Interpreting Indicators of Rangeland Health

Technical Reference 1734-6, Version 5

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Technical Reference 1734-6, Version 5

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1. Preface to Version 5

Version 5 of "Interpreting Indicators of Rangeland Health" (IIRH), Technical Reference 1734-6, is the third published edition of this protocol. Version 5 reflects protocol updates and clarifications identified through 15 years of teaching and applying the IIRH protocol using Version 4 (Pellant et al. 2005). Changes in Version 5 further improve the ease of protocol use and consistency in its application. In Version 5, some of the indicator names are slightly modified, and the protocol to assess functional/structural groups (indicator 12) improves user application.

A key clarification in Version 5 is that the indicator narratives described in the **reference sheet**[1] (Appendix 1a) should describe the **natural range of variability** within the reference state, a concept that was implied in Version 4. Advances in the understanding of reference states for ecological sites and their variability in space and time now enable better descriptions of the natural range of variability for each indicator.

Version 5 refines how several key concepts are defined and used in developing the IIRH reference sheet and conducting assessments. Disturbance events include weather events, fire, climate variability, and human and animal activities that influence ecosystem structure and function. The **natural range of variability** includes the range of variability associated with the **natural disturbance regime**. The natural disturbance regime describes the kind, frequency, and intensity of natural disturbance events that would have occurred on an ecological site prior to European influence (ca. 1600) (Winthers et al. 2005). Natural disturbances include, but are not limited to, native insect outbreaks, wildfires, native wildlife activities (herbivory, burrowing, etc.), indigenous human activities, and weather cycles and extremes (including droughts and unusual wet periods, temperatures, and snow and wind events). The natural range of variability does not include influences of nonnative plant or animal species and also does not encompass soil degradation, such as accelerated erosion, organic matter loss, changes in nutrient availability, or soil structure degradation, beyond what would be expected to occur under the natural disturbance regime.

Version 5 also introduces new guidance for reference sheet content. The **reference sheet** is the primary reference for all assessments of rangeland health and is required to conduct an IIRH assessment. It describes, to the extent possible, expected ranges for each of the 17 indicators under the **natural disturbance regime**. A **reference sheet checklist** (Appendix 1a) is provided to improve consistency in describing the natural disturbance regime within the **natural range of variability** for each indicator when developing and revising reference sheets. Additionally, Version 5 introduces four "subindicators" for indicator 12 (functional/structural groups) and incorporates a **functional/structural groups** table (Appendix 1b) for consistent organization of the required information in the reference sheet. The functional/

[1] Glossary terms are sometimes highlighted in bold throughout the technical reference, and definitions appear in the glossary.

structural groups table defines the **relative dominance** of functional/structural groups within each community phase in the reference state. Reference sheets providing the information identified in the reference sheet checklist, including the functional/structural groups table, will provide evaluators with the appropriate information to make consistent evaluations. Existing reference sheets can continue to be used while updates and revisions are occurring, as long as they are supplemented with completed functional/structural groups tables (Appendix 1b).

This version also reflects revisions to the **evaluation matrix** (Appendix 2) descriptors to increase consistency of indicator ratings. As stated in Version 4, the development and use of ecological site-specific evaluation matrices are strongly recommended. In addition, a functional/structural groups worksheet (Appendix 4) is provided to document observations at each evaluation area and facilitate consistent rating of the functional/structural groups indicator.

In this version, **ephemeral systems** (areas that receive more water than typical upland sites) can now be evaluated using the IIRH protocol when appropriate reference information is available (see Section 5.3).

In addition to these key changes and clarifications, Version 5 provides further instructions and resources for completing an assessment, including appendices describing the steps for identifying ecological sites, describing soils, and estimating annual production.

Supporting assessments of rangeland health with quantitative measurements is recommended when possible. Those working in the United States are particularly encouraged to apply the standardized **core methods** as described in the "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems," Volume I (Herrick et al. 2017). The use of these quantitative methods allows data to be combined and compared across ownership and jurisdictional boundaries. Examples of two applications of IIRH and the standardized core methods to national assessment and monitoring are provided in Herrick et al. (2010), the "RCA Appraisal: Soil and Water Resources Conservation Act" (USDA 2011; NRCS 2015), and the "Bureau of Land Management Rangeland Resource Assessment—2011" (Karl et al. 2016).

The authors acknowledge and support that IIRH is being used with modifications for various applications and for different objectives than those described under "Intended Applications of Version 5" (Section 3). However, completion of all protocol steps described herein is required in order to assess the status of the three attributes of rangeland health (Section 4).

