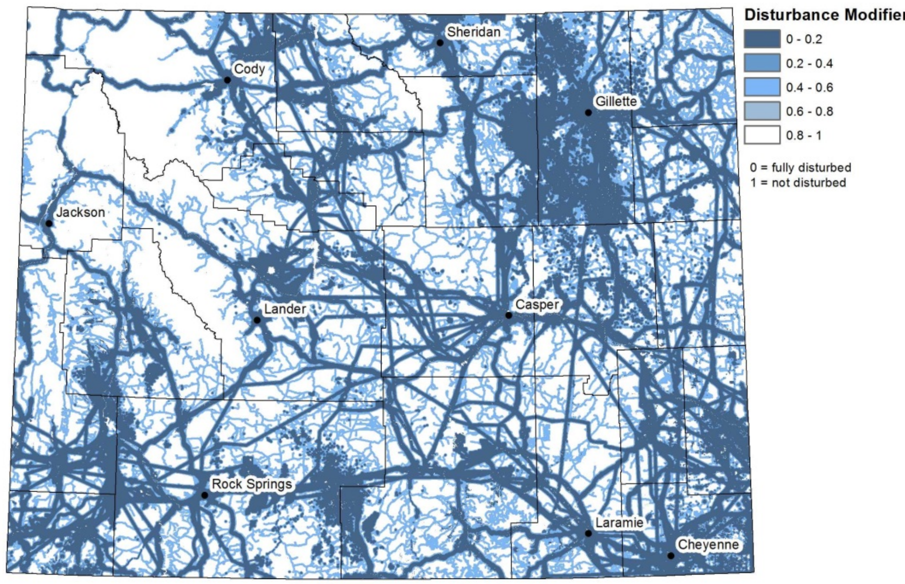


Figure 6. Map of site-level anthropogenic feature modifier where values of 0 represent fully disturbed locations and values of 1 represent no disturbance. County boundaries are shown in black.

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 wells are recorded by activity is not occurring regularly at the location.
Towers	Meteorological towers	50	0	Point locations for met towers. Any tower together with associated instrumentation or devices used for assessment of wind energy.
	Communication towers	50	0	Point locations for communication towers. Tall structure 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.

Feature	Subtype	Weight	Distance (km)	Description
Wind turbines		100	3	Point locations for individual wind turbines, a wind-driven turbine for generating electricity. We used the O'Donnell and Fancher 2010 dataset plus data points for three wind farms constructed since its publication (current as of April 2015).
Mines	Active – Large	100	2.1	Large mines have an area of 60 acres or more. For coal mines, polygons were available to represent mine boundaries.
	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 used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
	Untilled	85*	0	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
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	Includes road ramps to and including Interstate and U.S. numbered highways with interchanges, state highways and county highways that are always hard surface (concrete or asphalt).
	Secondary roads	50	1.5	Includes improved roads for which there is no route descriptor to indicate administrative responsibility. These roads are narrower than state highways and county highways, can include hard surface (concrete or asphalt) or aggregate surface and are usually undivided with single-lane characteristics. These roads usually have a local name along and intersect with other roads and driveways. Also includes roads or streets used for local traffic and usually has a single lane of traffic in each direction. In rural areas, this is a short-distance road connecting the smallest towns. Scenic park roads, unimproved or unpaved roads, minor residential roads, and industrial roads are included in this category.

* 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 HQT quantifies the response of GRSG to activity levels most representative of type of feature over its lifetime. 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 site 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 value 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 (breeding habitat only);
- Presence of sagebrush cover (summer habitat only).

Distance to Known Lek

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 (Holloran and Anderson 2005). 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 0.8, 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 15% sagebrush canopy cover and 20cm sagebrush height is located with 60-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 60-m of the sample point, the score is reduced by 85% (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 – 60	100%[A]
>60	15%

[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 60m of sagebrush cover. 15% value indicates the site level condition score is multiplied by .15.

3.3.2 2nd Order Modifier

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

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.

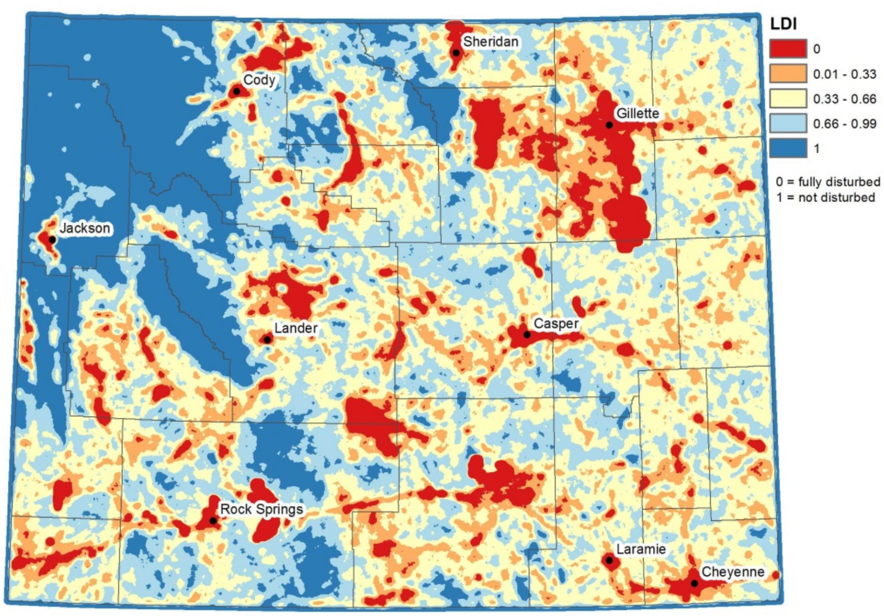


Figure 7. Map of the Landscape Disturbance Index, where values of 0 are above the upper disturbance threshold (i.e., fully disturbed) and values of 1 are below the lower disturbance threshold (i.e, not disturbed). County boundaries are shown in gray.

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 0.95. 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 15% and no conifer cover. The distance of the closest known lek to the site is 2.6 km. And the pre-project site-level anthropogenic feature modifier value is 0.93. 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; pre-project anthropogenic features modifier 0.93; distance to lek 1.0; and LDI 0.75. By multiplying the vegetation score by these modifier scores, a breeding season score of 0.53 is calculated.

		Modifiers						
		4th			**3rd**		**2nd**	
Seasonal Habitat	Site Veg Condition Score (4th Order)	Cheat-grass	Conifer Cover	Site-Level Anthropogenic Feature	Distance to Lek	Presence of Sagebrush	LDI*	Breeding Season Score
Breeding	0.95	0.80	1.00	0.93	1.00	N/A	0.75	0.53

* 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 =

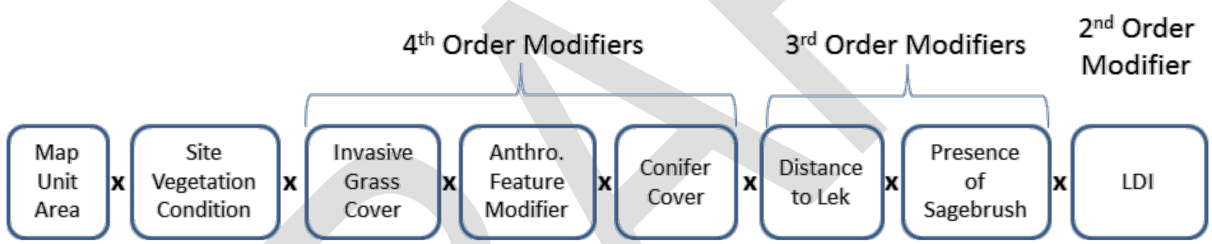


Table 11 shows the complete functional acre equation using hypothetical values for single map unit. The site vegetation condition score is multiplied by each modifier value in succession to establish the final functional acre score for each map unit. Note that for each map unit a separate and unique functional acre score results 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	1.00	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 * 1.00 * 087 * 0.83 = 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 HQT Calculator once the data has been inputted. The example calculations shown utilize hypothetical data.

Calculating functional acres for a site requires 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 E. Table 12 shows which attributes are derived using the User's Guide and attributes that are collected in the field.

Table 12. GIS-derived attribute measurements and attribute measurements collected in the field

GIS Data	Field Data
• Site-level anthropogenic feature modifier (pre-project and post-project) • Distance to known lek • Conifer cover • LDI	• Sagebrush height and percent cover • Grass height and percent cover • Forb percent cover 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 • Debit projects: based on the type of proposed (or removed) anthropogenic disturbance and associated distance effect(s)
2. Set map units	Apply pre-existing grid of map units to project area.
3. Calculate 4^{th} 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 E) for more information.
4. Calculate 3^{rd} order modifiers	Distance to lek is calculated. See *User's Guide* for more information. Presence of sagebrush is measured in the field. See *Field Data Collection Methods* (Appendix E) for more information.
5. Calculate 2^{nd} 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 E) for more information.

Steps	Detail
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 debits 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 behavior 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
Towers	Met towers	0
	Communication towers	0
Transmission Lines		3
Wind turbines		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.

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 Wyoming 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 4th order habitat quality. Map units are assigned a unique identifier and inputted into the HQT Calculator spreadsheet.

Step 3: Calculate 4th 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. For debit projects, all proposed anthropogenic features are digitized within a GIS. Existing features are used to calculate pre-project condition scores; proposed (or removed) features are used to calculate post-project condition scores. The calculated 4th order pre-project and post-project anthropogenic feature modifier values are inputted into the HQT Calculator.

Step 4: Calculate 3rd Order Modifiers

Distance to lek is calculated for each map unit according to the steps outlined in the *User's Guide*. Presence of sagebrush cover is measured in the field. Each 3rd 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 (3rd Order) Modifier
Breeding	Distance to Lek
Summer	Presence of Sagebrush

Step 5: Calculate 2nd 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

			Modifiers						
			4th			3rd		2nd	
Map Unit	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Conifer cover	Site-Level Anthropogenic features	Distance to Lek	Presence of Sagebrush	LDI	Functional Acres
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			1.00	0.82	N/A	N/A	0.89	
2	160			0.85	0.95	N/A	N/A	0.97	
3	160			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 disturbances 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 E *Field Data Collection Methods*.