In conclusion, interpretations made with Version 5 should be consistent with those made with Version 4 at the attribute level, provided that similar reference information is used.

2. Introduction

The science of assessing **rangelands** changes as concepts and protocols evolve (Briske et al. 2005). In 1994, the National Research Council presented the concept of **rangeland health** as an alternative to **range condition** (NRC 1994). Although the word "health" was initially controversial when used in association with natural systems (Wicklum and Davies 1995; Lackey 1998; Rapport et al. 1998; Smith 1999), such as rangelands, this technical reference follows the National Academy of Sciences suggestion (NRC 1994) and reflects the increasing acceptance of the term for condition of rangeland and agricultural soils (Brown and Herrick 2016).

A National Research Council publication, "Rangeland Health: New Methods to Classify, Inventory, and Monitor Rangelands" (NRC 1994), defines rangeland health as:

"The degree to which the integrity of the soil and ecological processes of rangeland ecosystems are maintained."

In a parallel effort, a Society for Range Management committee recommended that rangeland assessments should focus on the maintenance of soil at the site (Task Group on Unity in Concepts and Terminology 1995). Subsequently, a federal interagency committee was established to integrate concepts of these two groups into their agencies' rangeland inventories and assessments. This committee refined the National Research Council's definition to read:

"The degree to which the integrity of the soil, vegetation, water, and air, as well as the ecological processes of the rangeland ecosystem are balanced and sustained."

The interagency committee defined integrity as *"maintenance of the functional attributes characteristic of a locale, including normal variability"* (NRCS 2006).

Scientists and managers face continuing challenges to translate rangeland health into terms that the public can comprehend and that resource specialists can use to assist in identifying areas where ecological processes are or are not functioning properly.

Qualitative assessments provide relatively rapid techniques to rate site protection indicators, including both plant and soil components (Morgan 1986). The use of qualitative information to determine vegetation and soil conditions has a long history in land management inventory and monitoring. In some cases, qualitative assessments have been used independently. However, in other cases, they were used in conjunction with quantitative measurements (Wagner 1989).

Early procedures that used indicator ratings (e.g., a scorecard approach) included instructions for range surveys by the Interagency Range Survey Committee of 1937, the Deming two-phase method, and the Parker three-step method, which used indicators to assess soil and site stability and usefulness of forage for livestock grazing (Wagner 1989). The Bureau of Land Management (BLM) also used soil surface factors to determine the erosional status of public lands in the 1970s (BLM 1973). Interagency Technical Reference

1737-15 (Second Edition), titled "Riparian Area Management: Proper Functioning Condition Assessment for Lotic Areas" (Dickard et al. 2015), uses a qualitative checklist to assess the proper functioning condition of riparian areas.

The IIRH protocol is primarily a qualitative assessment of ecological processes using 17 observable indicators, most of which can be supported by appropriate quantitative measures. Version 5 and preceding versions of IIRH incorporate concepts and materials from previous inventory and monitoring procedures, as well as from the National Research Council's book on rangeland health (NRC 1994) and the Society for Range Management's Task Group on Unity in Concepts and Terminology (1995). Development of a landscape ecology approach to assessing rangeland function in Australia (see Section 6.1.3) also contributed to the understanding of soil processes on North American rangelands and to the interpretations derived from this protocol (Tongway 1994).

The earliest versions of IIRH were developed concurrently. An interagency team led by the BLM developed Version 1a (Pellant 1996). The Natural Resources Conservation Service (NRCS) developed Version 1b, as published in the "National Range and Pasture Handbook" (NRCS 1997b). An interagency team melded these concepts and protocols with the results of numerous field tests of Version 1a (Rasmussen et al. 1999) and Version 1b to develop Version 2. Extensive peer review of several iterations of Version 2 was used to generate Version 3 (Pellant et al. 2000), which was published as an interagency technical reference and was the first widely applied version. Version 4 (Pellant et al. 2005) incorporated reference sheet narratives of each indicator as the standard for evaluating sites (Pyke et al. 2002).

This version, Version 5, includes suggested changes and clarifications from a large number of users and peer reviewers of Versions 3 and 4, including feedback from more than 2,500 participants in multiday workshops led by the authors and contributors. These changes and clarifications improve the consistency of the application and interpretations made using this protocol. Future revisions are anticipated as science and experience provide additional information on indicators of rangeland health and their assessment.

3. Intended Applications of Version 5

"Interpreting Indicators of Rangeland Health" is intended to be used at the ecological site scale or equivalent landscape unit (see Sections 5.2 Ecological Sites and 5.7 Other Landscape Classification Systems), using ecological site descriptions, including site-specific state-and-transition models and reference sheets (Appendix 1a), and ecological reference areas (when available) to conduct assessments of rangeland health. The protocol is intended for use on the following types of land.

Rangelands are "lands on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly" (SRM 1999). Rangeland vegetation types appropriate for IIRH assessments include grasslands, savannas, shrublands, desert, tundra, and alpine communities.

Woodlands are areas with a low density of trees forming open plant communities that support an understory of shrubs and herbaceous plants. When appropriate reference information is available, the IIRH protocol can be applied in open and drier forest systems and woodlands (e.g., oak[2], pinyon-juniper).

Ephemeral systems in rangelands and woodlands are areas that receive more water than typical upland ecological sites, but the water remains for short periods of time (generally less than 1 month at a time in most years). If they are of sufficient size, ephemeral water systems can be evaluated using the IIRH protocol when appropriate reference information is available (see Section 5.3 for a complete description of ephemeral water systems).

Appropriate applications and limitations in the use of IIRH follow.

The protocol described in this technical reference is designed to:

- Be used within the context of a landscape classification system, such as ecological sites or equivalent units.
- Be used with an appropriate **reference sheet** describing the natural disturbance regime within the natural range of variability for the 17 indicators at a given site.
- Be used only by people who are knowledgeable and experienced with the protocol and the ecological system being evaluated (including formal training or working closely with others who have training and experience).
- Provide a preliminary evaluation of the three attributes of rangeland health (soil/site stability, hydrologic function, and biotic integrity) at an evaluation area by rating all 17 indicators and considering them in the attribute rating step of the assessment.
- Be used to communicate fundamental ecological concepts to a wide variety of audiences.

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2 The common names of plants are used in this technical reference. Refer to Appendix 11 for a list of common plant names and associated scientific names used in this technical reference.

- Improve communication by focusing discussion on critical ecosystem properties and processes.
- Assist in identifying monitoring priorities and selecting monitoring sites.
- Assist land managers in identifying areas that are at risk of degradation and where resource problems or management opportunities currently exist.
- Be used as a tool for prioritizing landscapes for potential types of restoration (Pyke 2011; Pyke et al. 2018).

The protocol is not to be used to:

- Identify the cause(s) of resource problems.
- Independently make grazing and other management changes.
- Independently monitor land or determine trend (repeated evaluations may be used to help interpret quantitative monitoring data collected at the same times).
- Independently generate national or regional assessments of rangeland health.

This protocol requires a sufficient understanding of ecological processes, vegetation, and soils for each evaluation area. Experience in IIRH trainings and field application has shown that the quality and consistency of assessments are improved when two or more individuals with collective knowledge of soils, vegetation, and disturbance relationships (e.g., rangeland ecologist, soil scientist, hydrologist) work together to apply this protocol and rate the indicators and attributes using a consensus approach.

4. Attributes of Rangeland Health

The product of an IIRH assessment is not a single rating of rangeland health but, rather, three attribute ratings based on assessments of subsets of the 17 indicators (Table 1). Each **attribute of rangeland health**, as used in the IIRH protocol, represents a suite of interrelated ecological properties (e.g., species composition) and processes (e.g., water cycle, energy flow, and nutrient cycle) that are essential to ecosystem function. The three attributes that collectively define rangeland health include soil/site stability, hydrologic function, and biotic integrity.

Ecological processes functioning within a **natural range of variability** support specific plant and animal communities. **Ecological processes** include the **water cycle** (the capture, storage, and redistribution of precipitation), **energy flow** (conversion of sunlight to plant and then animal matter), and the **nutrient cycle** (the cycle of nutrients through the physical and biotic components of the environment).

Due to the complexity of the ecological processes and their interrelationships, direct measures of the processes are usually not feasible for land managers. However, observable biological and physical components can be used as **indicators** of the functional status of ecological processes. The IIRH protocol uses 17 indicators (Table 1) for the assessment of functional status of ecological processes, which are interpreted within the context of the three attributes of rangeland health.

Definitions of the three interrelated attributes are:

Soil/site stability: the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water and to recover this capacity when a reduction does occur.

Hydrologic function: the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity when a reduction does occur.

Biotic integrity: the capacity of the biotic community to support ecological processes within the natural range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants (vascular and nonvascular), animals, insects, and microorganisms occurring both above and below ground.