Step 7: Calculate Functional Acres Using HQT Calculator

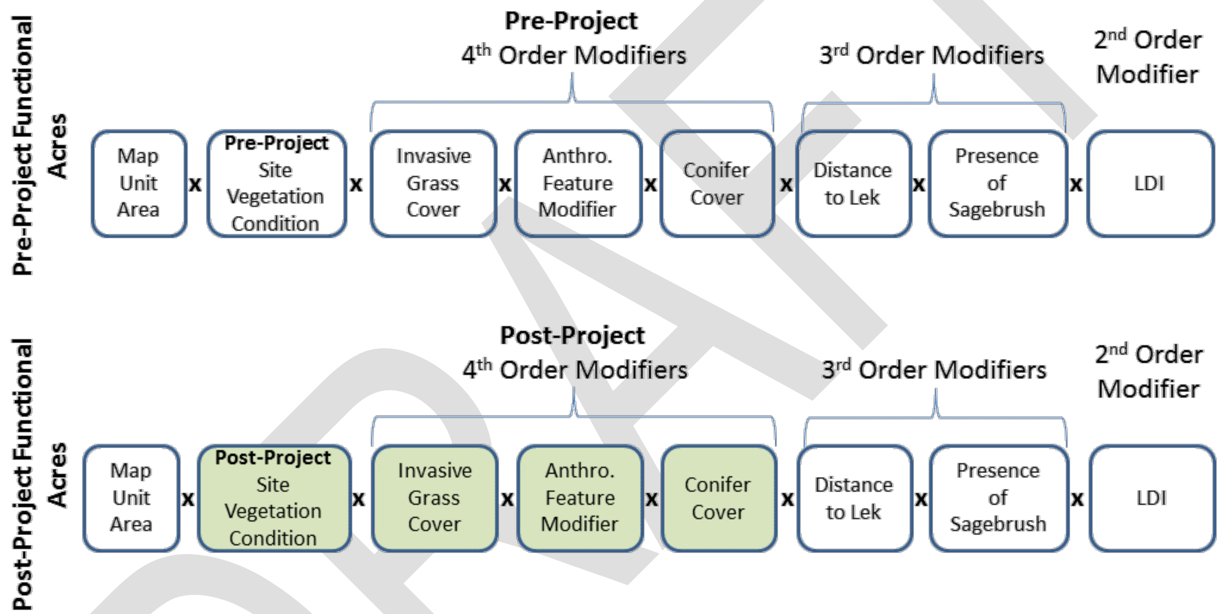
Field data and outputs from the desktop analyses are inputted into the HQT Calculator and functional acres are calculated automatically. At the end of Step 6, all of the data required to calculate functional acres have been obtained and can be inputted into the HQT Calculator spreadsheet. The vegetation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

Table 17. Data Inputs for the Calculation of Functional Acres

			Modifiers						
			4th			3rd		2nd	
Map Unit	Acres	Site Veg Condition Score (4th Order)	Cheat-grass	Conifer cover	Site-Level Anthropogenic Disturbance	Distance to Lek	Presence of Sagebrush	LDI	Functional Acres
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	0.80	1.00	0.82	N/A	N/A	0.89	**49.51**
2	160	0.74	1.00	0.85	0.95	N/A	N/A	0.97	**92.74**
3	160	0.54	0.80	0.85	0.78	N/A	N/A	0.81	**37.12**

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 4th order modifiers are changed by a landowner or developer. The 2nd and 3rd 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. Exchange participants who generate a Density and Disturbance Calculation Tool (DDCT) assessment area will have digitized existing and proposed (or removed) features. These vectors can be used to calculate the pre- and post-project site-level anthropogenic feature modifier values (see the *User's Guide* for detailed steps for calculating pre- and post-project site-level anthropogenic feature modifier values). Table 18 shows the pre-project functional acre calculation using hypothetical values for single map unit. Table 19 shows the pre-project functional acre calculation using hypothetical values for single map unit, where an additional anthropogenic feature was added to the project area. Table 19 also shows the pre-project functional acre calculation using hypothetical values for a single map unit that is located within the indirect area of effect of an anthropogenic feature that was added to the project area.

Table 18. Pre-Project Condition Functional Acres

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

Table 19. Post-Project Condition Functional Acres

Seasonal Habitat	Acres	Site Veg Condition Score (4th Order)	**Modifiers**						Functional Acres
			4th			**3rd**		**2nd**	
			Cheat-grass	Conifer Cover	Post-Project Site-Level Anthropogenic Feature	Distance to Lek	Presence of Sagebrush	LDI	
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	1.00	1.00	**0.62**	N/A	N/A	0.82	**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	70.76	80.37	**- 9.61**
Winter	75.43	92.43	**- 17.00**

4.3 Establishing a Standardized Scale of Measure

At the 4th order, vegetation attributes are measured and quantified using transects resulting in 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 30×30-m pixels. To establish a standardized scale of measure such that estimates can be scored for each map unit, the 30×30-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.

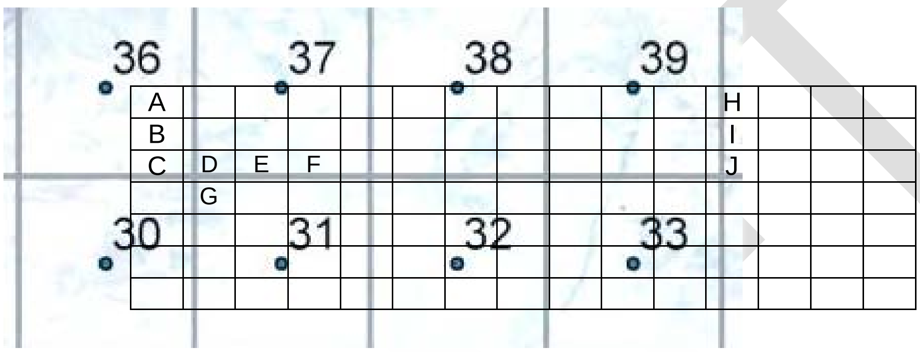


Figure 8. 30x30-m Raster Grid Cell Laid Over Project Area (figure is not drawn to scale)

5.0 Example Projects

5.1 Example Debit Project

Hypothetical data for low quality and high quality project areas were used to demonstrate the calculation of functional acres. Average values for each scenario are depicted in Table 21. Scoring curves for >5% slope were used. These values are based on field data only (sagebrush cover and height, grass cover and height, forb cover, percent of forb cover that is noxious weeds, and cheatgrass). 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 would also take into consideration the change in site conditions associated with vegetation disturbance from activities outside of the well pad.

Table 21. Average Field Data Scores for Hypothetical Low and High Quality Habitat Scenarios

Attribute	Low-Quality Habitat Average Value for Project Area	High-Quality Habitat Average Value for Project Area
Sagebrush Cover	60-65%	15-20%
Sagebrush Height	5-10cm	20-25cm
Grass Cover	2%	10%
Grass Height	6cm	12cm
Forb Cover	5%	5%
% Forb that is Noxious Weeds	0	0
Presence of Facultative Forbs	Yes	Yes
BRTE	0	0

5.1.1 Project Details

A proposed 10 acre pad in service area 4 will contain two active wells. The location reference for the facility is latitude 42.468794, longitude -109.566650, and is depicted in Figure 9.

Figure 9. Location of Proposed Well Pad in Service Area 4

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 3851 acres, makes up the project area (Figure 10).

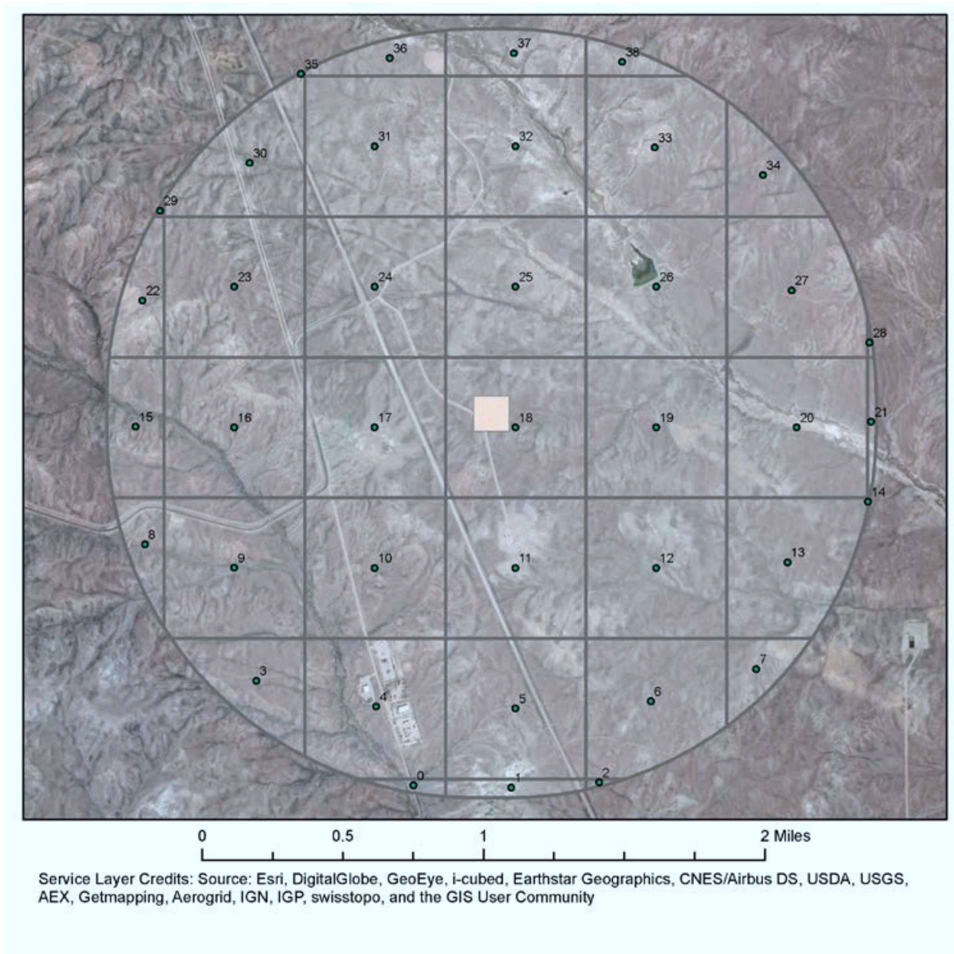


Figure 10. Predefined Map Unit Grid Overlaid on the Project Area

5.1.2 Field and GIS Data

Hypothetical field data for the two scenarios is entered into the HQT Calculator, which combines vegetation attributes (as described in the previous section) into a site vegetation condition score. GIS data for the project area is also input into the HQT Calculator. Table 22 shows the GIS data that would be input into the HQT Calculator.