Each of these three attributes is summarized at the end of the evaluation sheet (Appendix 4) based on a **preponderance of evidence** approach using the applicable indicators. An IIRH assessment provides a rating of the three attributes, which may be used with applicable quantitative inventory and monitoring data to complete a rangeland evaluation.

Table 1. The three attributes of rangeland health (blue) and their associated indicators (gray boxes). The indicators are arranged under the attribute(s) to which they relate. Indicators that relate to more than one attribute are represented by a longer box spanning columns for the attributes to which they relate.

<table>
<tr><th>Soil/Site Stability</th><th>Hydrologic Function</th><th>Biotic Integrity</th></tr>
<tr><td colspan="2">1. Rills</td><td>12. Functional/Structural Groups</td></tr>
<tr><td colspan="2">2. Water Flow Patterns</td><td>13. Dead or Dying Plants or Plant Parts</td></tr>
<tr><td colspan="2">3. Pedestals and/or Terracettes</td><td>15. Annual Production</td></tr>
<tr><td colspan="2">4. Bare Ground</td><td rowspan="2">16. Invasive Plants</td></tr>
<tr><td colspan="2">5.Gullies</td></tr>
<tr><td>6. Wind-Scoured and/or Depositional Areas</td><td colspan="2">14. Litter Cover and Depth</td></tr>
<tr><td>7. Litter Movement</td><td>10. Effects of Plant Community Composition and Distribution on Infiltration</td><td>17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants</td></tr>
<tr><td colspan="3">8. Soil Surface Resistance to Erosion</td></tr>
<tr><td colspan="3">9. Soil Surface Loss and Degradation</td></tr>
<tr><td colspan="3">11. Compaction Layer</td></tr>
</table>

The 17 indicators are rated individually, and then the suite of indicators related to each attribute are considered collectively to determine the attribute ratings. Five departure categories (Table 2) are used to describe the degree of departure from conditions described in the reference sheet for each indicator (Appendix 1a). Degree of departure (Table 2) for each attribute is then rated based on the preponderance of evidence of the appropriate indicators (Table1).

Table 2. The 5 departure categories used to rate the 17 indicators and 3 attributes of rangeland health.

Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight

5. Concepts

It is important to understand the following concepts to apply the IIRH protocol. Familiarity with these concepts will improve an evaluator's ability to select an evaluation area, determine onsite and offsite influences, and understand the connection between land potential and an IIRH assessment, as well as the spatial and temporal variability associated with an ecological site or equivalent unit.

5.1 Landscape Context

Landscapes are large, connected geographical regions that have similar environmental characteristics and that may consist of part or all of one or more watersheds. Major (1951) identified five factors—climate, soil parent material, topography or relief, organisms, and time—that collectively describe the character of any ecosystem or geographic landscape. The IIRH protocol requires the use of a system that classifies landscapes into units based on their potential to produce distinctive kinds, amounts, and proportions of vegetation and their ability to respond similarly to management actions and natural disturbances. Together, soils, climate, and topography determine this potential.

The ecological site classification system (Caudle et. al 2013) meets these criteria and is the standard system for IIRH assessments described in this technical reference (see Section 5.2 Ecological Sites). An ecological site is part of the NRCS hierarchical landscape classification system (e.g., Land Resource Hierarchy) that ranges from vegetation patches up to broad continental physiographic and bioclimatic zones (Salley et al. 2016). The broader scale classification units above the ecological site provide the setting and context to develop finer scale ecological site descriptions.

5.2 Ecological Sites

An **ecological site** is "a conceptual division of the landscape that is defined as a distinctive kind of land based on recurring soil, landform, geological, and climate characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its ability to respond similarly to management actions and natural disturbances" (Caudle et al. 2013).

Because natural systems seldom include distinct boundaries in either space or time, ecological sites include a certain amount of variability and uncertainty. However, the fundamental assumption for the ecological site concept is that locations with common soils, climate, and geomorphology can be delineated into units that support similar plant species and respond similarly to management actions and natural disturbances.

Important aspects and principles relative to ecological sites include:

Historical baseline: The inherent complexities of vegetation dynamics (e.g., how vegetation originated in an area and how it might change in the future) require an understanding of historic disturbance regimes, climatic variability (including climate change), and current vegetation. Although long-term trends in historic vegetation can be displayed over time periods spanning thousands of years using pollen analysis and other paleoecological techniques, the relevance of ecological data to current state-and-transition models diminishes further back in time due to increasing differences in climate, disturbance regimes, and species distributions. In western North America, a 500-year or shorter period immediately preceding European settlement is a reasonable time period for describing the reference state (Winthers et al. 2005).

Modal concept: An **ecological site description** reflects the modal (most common) physical characteristics of an ecological site (Figure 1). The physical aspects of a site described in an ecological site description (exposure, slope, landform, soil surface texture, etc.) usually do not include the entire range of values but, rather, the modal values of these variables.

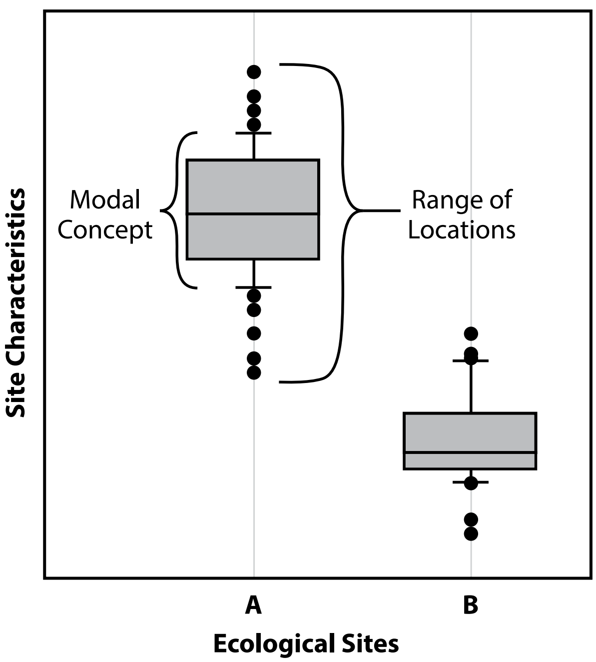


Figure 1. Visualization of the modal concept using a box and whisker diagram. Locations will vary in their individual site characteristics. Most physical aspects of sites will be represented by the central variation (modal concept). An ecological site description represents the central set of site characteristics (e.g., precipitation), but some locations may fall outside of this central group (outliers). In this diagram, the solid dots represent locations with site characteristics outside of the modal concept. These outliers are still part of the ecological site, but some of their characteristics may fall outside of the modal concept and may overlap in site characteristics with other ecological sites.

The reference sheet associated with each ecological site description includes, to the extent possible, expected ranges for each of the 17 indicators relative to community phases in the reference state that are functioning under the natural disturbance regime (e.g., native insect outbreaks, wildfires, native wildlife activities, weather cycles and extremes, including droughts, unusual wet periods, and snow and wind events). The reference sheet may include descriptions of the natural range of variability of indicators that are outside the range of the modal concept (physical characteristics) for the ecological site (Figure 1). However, because states are ultimately defined based on thresholds, it is possible for community phases to exist within the reference state that are outside the natural range of variability relative to the natural disturbance regime (e.g., a community phase that is well outside the natural return interval for wildfire). These community phases are not included as the reference for IIRH assessments.

Ecological site groups: These are ecological sites grouped by their similar responses to disturbances (e.g., disturbance response groups) (Stringham et al. 2016) or based on physiographic, geological, and landform breaks associated with important shifts in climate and vegetation (Bestelmeyer et al. 2016). With both of these approaches, a generalized state-and-transition model is developed at the ecological site group level to help managers understand disturbance responses for similar types of sites within a landscape. The IIRH protocol is designed to be used at the ecological site scale. However, it is not appropriate to develop reference sheets for generalized ecological site groups, including disturbance response groups, for an IIRH assessment.

Additional information: Additional information about ecological sites can be found on the EDIT (Ecosystem Dynamics Interpretive Tool) website (currently *https://edit.jornada.nmsu.edu/*), as well as in the "Interagency Ecological Site Handbook for Rangelands" (Caudle et al. 2013).

In countries where ecological site concepts have not been developed, see Section 5.7 (Other

Landscape Classification Systems) for information on developing soil/climate relationships similar to those found in ecological site descriptions.

5.3 Ephemeral Systems

Vegetation composition and production at a site are influenced not only by soils but also by water, including its volume, frequency, and duration in the soil profile. **Ephemeral systems** are areas that receive more water than typical upland ecological sites, but it remains for short periods of time (generally less than 1 month at a time in most years). Ephemeral systems differ from lentic and lotic systems because they lack riparian or hydric vegetation and hydric soils (or seasonally saturated soils) typically found in riparian or wetland areas. Also, these systems often represent a different ecological site than the surrounding uplands (Figure 2B). The plant communities and soil features that typify riparian areas commonly require at least 30 days of saturated conditions to be developed and maintained. However, this timeframe varies based on a range of factors.