Table 22. GIS Data Input for the Project Example

Map Unit ID	Map Unit Area	LDI Modifier	Pre-Project Site-Level Anthropogenic Disturbance	Post-project Site-Level Anthropogenic Disturbance	Distance to Known Lek (km) (rounded to nearest km)	Proportion Conifer Cover
1	6.4	0.2262350	0.013059737	0.013059737	3	0.00
2	19.6	0.1614119	0.003103481	0.003103481	3	0.00
3	2.4	0.1138232	0.000857331	0.000857331	4	0.00
4	73.8	0.2519675	0.13105044	0.13105044	3	0.00
5	155.0	0.2286917	0.024701263	0.024701263	3	0.00
6	159.0	0.1465685	0.001457192	0.001457192	4	0.00
7	139.4	0.1085359	0.006240753	0.006240753	4	0.00
8	33.1	0.0982284	0.042094863	0.042094863	3	0.00
9	31.6	0.2071851	0.115021872	0.115021872	2	0.00
10	158.6	0.1959666	0.095466513	0.095414903	2	0.00
11	158.8	0.1756124	0.006652543	0.006650929	3	0.00
12	158.6	0.1401647	0.000147432	0.000147432	3	0.00
13	159.0	0.1189916	0.017784582	0.017784582	3	0.00
14	135.9	0.0896134	0.177844194	0.177844194	2	0.00
15	62.3	0.1149194	0.102321012	0.102321012	2	0.00
16	159.0	0.1229861	0.048543743	0.046715966	1	0.00
17	158.8	0.1086809	0.002077712	0.001111806	2	0.00
18	158.8	0.1034222	0.002885488	0.000560555	2	0.00
19	159.2	0.0874942	0.069779387	0.055891057	3	0.00
20	159.2	0.0845653	0.383988072	0.380734786	3	0.00
21	8.5	0.1116152	0.622832219	0.622832219	2	0.00
22	43.8	0.0251671	0.078232552	0.078232552	2	0.00
23	159.0	0.0563464	0.018842818	0.018302976	1	0.00
24	159.2	0.0814252	0.002576857	0.001298463	1	0.00
25	158.6	0.1220585	0.032239772	0.012151335	2	0.00
26	159.2	0.1284324	0.207298098	0.160927742	3	0.00
27	145.7	0.1103530	0.57080946	0.55983297	3	0.00
28	0.9	0.1246574	0.719456159	0.719456159	2	0.00
29	0.4	0.0019400	0.026074645	0.026074645	2	0.00
30	105.2	0.0625866	0.004316072	0.004308536	1	0.00
31	158.8	0.1142473	0.007945416	0.007406023	1	0.00
32	158.6	0.1829552	0.088844726	0.080402385	2	0.00
33	155.7	0.2006822	0.361097866	0.349412171	3	0.00
34	55.2	0.1584855	0.639748508	0.635927334	3	0.00
35	0.4	0.0919802	0.002469709	0.002469709	3	0.00
36	35.4	0.1336780	0.021066727	0.020979249	2	0.00
37	51.8	0.2002331	0.1438837	0.143141954	2	0.00
38	18.0	0.2093918	0.368634146	0.368164203	3	0.00

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

- LDI: 0.13
- Pre-Project Site-Level Anthropogenic Feature modifier: 0.14
- Post-Project Site-Level Anthropogenic Feature modifier: 0.13
- Distance to Known Lek: 1.0
- Conifer cover: 1.0

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	22.91	23.91	- 1.00
	Summer	27.69	28.90	- 1.21
	Winter	26.48	27.64	- 1.16
High-quality habitat	Breeding	52.89	55.20	- 2.31
	Summer	52.91	55.22	- 2.31
	Winter	52.70	55.00	- 2.30

5.2 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; 2^{nd} and 3^{rd} order modifiers do not change. Table 24 depicts 4^{th} order scores for pre-project condition; Table 25 depicts 4^{th} 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 24. Pre-Project 4th Order Vegetation Condition Scores

BREEDING Pre-Project 4^{th} Order Vegetation Condition										
Map Unit	Acres	Sagebrush		Grass		Forbs		Modifier	4^{th} Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Height	% Cover	% Cover	% Noxious weed cover	Invasive Grass		
1	160	15-20	5-10	10	>20	5	0	20-30	0.09	14.64
2	160	20-25	5-10	8	15	2	0	30-40	0.03	4.44
3	160	15-20	5-10	8	10	2	0	40-50	0.01	1.46
									Total Functional Acres	20.53
SUMMER Pre-Project 4^{th} Order Vegetation Condition										
Map Unit	Acres	Sagebrush		Grass		Forbs		Modifier	4^{th} Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Height	% Cover	% Cover	% Noxious weed cover	Invasive Grass		
1	160	N/A	N/A	N/A	>20	5	0	20-30	0.05	8.64
2	160	N/A	N/A	N/A	15	6	0	30-40	0.07	11.52
3	160	N/A	N/A	N/A	10	7	0	40-50	0.04	6.05
									Total Functional Acres	26.21
WINTER Pre-Project 4^{th} Order Vegetation Condition*										
Map Unit	Acres	Sagebrush		Grass		Forbs		Modifier	4^{th} Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Height	% Cover	% Cover	% Noxious weed cover	Invasive Grass		
1	160	15-20	5-10	N/A	N/A	N/A	N/A	N/A	0.33	52.80
2	160	20-25	5-10	N/A	N/A	N/A	N/A	N/A	0.50	79.20
3	160	15-20	5-10	N/A	N/A	N/A	N/A	N/A	0.33	52.80
									Total Functional Acres	184.80

* In this hypothetical example, the scoring curves for slope <5% were used.

5.2.2 Results for Post-Project Condition

For the purposes of this example, we assumed that the landowner's credit project was vegetation management that reduced invasive grass cover and resulted in an increase in forb cover and grass height for some map units. Table 25 shows the post-project conditions scores, and the data entries in red are the vegetation attributes that changed as a result of the vegetation management project.

Table 25. Post-Project 4th Order Vegetation Condition Scores, With Changed Attributes Highlighted

BREEDING Post-Project 4^{th} Order Vegetation Condition										
Map Unit	Acres	Sagebrush		Grass		Forbs		Modifier	4^{th} Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Height	% Cover	% Cover	% Noxious weed cover	Invasive Grass		
1	160	15-20	5-10	10	>20	5	0	10-20	0.12	19.51
2	160	20-25	5-10	8	15	2	0	10-20	0.06	8.87
3	160	15-20	5-10	10	10	5	0	20-30	0.09	14.64
									Total Functional Acres	43.02
SUMMER Post-Project 4^{th} Order Vegetation Condition										
Map Unit	Acres	Sagebrush		Grass		Forbs		Modifier	4^{th} Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Height	% Cover	% Cover	% Noxious weed cover	Invasive Grass		
1	160	N/A	N/A	N/A	>20	5	0	10-20	0.07	11.52
2	160	N/A	N/A	N/A	15	6	0	10-20	0.14	23.04
3	160	N/A	N/A	N/A	10	10	0	20-30	0.23	36.29
									Total Functional Acres	70.85
WINTER Post-Project 4^{th} Order Vegetation Condition*										
Map Unit	Acres	Sagebrush		Grass		Forbs		Modifier	4^{th} Order Habitat Function	Functional Acres
		Height (cm)	% Cover	Height	% Cover	% Cover	% Noxious weed cover	Invasive Grass		
1	160	15-20	5-10	N/A	N/A	N/A	N/A	N/A	0.33	52.80
2	160	20-25	5-10	N/A	N/A	N/A	N/A	N/A	0.50	79.20
3	160	15-20	5-10	N/A	N/A	N/A	N/A	N/A	0.33	52.80
									Total Functional Acres	184.80

* In this hypothetical example, the scoring curves for slope <5% were used.

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 26).

Table 26. Functional Acre Change by Season for the Example Credit Project

FUNCTIONAL ACRE CHANGE BY SEASON			
Seasonal Habitat	**Post-Project**	**Pre-Project**	**Change**
Breeding	43.02 functional acres	20.53 functional acres	+22.49 functional acres
Summer	70.85 functional acres	26.21 functional acres	+44.64 functional acres
Winter	184.80 functional acres	184.80 functional acres	No change in functional acres

6.0 Adaptive Management and Monitoring

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 implements an adaptive management process that evaluates the effectiveness of practices in meeting desired outcomes. An adaptive 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 as not just one component of implementation process, but is the foundation of implementation itself. There needs to be explicit, straightforward processes 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 needs also 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 plan 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.

In the adaptive management and monitoring plan, we will develop a link between habitat as quantified through the Exchange and sage-grouse 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 sage-grouse population metrics with these geospatial covariates. Developed models would be used to assess the potential associated with the Exchange in terms of sage-grouse 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 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 invasive grass 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 Wyoming Conservation Exchange should not be used as justification for wide-scale modification of sagebrush ecosystems as a GRSG management tool. Over time, the adaptive management process should be used to 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 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 Fedy et al. (2014) – 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 Fedy et al. (2014) 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 infrastructure. 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

Vegetation scoring curves (beginning on the following page) have been developed initially for Service Area 4 as a template for other Wyoming Service Areas. These curves were developed from extant data collected at sage-grouse nest and early brood-rearing locations near Pinedale, Wyoming between 1998 and 2010.

To standardize frequency values presented in the figures, we normalized counts by dividing the number of sites in each category by the number in the category with the greatest number of sites. By figure, this is what occurred:

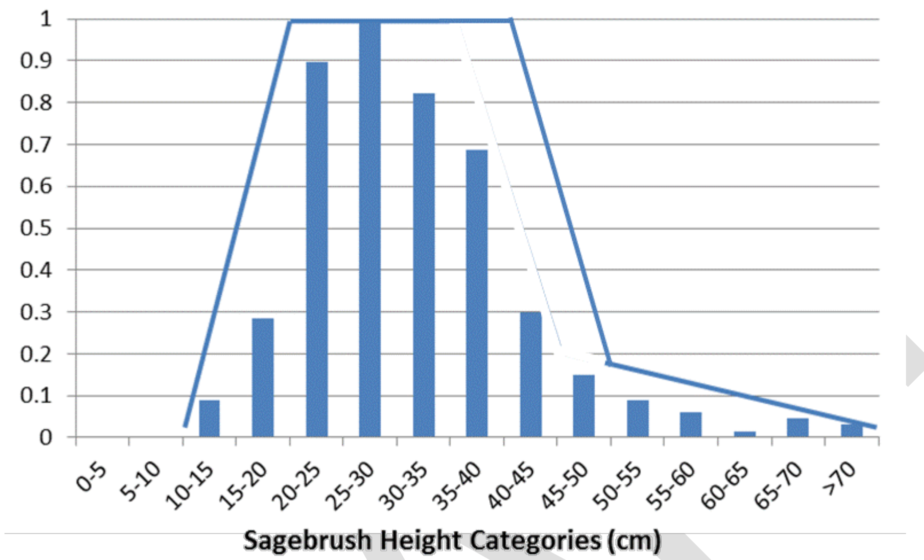
- Sagebrush height categories are displayed as a proportion of the category with the greatest number of locations (e.g., 60 nests plus early brood locations had mean sagebrush height between 20 and 25 cm, while 67 locations had mean sagebrush height between 25 and 30 cm; so the 20 to 25 cm category had 0.9 the number of locations as the 25 to 30 cm category (60/67 = 0.90)).
- Sagebrush canopy cover 83 nest/eb in 20-25% category; 56 nests/eb in 25-30% category (56/83=0.67).
- Grass height 91 nests/eb in 10-12.5cm category; 86 in 12.5-15 cm category (86/91=0.95).
- Grass cover 66 nests/eb in 2.5-5% category; 47 in 5-7.5% category (47/66 = 0.71).
- Forb cover 27 eb in 2.5-5% category; 22 in 0-2.5% category (22/27=0.81).
- Forb spp. diversity 26 eb in 3 spp. category; 20 in 2 spp. category (20/26 = 0.77)

To establish vegetation scoring curves in the other Wyoming Service Areas (1, 2, 3, 5) the following process will be followed:

1. Contact local vegetation and sage-grouse experts in each Service Area. Experts could include but would not be limited to: WY Game and Fish, Natural Resources Conservation Service, Bureau of Land Management, local Sage-Grouse Working Groups;
2. Identify and obtain any relevant data (published or unpublished);
3. Use available data to derive scoring curves specific to the service area where those data were collected;
4. If locally-derived data are not sufficient to establish curves, use vegetation scoring curves derived from literature as a starting point and modify those curves based on the local data that are available and expert opinion of local vegetation and sage-grouse experts;
5. Science team reviews and approves modifications and readiness for use;

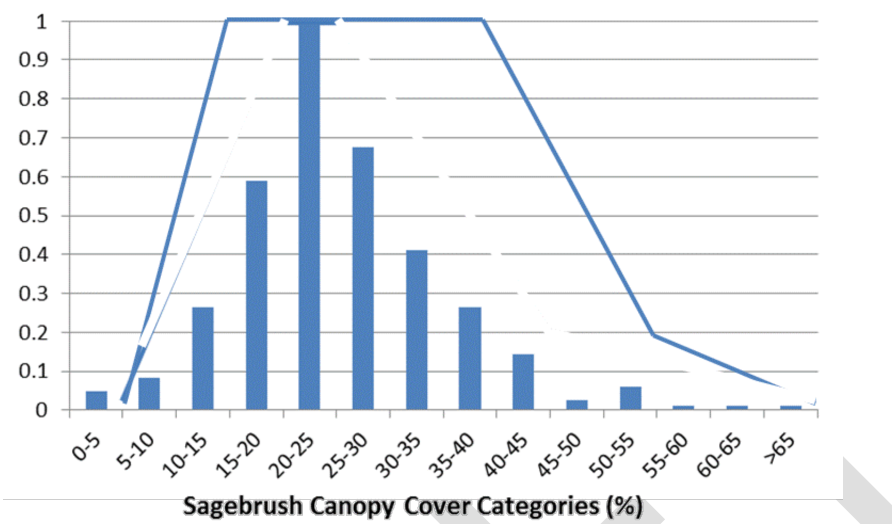
6. All vegetation scoring curves for all Service Areas are updated over time as field experience and additional data become available.

Breeding Habitat: Sagebrush Height, Mesic and Arid Sites in the Upper Green River Basin



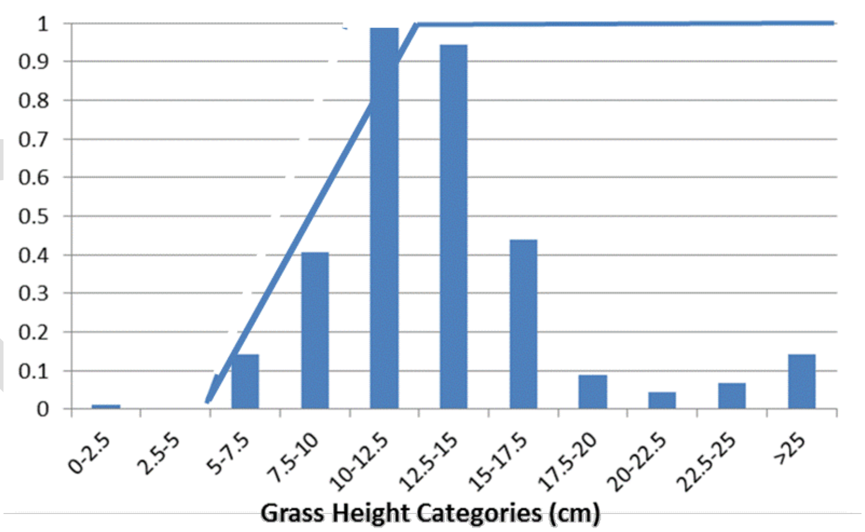
Sagebrush Height	<5	5-10	10-15	15-20	20-45	45-50	50-55	55-60	60-65	65-70	>70
Functionality	0	0	0.33	0.66	1	0.6	0.2	0.15	0.1	0.05	0

Breeding Habitat: Sagebrush Canopy Cover, Mesic and Arid Sites in the Upper Green River Basin



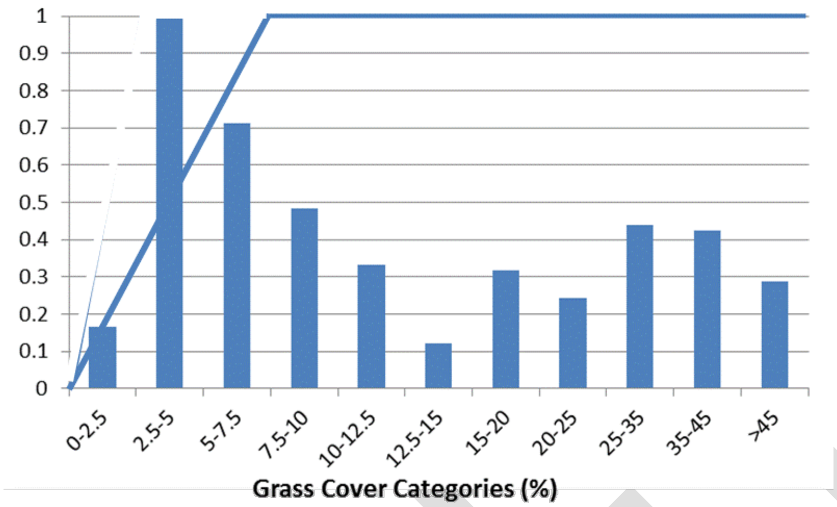
Sagebrush Cover	<5	5-10	10-15	15-45	45-50	50-55	55-60	60-65	65-70	70-75	>75
Functionality	0	0.33	0.66	1	0.8	0.6	0.4	0.2	0.1	0.05	0

Breeding Habitat: Grass Height, Mesic and Arid Sites in the Upper Green River Basin



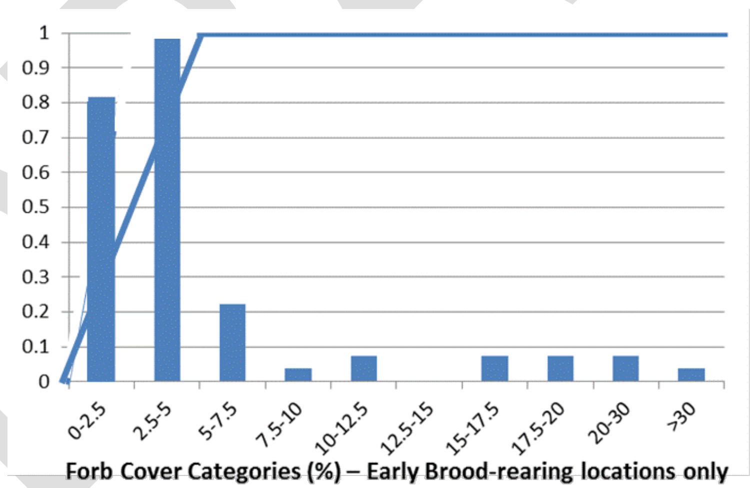
Grass Height	<5	6	7	8	9	10	11	12	13	>13
Functionality	0	0.14	0.28	0.42	0.56	0.7	0.84	0.98	1	1

Breeding Habitat: Grass Canopy Cover, Mesic and Arid Sites in the Upper Green River Basin



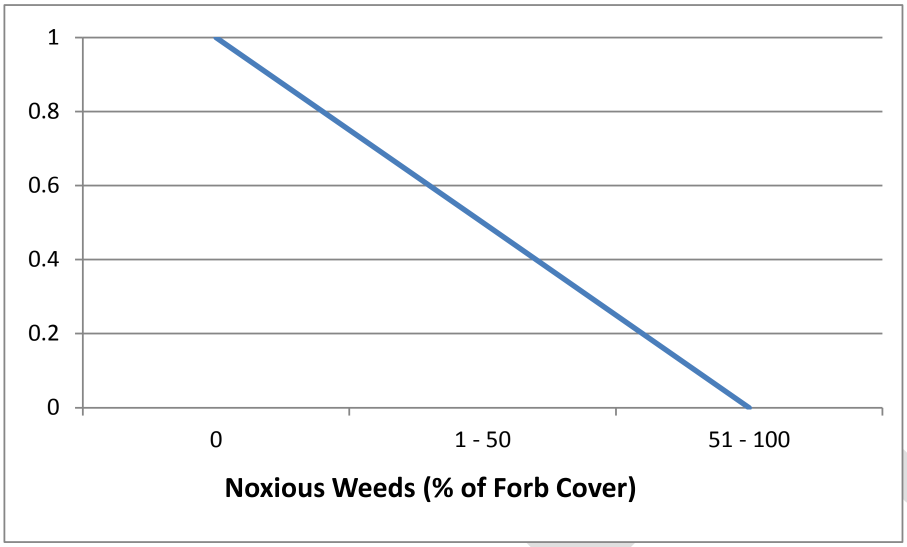
Grass Cover	0	1	2	3	4	5	6	7	8	>9
Functionality	0	0.125	0.25	0.375	0.5	0.625	0.75	0.875	1	1

Breeding Habitat: Forb Cover, Mesic and Arid Sites in the Upper Green River Basin



Forb Cover	0	<5	5	>6
Functionality	0	0.5	1	1

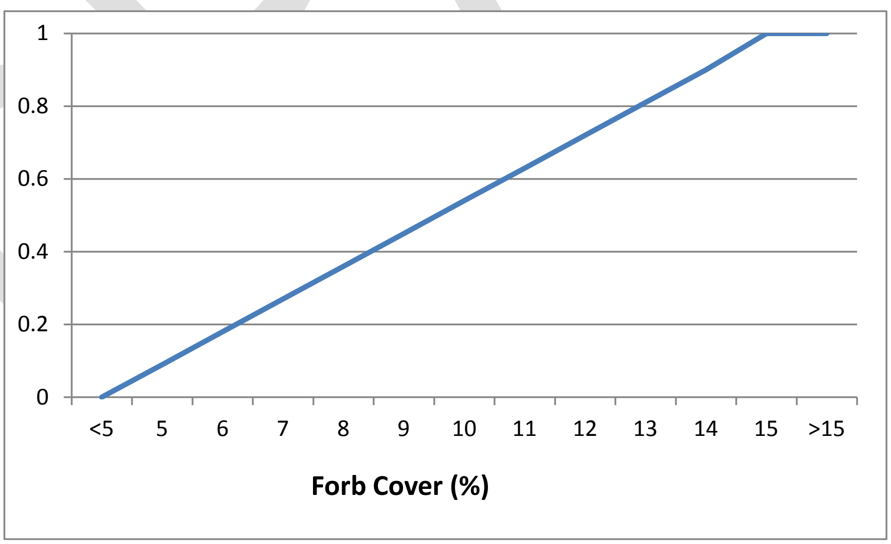
Breeding Habitat: Percent of Forbs That is Noxious Weeds, Mesic and Arid Site in the Upper Green River Basin*