Figure 2. Examples of ephemeral and perennial systems.

A. An ephemeral system, such as this one, may be of sufficient size to conduct an IIRH assessment when appropriate reference information is available.

B. It is generally not practical to complete an IIRH assessment on narrower or smaller ephemeral systems. Because this ephemeral system is a different ecological site than the adjacent uplands, it should be excluded when conducting an assessment of the upland ecological site.

C. Example of a perennial stream and associated riparian area (inside the blue line), which would be evaluated using the lotic proper functioning condition method (Dickard et al. 2015).

D. Example of a lentic area, which would be evaluated using the lentic proper functioning condition method (Prichard et al. 2003).

The IIRH protocol can be used to evaluate ephemeral systems when they are of sufficient size (Figure 2A) in an evaluation area. Smaller ephemeral systems (Figure 2B) that occur within an evaluation area represent soil inclusions that should be excluded from the assessment of the surrounding upland evaluation area. An example of an ephemeral system is an Overflow R067BY036CO ecological site in the Central High Plains MLRA where floodplains, terraces, and drainageways are described. Determining the duration of saturation, which can often be found in an ecological site description or a soil map unit description, can assist in selecting the correct assessment protocol.

Proper functioning condition, a riparian assessment protocol (see Section 6.1.6), is not used to assess ephemeral systems because their vegetation attributes and soil properties have no riparian characteristics (e.g., hydrophilic plants) and are "upland" in character.

5.4 Natural Range of Variability

The **natural range of variability** is defined as the deviation of characteristics of biotic communities and their environment that can be expected given natural variability in climate and natural disturbance regimes. The **natural disturbance regime** describes the kind, frequency, and intensity of natural disturbance events that would have occurred on an ecological site prior to European influence (ca. 1600) (Winthers et al. 2005). Natural disturbances include, but are not limited to, native insect outbreaks, wildfires, native wildlife activities (herbivory, burrowing, etc.), indigenous human activities, and weather cycles and extremes (including droughts and unusual wet periods, temperatures, and snow and wind events). The natural range of variability does not include influences of nonnative plant or animal species and also does not encompass soil degradation, such as accelerated erosion, organic matter loss, changes in nutrient availability, or soil structure degradation, beyond what would be expected to occur under the natural disturbance regime.

The biological and physical potential of every location on earth is unique in space and time (Bestelmeyer et al. 2004). To the extent possible, the types and sources of natural spatial and temporal variability should be described for each indicator in the reference sheet (Appendix 1a). The process used to describe the natural range of variability (including the natural disturbance regime) in the reference sheet is outlined Appendix 1a. The following sections describe the two components of the natural range of variability, spatial and temporal variability.

5.4.1 Spatial Variability

An understanding of the potential range of spatial variability both within and among ecological sites is necessary to apply the IIRH protocol. Sources of spatial variability include soils (e.g., soil depth, texture, and coarse rock fragments), topographic position, slope, aspect, events within the natural disturbance regime, and plant communities associated with the natural range of variability (see Section 5.1 Landscape Context and Section 5.5 States, Transitions, and Disturbances). For example, south-facing slopes are subject to higher evaporation rates and generally have less developed soils than north-facing slopes. Both higher evaporation rates and less developed soil can result in lower soil moisture availability, which increases bare ground and the potential for accelerated erosion, even on sites that are at or near their potential. These factors may in turn affect potential vegetation composition across the gradient of moisture availability and elevation for the ecological site (Figure 3).