% Noxious Weeds	0	1 - 50	51 - 100
Functionality	1	0.5	0

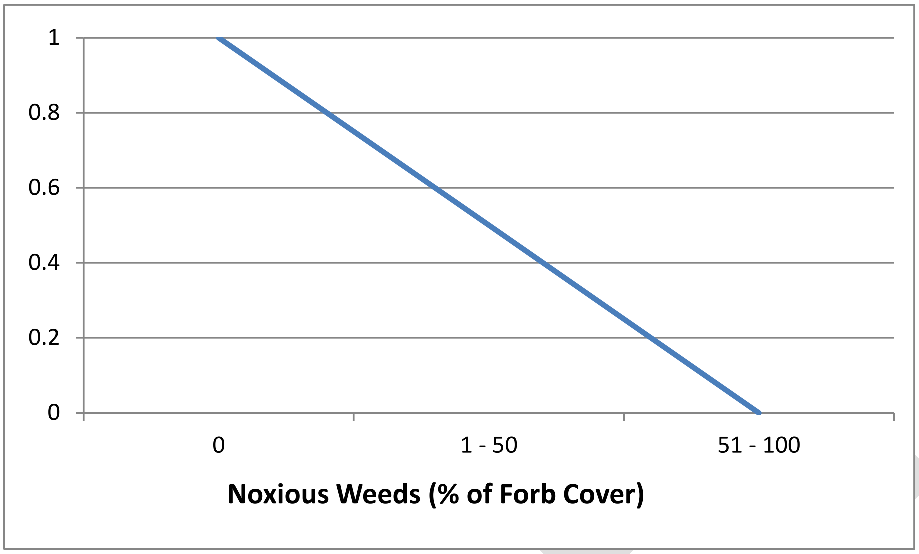
* This curve is a starting point and may be modified as information becomes available.

Summer Habitat: Forb Cover, Mesic and Arid Sites in the Upper Green River Basin



Forb Cover	<5	5	6	7	8	9	10	11	12	13	14	15	>15
Functionality	0	0.09	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.81	0.9	1	1

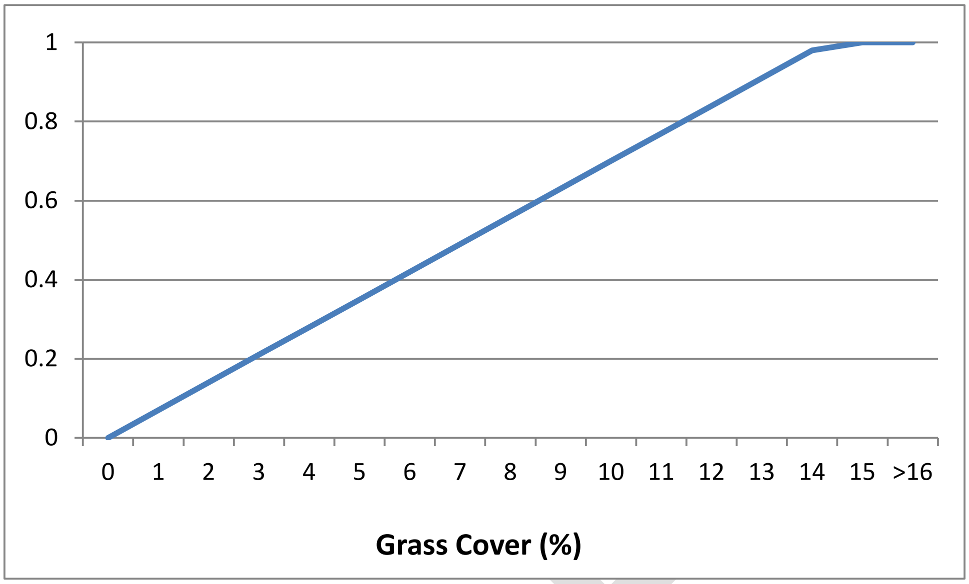
Summer Habitat: Percent of Forbs That is Noxious Weeds, Mesic and Arid Site in the Upper Green River Basin*



% Noxious Weeds	0	1 - 50	51 - 100
Functionality	1	0.5	0

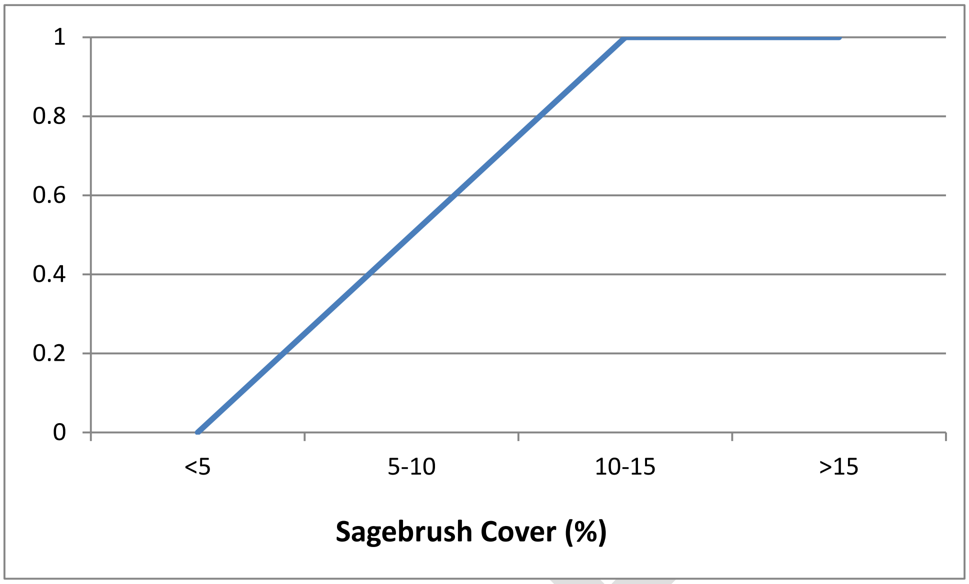
***** This curve is a starting point and may be modified as information becomes available.

Summer Habitat: Grass Cover, Mesic and Arid Site in the Upper Green River Basin



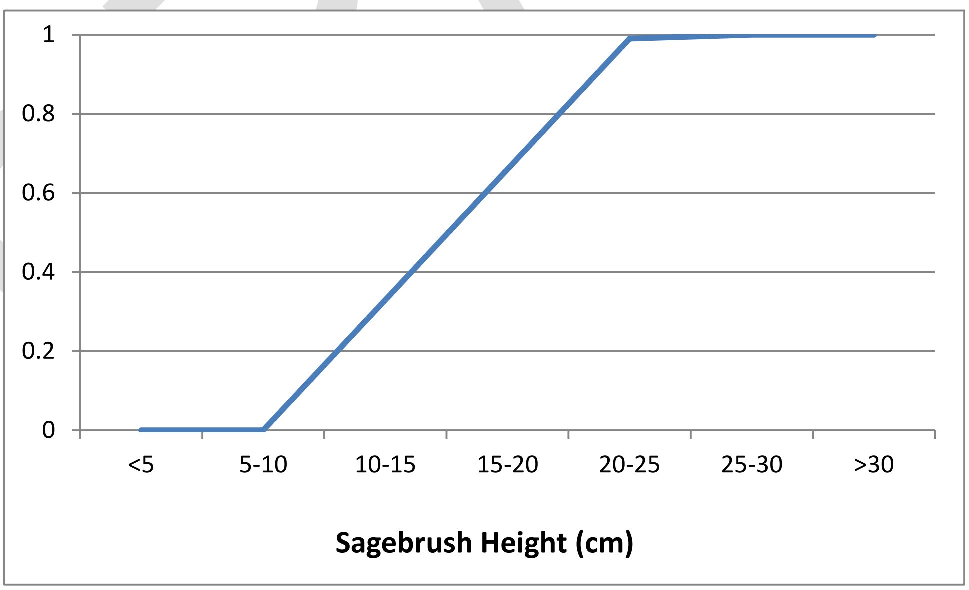
Grass Cover	0	1	2	3	4	5	6	7	8
Functionality	0	0.07	0.14	0.21	0.28	0.35	0.42	0.49	0.56
Grass Cover	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**>16**	
Functionality	0.63	0.7	0.77	0.84	0.91	0.98	1	1	

Winter Habitat: Sagebrush Cover, Mesic and Arid Site in the Upper Green River Basin



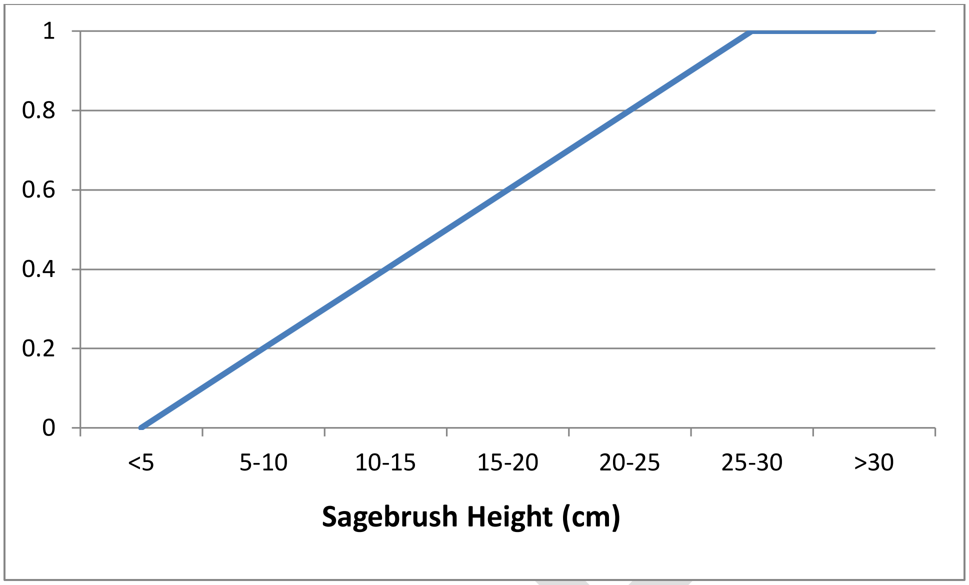
Sagebrush Cover	<5	5-10	10-15	>15
Functionality	0	0.5	1	1

Winter Habitat: Sagebrush Height, Topography <5%, Mesic and Arid Site in the Upper Green River Basin



Sagebrush Height	<5	5-10	10-15	15-20	20-25	25-30	>30
Functionality	0	0	0.33	0.66	0.99	1	1

Winter Habitat: Sagebrush Height, Topography >5%, Mesic and Arid Site in the Upper Green River Basin



Sagebrush Height	<5	5-10	10-15	15-20	20-25	25-30	>30
Functionality	0	0.2	0.4	0.6	0.8	1	1

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

Introduction and Rationale

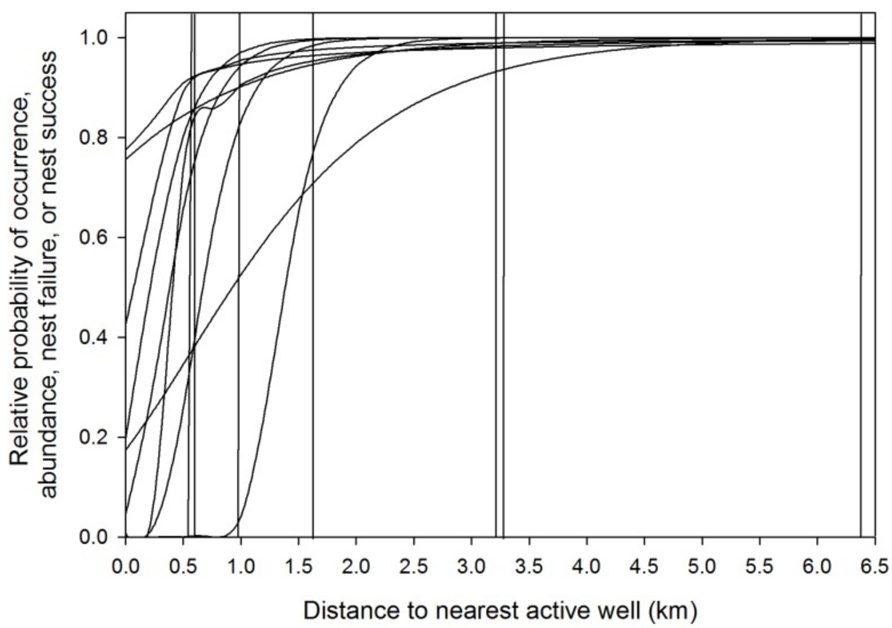
The HQT contains a 4th order or site-level anthropogenic feature modifier to represent the local impacts of anthropogenic features on individual GRSG. Literature results describing the ecology of individual GRSG birds in relation to distance-to-feature were used to inform the modifier values in the site-level 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.

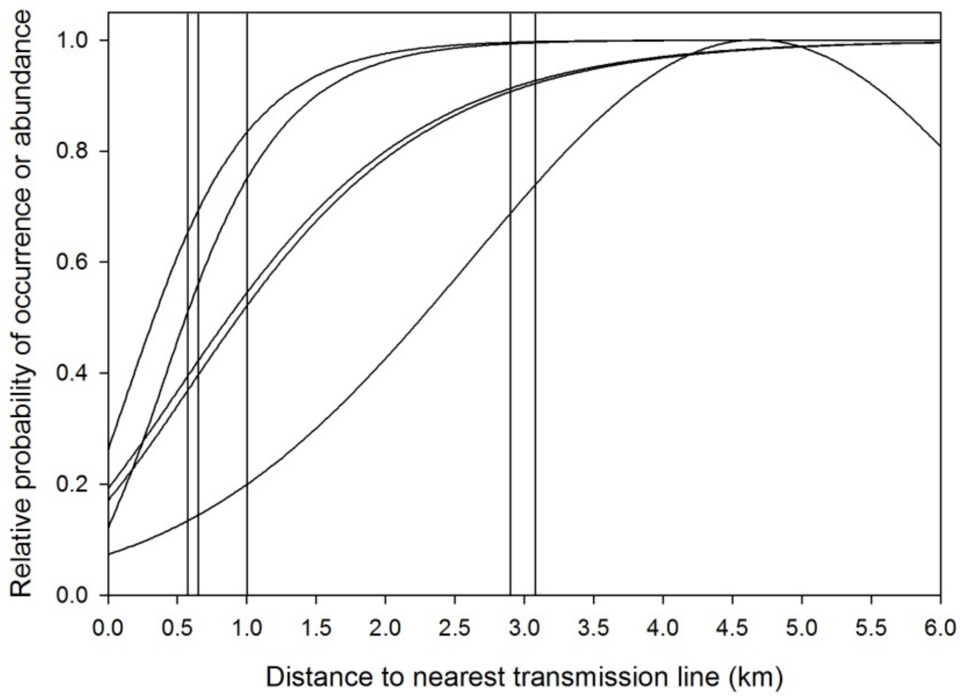
All non-linear curves were obtained by back-transforming the coefficient estimate to a continuous line along the range of the distance-to-feature according to the specific model used in each study (e.g., decay curve, broken-stick models, curvilinear regression, etc.; y = exp(coeff. * distance)). If necessary, 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.



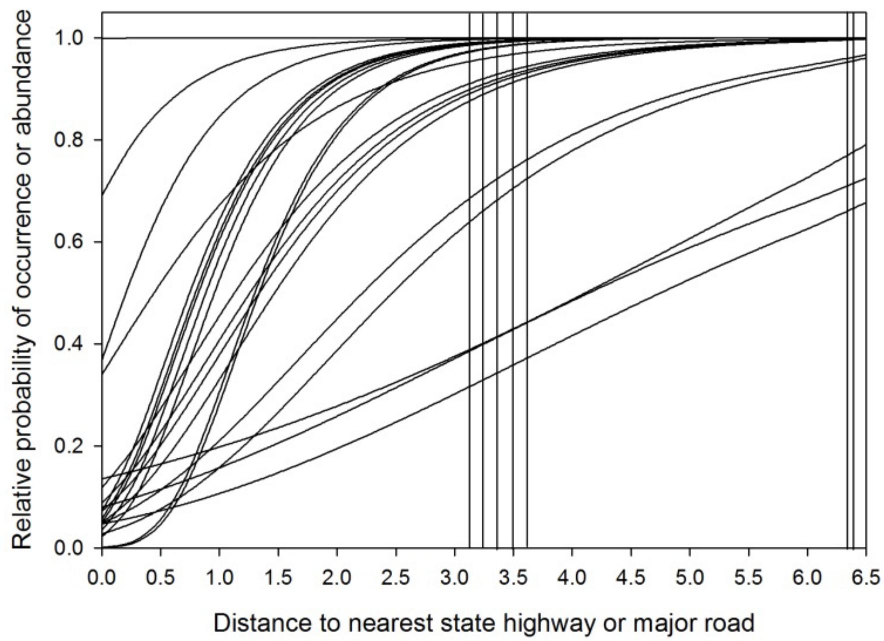
Distance relationships between the nearest active well and sage-grouse brood and winter occurrence, nest site selection, general abundance, and nest failure/success. Each curve or vertical bar is from a separate analysis (n=16). Curves relate to both y- and x-axis; bars relate only to x-axis. Vertical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

Figure 11. Distance to Nearest Active Well (km)



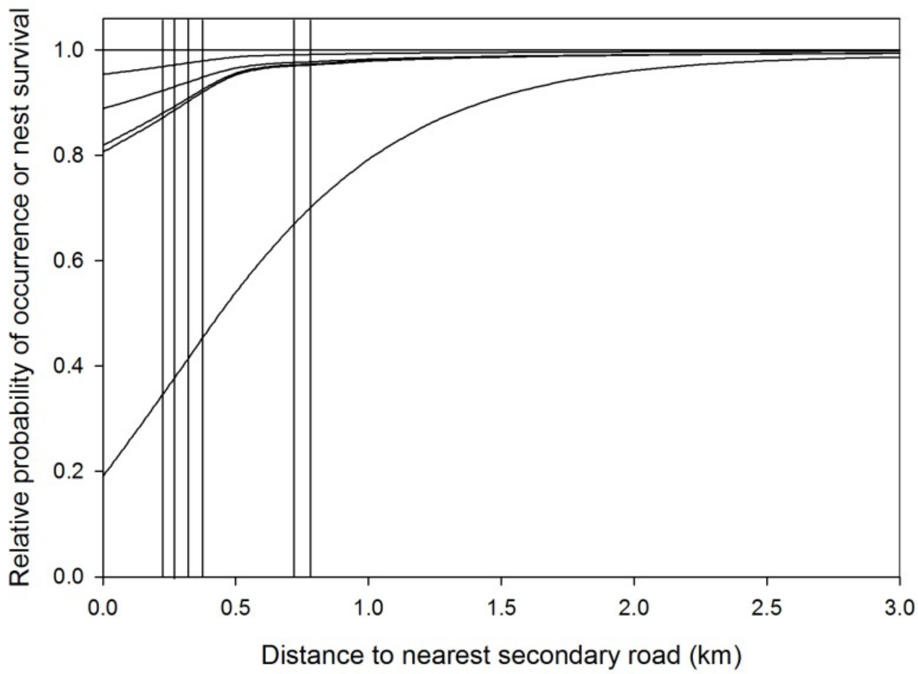
Distance relationships between the nearest transmission line and sage-grouse brood occurrence, adult general occurrence, pellet abundance, and adult survival. Each curve or vertical bar is from a separate analysis (n=10). Curves relate to both y- and x-axis; bars relate only to x-axis. Vertical bars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

Figure 12. 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 13. 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 14. 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 27). For other anthropogenic features, we applied literature-derived distances established for what we considered the most similar feature type (Table 27).

Table 27. 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 30 x 30-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 28. 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 29).	Wyoming Oil and Gas Conservation Commission (2015). Oil and gas well locations. http://wogcc.state.wy.us/ Source date: January 9, 2015
	Inactive	Inactive wells represent locations where wells are recorded by activity is not occurring regularly at the location.	
Towers	Met towers	Point locations for met towers.	Wyoming Game and Fish Department (2015). Met tower spatial locations. http://gf.state.wy.us/METTowers/default.aspx, Accessed February 23, 2015
	Communication 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.
Wind turbines		Point locations for individual wind turbines. We used the O'Donnell and Fancher 2010 dataset plus data points for three wind farms constructed since its publication (current as of April 2015).	O'Donnell, M.S., and T.S. Fancher. 2010. Spatial mapping and attribution of Wyoming wind turbines. U.S. Geological Survey, Denver, Colorado.
Mines	Active – Large	Large mines have an area of 60 acres or more. For coal mines, polygons were available to represent mine boundaries. Other mines were only available as point locations with a reported size. Each point was buffered by a circular radius resulting in a polygon of the same area as that mine's reported size. Activity level was active according to status code of "A".	Active coal permit boundaries, Wyoming Department of Environmental Quality (February 2015) http://deq.wyoming.gov/lqd/coal/resources/chia/ Mine permit dataset. Wyoming Department of Environmental Quality (2014)
	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 "F".	
	Inactive – Small	Small mines have an area of less than 60 acres. Activity level was inactive according to status code of "F".	