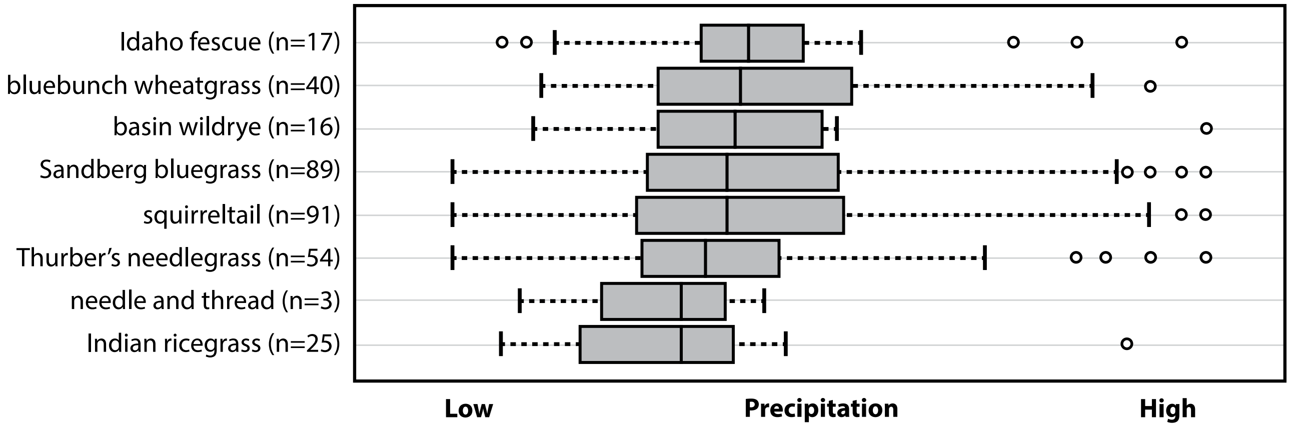


Figure 3. Box and whisker diagram of perennial bunchgrass species occurrence in 95 field plots across a precipitation gradient within a given ecological site. n = the number of plots in which each species was recorded. The boxes represent the precipitation range for 50% of field plots in which each species was recorded. The vertical line within each box indicates the median, the boundaries of the boxes indicate the 25th and 75th percentiles, and the whiskers indicate the highest and lowest precipitation values (excluding outliers which are represented by dots).

Most ecological site descriptions include a range of subtle differences in slopes, aspects, and soil properties that are within the natural range of variability associated with that landscape unit. Understanding and documenting both the expected variation and how these sources of variation may influence individual indicators of rangeland health improves assessments. For example, sites that are located lower on the landscape (downslope) may receive run-on water during intense storms or snowmelt. The effect of receiving runoff water can be positive for plant growth downslope in run-on areas. However, run-on water can be negative if it is associated with soil deposition that affects soil surface structure and stability. Similarly, portions of a landscape that capture wind-driven snow generally have a higher production potential than sites that are typically free of snow, except where snow persists long enough that it significantly limits the length of the growing season. Sometimes these differences collectively result in a different ecological site classification.

5.4.2 Temporal Variability

Plant communities and soils also vary naturally through time. Seasonal and year-to-year variation in weather conditions affects ecological sites. Within a growing season, soils go through periods of wetting and drying. During periods with high-intensity precipitation, soils may show evidence of erosion (e.g., rills) and water movement (e.g., water flow patterns) that may not be visible later in the season. Moisture availability and temperature determine plant growth and development patterns, with biomass and seed production occurring while soil water is available and temperatures are at levels that allow growth. Aboveground biomass of herbaceous plants becomes standing dead vegetation or litter following mortality-inducing weather events or senescence. In grazed or browsed systems, some of the plant biomass and seed production may be harvested. All of these seasonal changes can affect indicators of rangeland health and must be considered when conducting an IIRH assessment.

During a short-term drought (1–2 years), annual plant production is expected to decline relative to the long-term average. This change may also result in less seed production, reduced canopy cover and litter, and increased bare ground. Prolonged droughts (e.g., greater than 3 years in the Great Basin) may cause dead plant parts or mortality of some perennial plants. As the plant community responds to prolonged drought, the amount of bare ground increases and the site may become more susceptible to erosion and other degradation processes. During years with above average precipitation, one would expect the response of vegetation and soils to be the opposite, although an intense precipitation event may result in accelerated erosion, particularly if the event follows a dry period. Other examples of temporal variability include warmer or colder than normal temperatures, shorter or longer than normal growing seasons, and natural disturbance occurrences and intensities (e.g., fire).

5.5 States, Transitions, and Disturbances

State-and-transition models reflect the potential for multiple stable plant communities to be present in individual ecological sites (Briske et al. 2005). A **state** includes one or more vegetation **community phases** (including associated dynamic soil properties) that occur in dynamic equilibrium on a particular ecological site and that are functionally similar with respect to the three attributes of rangeland health (soil/site stability, hydrologic function, and biotic integrity) (Figure 4). A state interacts with relatively static soil properties and topography that define an ecological site to produce persistent functional and structural attributes associated with a characteristic range of variability (Caudle et al. 2013).

Generic state and transition diagram. Dotted lines between communities within an ecological state are community pathways; solid lines between ecological states are transitions; and dashed lines between states indicate unlikely reverse transitions. Each state has a unique set of values for soil health indicators that are functionally different from other states. Communities within a reference state should be functionally equivalent, but soils and ecosystem attributes may vary slightly.