Agriculture	Tilled	Polygons representing tilled agriculture were pulled from the National Land Cover Dataset. Code: Cultivated crops (class 82)	U.S. Geological Survey. 2014. NLCD 2011 Land Cover (2011 Edition, amended 2014) - National Geospatial Data Asset (NGDA) Land Use Land Cover.*in* U. S. G. Survey, editor., Sioux Falls, South Dakota.
	Untilled	Polygons representing untilled agriculture were pulled from the National Land Cover Dataset. Code: Pasture/Hay (class 81)	
Urban Development	Medium or High intensity	Polygons representing urban areas were pulled from the National Land Cover Dataset. Two categories were used: Developed, medium intensity (class 23) and Developed, high intensity (class 24).	U.S. Geological Survey. 2014. NLCD 2011 Land Cover (2011 Edition, amended 2014) - National Geospatial Data Asset (NGDA) Land Use Land Cover.*in* U. S. G. Survey, editor., Sioux Falls, South Dakota.
	Low intensity	The developed, low intensity (class 22) category was used.	
Roads	Major roads	This line dataset represents Interstates, state highways and other major roads. Data codes included from the referenced dataset: 1700201, 1700203, 1700205, 1700402	O'Donnell, M.S., T.S. Fancher, A.T. Freeman, A.E. Ziegler, Z.H. Bowen, and C.L. Aldridge. 2014. Large scale Wyoming transportation data - A resource planning tool.*in* U. S. G. S. D. S. 821, editor., http://dx.doi.org/10.3133/ds821.
	Secondary roads	This line dataset represents narrower roads that are may be unpaved and smaller streets and driveways. Data codes included: 1700209, 1700210	

Table 29. Wyoming well status codes present in the oil and gas well dataset used to construct the site-level disturbance index.

Well status code	Well description	Assigned activity level[1]
PO	Producing Oil Well	Active
PG	Producing Gas Well	Active
NI	Notice of Intent to Abandon	Active
SP	Well spudded	Active
FL	Flowing	Active
GL	Gas Lift	Active
PH	Pumping Hydraulic	Active
PL	Plunger Lift	Active
PR	Pumping Rods	Active
PS	Pumping Submersible	Active
AI	Active Injector	Active
PA	Permanently Abandoned	Inactive
DH	Dry Hole	Inactive
SI	Shut-In	Inactive
TA	Temporarily Abandoned	Inactive
DR	Dormant	Inactive
SR	Subsequent Report of Abandonment	Inactive
SO	Suspended Operations	Inactive
M or MW	Monitor Well	Inactive
AP	Active Permit	Inactive
SW	Source Well	Inactive
ND	Not defined in status codes	Inactive
NR	No report	Inactive

[1]Activity levels were assigned to each status code based on communication with Wyoming Oil and Gas Conservation Commission staff.

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, powerline, or oil/natural gas well pad on greater sage-grouse 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. 2013. Common raven density and greater sage-grouse nesting success in southern Wyoming: potential conservation and management implications. Ph.D. Dissertation, Utah State University, Logan, Utah.

Dinkins, J. B., M. R. Conover, C. P. Kirol, J. L. Beck, and S. N. Frey. 2014. Greater sage-grouse (*Centrocercus urophasianus*) hen survival: effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology 92: 319-330.

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 C. 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 30.

Each upper or lower threshold was represented by an amount of anthropogenic feature per unit area (Table 30). 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 30). These areas were assigned to be consistent with the 30-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 31, 32). 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 30-m raster resolution associated with statewide land cover datasets for Wyoming (i.e., the smallest footprint possible for any point feature was 30 m by 30 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 30). 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 30. Disturbance density thresholds applied for the Landscape Disturbance Index in Wyoming

	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	0.04 km^2/km^2	0.11 km^2/km^2
Density threshold applied to 3.2 km radius	0.96 km^2/ 32.2 km^2 (237 acres/12.4 mi^2 or 7936 acres	3.73 km^2/ 32.2 km^2 (922 acres/12.4 mi^2 or 7936 acres
Area associated with density threshold at 3.2-km radius	237 acres; equivalent to 3% disturbance	922 acres; equivalent to 11.5% disturbance

[A] 4047 m^2 (1 acre) was used to represent the footprint per well pad.
[B] 0.03 km^2 (1 km, 30-m wide) was used to represent the footprint per kilometer of road.

Table 31. Disturbance footprint determination for the Landscape Disturbance Index in Wyoming

Disturbance feature	**Feature type**	**Footprint per feature**	**How disturbance footprint was determined**
Active Oil & Gas Wells	point	60 m x 60 m	Average well pad size was 0.4 ha (1 acre). A 60-m x 60-m footprint equates to 0.36 ha (0.89 acre). Multiple well pads in each of the Jonah Field, Pinedale Anticline, Bighorn Basin and Powder River Basin were measured 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.
Wind Turbines	point	30 m x 30 m	Turbine pads average 10m x 10m and width of turbines including blades average 50m x 50 m. Measurements were made using high-resolution aerial imagery.
Towers	point	30 m x 30 m	Towers typically range in size from 5x 5 m to 30 x 30 m.
Transmission Lines	line	30 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	60 m width	The widths of Interstates 25 and 80, including the medians, ranges from 40 m to 75 m. Measurements were made using high-resolution aerial imagery.
Roads – State Highways and Secondary Roads	line	30 m width	State highways are 10-15m wide, and secondary roads are typically 10 m wide or less. Measurements were made using high-resolution aerial imagery.
Active Coal Mines	polygon	Polygon extent	Polygons represent mine boundaries. Boundaries were only available for this type of mine, which are generally the largest surface mines in Wyoming. Only active mines were included due to associated levels of activity.
Other Active Mines	point	Variable, based on mine size	An estimate of size (ha) was available for each mine point location. Each point was buffered by a circular radius resulting in a polygon of the same area as that mine's size.

Table 32. 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 33).	Wyoming Oil and Gas Conservation Commission (2015). Oil and gas well locations. http://wogcc.state.wy.us/ Source date: January 9, 2015
Wind Turbines	Point locations for individual wind turbines. We used the O'Donnell and Fancher 2010 dataset plus data points for three wind farms constructed since its publication (current as of April 2015).	O'Donnell, M.S., and T.S. Fancher. 2010. Spatial mapping and attribution of Wyoming wind turbines. U.S. Geological Survey, Denver, Colorado.
Towers	Point locations for met towers and communication towers.	Wyoming Game and Fish Department (2015). Met tower spatial locations. http://gf.state.wy.us/METTowers/ default.aspx, Accessed February 23, 2015 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	Polygons representing urban areas were pulled from the National Land Cover Dataset. Three categories were used: Developed, medium intensity (class 23); Developed, high intensity (class 24); and Developed, low intensity (class 22).	U.S. Geological Survey. 2014. NLCD 2011 Land Cover (2011 Edition, amended 2014) - National Geospatial Data Asset (NGDA) Land Use Land Cover.*in* U. S. G. Survey, editor., Sioux Falls, South Dakota.
Roads – Interstate Highways	This line dataset represents Interstates 25 and 80 in Wyoming. Data codes included from the referenced dataset: 1700201, 1700203	O'Donnell, M.S., T.S. Fancher, A.T. Freeman, A.E. Ziegler, Z.H. Bowen, and C.L. Aldridge. 2014. Large scale Wyoming transportation data - A resource planning tool.*in* U. S. G. S. D. S. 821, editor., http://dx.doi.org/10.3133/ds821.
Roads – State Highways and Secondary Roads	This line dataset represents other highways and secondary roads. Data codes included from the referenced dataset: 1700205, 1700209, 1700210, 1700211, 1700402	O'Donnell, M.S., T.S. Fancher, A.T. Freeman, A.E. Ziegler, Z.H. Bowen, and C.L. Aldridge. 2014. Large scale Wyoming transportation data - A resource planning tool.*in* U. S. G. S. D. S. 821, editor., http://dx.doi.org/10.3133/ds821.
Active Coal Mines	This polygon dataset represents the boundaries of active coal mines.	Active coal permit boundaries, Wyoming Department of Environmental Quality (February 2015) http://deq.wyoming.gov/lqd/coal/ resources/chia/
Other Active Mines	Point locations for active mine permits other than coal. Active mines (code =A) were selected from this dataset. Size representation of mines of these mines is described in Table 30.	Mine permit dataset. Wyoming Department of Environmental Quality (2014)

Table 33. **Wyoming 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[1]
PO	Producing Oil Well	Active
PG	Producing Gas Well	Active
NI	Notice of Intent to Abandon	Active
SP	Well spudded	Active
FL	Flowing	Active
GL	Gas Lift	Active
PH	Pumping Hydraulic	Active
PL	Plunger Lift	Active
PR	Pumping Rods	Active
PS	Pumping Submersible	Active
AI	Active Injector	Active
PA	Permanently Abandoned	Inactive
DH	Dry Hole	Inactive
SI	Shut-In	Inactive
TA	Temporarily Abandoned	Inactive
DR	Dormant	Inactive
SR	Subsequent Report of Abandonment	Inactive
SO	Suspended Operations	Inactive
M or MW	Monitor Well	Inactive
AP	Active Permit	Inactive
SW	Source Well	Inactive
ND	Not defined in status codes	Inactive
NR	No report	Inactive

[1]Activity levels were assigned to each status code based on communication with Wyoming Oil and Gas Conservation Commission staff.

Appendix D. Forb and Grass Species List

Information compiled by Alan Sands and Kerry Reese. Modified from a list compiled by Scott Lambert for the northern Great Basin with additions to reflect conditions across the species range.

Species Name	Common Name	Species Name	Common Name
Achillea lanulosa	Yarrow	Lithophragma parvifolia	Woodland star
Agoseris glauca	False dandelion	L. bulbifera	Woodland star
Allium spp.	Wild onion	Lithospermum ruderale	Western stoneseed
Androsace septentrionalis	Northern rock jasmine	Lomatium dissectum	Fernleaf biscuitroot
Antennaria spp.	Pussytoes	L. triternatum	Nineleaf biscuitroot
Arabis cobrensis	Sagebrush rockcress	L. nevadense	Nevada biscuitroot
Arnica spp.	Arnica	Lupinus spp.	Lupine
Aster occidentalis	Western aster	Medicago sativa	Alfalfa
Astragalus spp.	Milkvetch (native aridland ecotypes)	Melilotus officinalis	Yellow sweetclover
Balsamorhiza sagittata	Arrowleaf balsamroot	Mertensia oblongifolia	Oblongleaf bluebells
B. hookeri	Rock balsamroot	Microseris nutans	Nodding microceris
Calochortus macrocarpus	Sagebrush mariposa lily	Oenothera spp.	Evening-primrose
C. nuttallii	Sego lily	Onobrychis viciifolia	Sainfoin
C. gunnisoni	Gunnison’s mariposa lily	Penstemon strictus	Rocky mountain penstemon
Castilleja spp.	Indian paintbrush	Phlox hoodii	Hoods phlox
Cleome lutea	Yellow spikeflower	P. gracilis	Slender phlox
C. serrulata	Rocky mountain beeplant	P. longfolia	Longleaf phlox
Collinsia parviflora	Maiden blue eyed Mary	Polygonum spp.	Knotweed
Crepis acuminata	Tapertip hawksbeard	Sanguisorba minor	Small burnet
C. occidentalis	Largeflower hawksbeard	Sphaeralcea munroana	Globemallow
C. intermedia	Limestone hawksbeard	Taraxicum officinale	Dandelion
Erigeron spp.	Fleabane	Townsendia hookeri	Hooker’s townsend daisy
Eriogonum umbellatum	Sulphur-flower buckwheat	Tragopogon dubius	Yellow salsify
Grindelia squarrosa	Curlcup gumweed	Trifolium macrocephalum	Largehead clover
Hydrophyllum capitatum	Ballhead waterleaf	T. variegatum	Whitetip clover
Lactuca serriola	Prickly lettuce	T. gymnocarpon	Hollyleaf clover
Lepidium densiflorum	Common pepperweed	Vicia spp.	Vetch
Linum lewisii	Prairie flax		
L. perenne	Blue flax		

Appendix E. Field Data Collection Methods

The methods outlined below are for field data collection of attributes associated with the 4th order scale, which defines habitat conditions at the site of proposed activities. The attributes in Table 34 collected for the habitat model result in functional acre scores for specified habitat areas.

Table 34. Methods for Data Collection of Field Attributes

ATTRIBUTE	RESOURCE	GRSG SEASON	ATTRIBUTE DATA COLLECTION SUMMARY
Sagebrush Height	Cover / Refugia	Breeding	The sagebrush height is measured for plants intersecting transect line (see also sagebrush canopy cover).
Sagebrush Canopy Cover		Breeding	The percent canopy cover is estimated with line intercept (% of shrub canopy intersecting transect line).
Perennial Grass Height		Breeding	The grass height is measured for plants intersecting transect line (see also grass canopy cover).
Perennial Grass Cover		Breeding, Summer	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.
Forb Cover	Foraging	Breeding, Summer	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.
Percent of Forbs that is Noxious Weeds		Breeding, Summer	Presence of noxious weeds 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.
Sagebrush Height	Cover / Refugia and Foraging	Winter	The sagebrush height is measured for plants intersecting transect line (see also sagebrush canopy cover).
Sagebrush Canopy Cover		Winter	The percent canopy cover is estimated with line intercept (% of shrub canopy intersecting transect line).
Invasive Grass Canopy Cover			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.
Presence of Facultative Forb Species			Presence of facultative forbs is measured for plants intersecting transect line.

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 site is defined as the area being evaluated and includes all habitats within a maximum zone of influence surrounding existing and proposed installations. 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 sampling location at the center of 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 move at least 200 feet from the area, throw a Frisbee or other identifiable object a short direction and use that as the center stake of the transect line.

Although the HQT generally describes seasonal habitat use by GRSG, 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).

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 5.2. The HQT Calculator includes this option for maximizing 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.

Transect Layout and Initial Measurements

The core layout for the measurements that follow will be a 50-meter 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-meter 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 meters) 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-line 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 wooden 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.
- 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.
- Height of Other Shrubs. If another non-sage shrub is within one meter of the meter mark, note the species and the height of the plant.

Sagebrush Cover via Line- or Point-Line Intercept

Record the start and stop points of the sagebrush and conifer intersections along the 50-meter tape. Consider a length of sagebrush unbroken if there is no more than a 5.0 cm. gap. Measure intersections of both 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.

Anthropogenic Features Measurements

All of the measurements in the datasheet related to anthropogenic disturbance will be accomplished with GIS.

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 F. Field Datasheet

EcoMetrix Revised 03-18-15 (JKo)

SAGE-GROUSE Attribute Measurements

Site Name:

Map Unit ID: | Date: | Observers:

Transect #: | Transect UTM E: | Transect UTM N:

Transect Sample Bearing (^{0}): | Camera / Photo #'s:

% Slope: <5% or >5% (Circle one) | Aspect (°):

Presence of quality sagebrush cover* within 60 m? Yes No (Circle one)

*quality sagebrush cover = 30 x 30 meter or greater area with ave. cover value of ≥15% and ave. height of ≥20 cm

LINE INTERCEPT (SHRUB COVER)

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

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

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

Notes for Line Transect:

EcoMetrix Revised 03-18-15 (JKo)

SAGE-GROUSE Attribute Measurements

Site Name:

Map Unit ID: | Date: | Observers:

Transect #: | Transect UTM E: | Transect UTM N:

Transect Sample Bearing (^{0}): | Camera / Photo #'s:

% Slope: <5% or >5% (Circle one) | Aspect (°):

Presence of quality sagebrush cover* within 60 m? Yes No (Circle one)

*quality sagebrush cover = 30 x 30 meter or greater area with ave. cover value of ≥15% and ave. height of ≥20 cm

DAUBENMIRE PLOTS (HERBACEOUS COVER)

Record percent cover

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

Notes for Daubenmire plots and unknown species codes/descriptions:

Appendix G. Relationship of the Habitat Quantification Tool to the Wyoming Core Areas Strategy and Executive Order

The Wyoming core areas strategy (*Sage-Grouse Core Area Protection,* Wyoming Exec. Order No. 2011-5) identifies core population areas for the sage-grouse in Wyoming. A goal of the strategy is to reduce impacts to sage-grouse within core areas. In core areas, the strategy requires that new development or land uses should be authorized or conducted only when it can be demonstrated that the activities will not cause declines in sage grouse populations (EO No. 2011-5). The strategy states that disturbances within core areas will be deemed to not cause declines in sage-grouse populations provided that total disturbance within the core areas is limited to 5% and 1 disturbance per section. The Executive Order is a regulatory mechanism. As detailed in the WCE Manual, the WCE is designed to work within the rules and regulations of the state of Wyoming and the federal agencies. Projects using the WCE will ultimately be governed by these rules and regulations.

The goal of the Wyoming Conservation Exchange (WCE) is to encourage compensatory mitigation as part of the mitigation hierarchy (avoidance, then minimization, then restoration, then compensatory mitigation). The purpose of the Habitat Quantification Tool (HQT) as an essential part of the WCE is to quantify the change in quality of sage-grouse habitat resulting from management activities. Quantified values are used to equilibrate impacts and offsets in order to determine the offset when compensatory mitigation is appropriate. Thus, the WCE is a voluntary compensatory mitigation tool, whereas the core areas policy is a mitigation regulation. They have different goals and therefore are designed differently. However, the metrics used to evaluate habitat conditions relevant to the core areas strategy and the WCE are similar.

The HQT is a measure of the existing quality of the habitat relative to optimal conditions. Quality is measured first by assessing the existing habitat conditions on a particular development (impact) or habitat project (offset) location. The quality of this site is then modified by the quality of the surrounding landscape. The result is a functionality score (expressed as a percentage) that is then multiplied by the size of the site resulting in functional acres. “Functional acres” then serve as a “currency” for the program whereby “debits” accrued as a function of actions that decrease habitat quality are offset by “credits” that accrue as a function of actions that increase habitat quality.

The HQT includes metrics that are consistent with the core area strategy.

1) *Use of direct surface disturbance density*

   In the EO, direct surface disturbance on a project-by-project basis is quantified by implementing the Density and Disturbance Calculation Tool (DDCT). The HQT uses a “Landscape Disturbance

Index" (LDI) to quantify direct surface disturbance across the landscape. Direct surface disturbance density (i.e., the cumulative density of anthropogenic structures on the landscape) is used as a metric to determine the quality of the landscape surrounding an impact or offset project. In other words, direct disturbance density is a measure of the quality of the landscape and is used in the determination of the value of a site for the greater sage-grouse. Although the LDI incudes similar disturbance types and similar spatial representations of disturbance as the EO, the LDI is implemented at a coarse statewide scale while the DDCT is implemented at fine-resolution scales specific to individual projects.

The LDI quantifies density over a 3.2-km radius surrounding each raster cell, which is the median distance over which disturbance-density effects have been measured for sage-grouse in the scientific literature. This differs from the spatial scale at which densities are calculated in the DDCT (*Density and Disturbance Calculation Tool Manual*, 04-16-12). The reason the two approaches do not calculate density across the same area is that they have different purposes. The DDCT's purpose is to calculate the density within a defined project area to determine whether the 5% threshold has been met. The LDI's purpose is to calculate density as a way to assess the quality of landscape contexts across a broad area and use this quality measure as a way to estimate the value of a site for sage-grouse.

Similar to the EO, the LDI uses literature-based density thresholds to determine locations on the landscape that are unsuitable because of direct surface disturbance. In the LDI, a location on the landscape is considered unsuitable (i.e., fully disturbed) if the cumulative density of disturbance on the landscape is greater than a density of 3.73 km^2/32.2 km^2 (or 11.6% disturbed). A location is considered 100% suitable if the density of disturbance on the landscape is less than a density equivalent to 0.96 km^2/32.2 km^2 (or 3.0% disturbed). The HQT considers densities between 3.0% and 11.6% to be intermediate levels of suitability. Note that, that these threshold numbers are specific to the 30-m resolution at which they were applied (see Appendix C for details).

In addition to the 5% surface disturbance threshold, the Core Areas approach includes a threshold that establishes infrastructure densities below 1 pad/section as "de minimus". This metric in the EO corresponds to the lower threshold in the LDI (i.e., 3% surface disturbance). But, the lower threshold in the LDI is expressed as the proportion of the landscape directly influenced by the footprint associated with this infrastructure density level, not as a count of infrastructure present. This is the reason for differences in the thresholds established between the 2 approaches. Although both approaches are using the proportion of the surface disturbed as a measure of habitat quality, the 3% threshold in the LDI corresponds more directly to the 1 pad/section threshold in the EO; it does not directly correspond to the 5% threshold in the EO. The LDI only included the footprint associated with anthropogenic infrastructure to establish thresholds while the EO included additional types of disturbances in the 5% threshold.

2) *Distance to lek*

The EO uses 4 miles (or 6 km) from a lek as a way to delineate a project area. The HQT uses the same literature-derived distance to modify the value of a site. A site is considered 100% suitable as breeding habitat if it is within 6 km of a lek. If a site is further than 6 km from a lek, then its value as breeding habitat is modified downward as this distance increases. However, at no point is a site considered unsuitable as breeding habitat based just on this metric.

3) *Sagebrush canopy cover*

The HQT uses sagebrush canopy cover to establish suitable habitat similarly to the EO, and the HQT is restricted to occupied range similarly to the EO. These establish that both approaches will occur on the same landscape, suggesting that the Exchange could be considered a tool used to complement the EO.

Understanding the outputs of the DDCT and the HQT

As described above, the DDCT and the HQT have been designed for different purposes, and therefore have somewhat different outputs. However, because the DDCT and the HQT are measuring direct surface density in a similar way, they are using similar measures of landscape habitat quality and suitability. The differences in approaches given similar metrics (density and surface disturbance) may present opportunities for using the HQT, or tools within the HQT, to complement conservation through the EO.

For example, the LDI could be used to inform the spatial arrangement of infrastructure at the scale of a core area. The LDI will suggest where on the landscape surface disturbance densities are already high, thereby spatially informing where co-location of infrastructure could be accomplished. Although the EO currently recommends the co-location of infrastructure, the LDI provides quantified information on where that recommendation could be achieved thereby complementing implementation of the EO.

Ultimately, the HQT can potentially provide information to support and complement the Core Area Strategy that could be valuable beyond its specific use in the WCE.

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