In this example, transition 1 occurs when wildfire that is outside the natural range of variability changes ecosystem dynamics, allowing the introduction and spread of invasive annual grasses; transition 2 occurs when annual grasses replace perennial grasses; and transition 3 occurs when the soil surface horizon has been lost or degraded, greatly limiting understory vegetation. In this example, transition 1 occurs through mechanisms of wildfire and introduction of invasive annual grasses; transition 2 occurs through understory loss and subsequent erosion of bare soils.

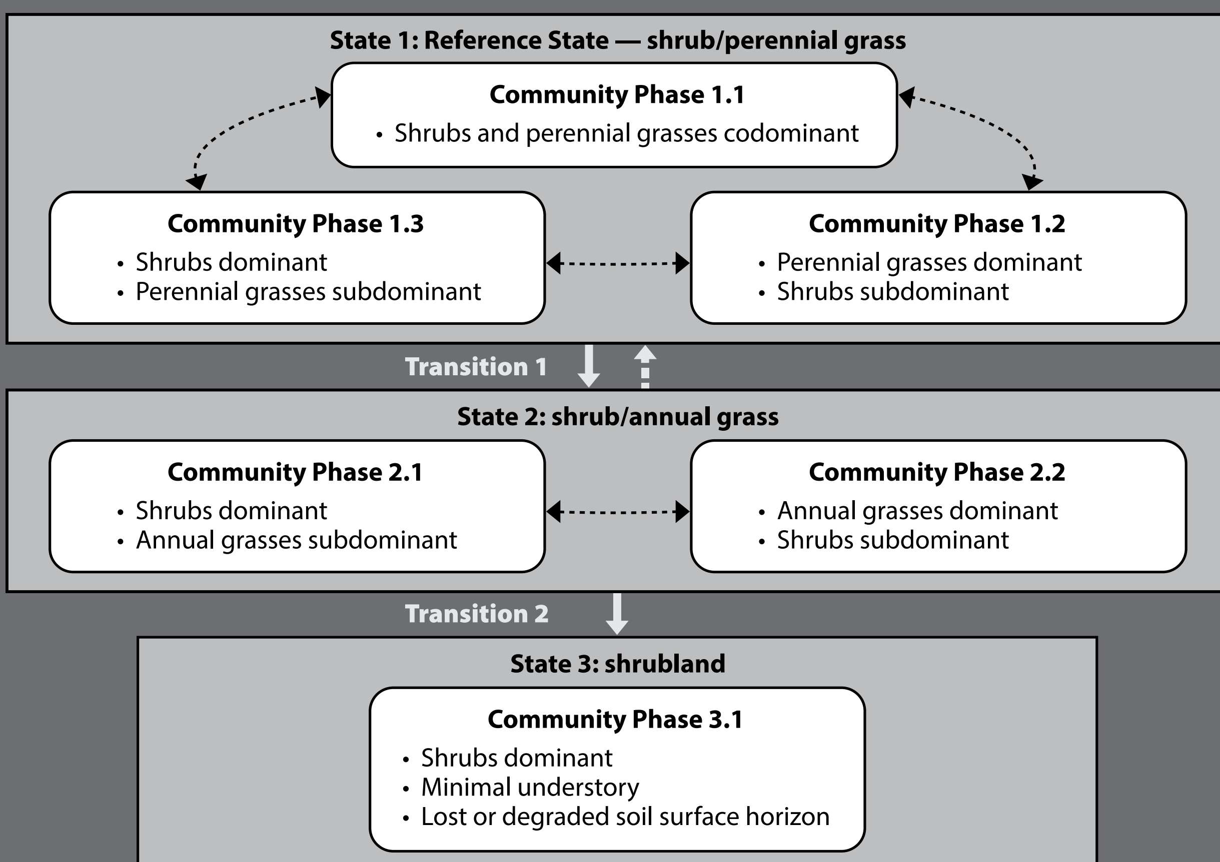


Figure 4. Conceptual example of a state-and-transition diagram for a hypothetical shrub-steppe ecological site, showing states, community phases, community pathways, and transitions.

States are distinguished from each other by large differences in dominance among plant functional groups, dynamic soil properties, ecosystem processes, and consequently in vegetation structure, biodiversity, and management requirements that persist over long periods of time. They also differ by their responses to disturbance. However, a state may include a number of different plant communities known as **community phases**, which are connected by **community pathways** (Bestelmeyer et al. 2003; Stringham et al. 2003; Caudle et al. 2013) (Figure 4). Community pathways (Caudle et al. 2013) describe the causes of shifts between community phases. Community pathways can include concepts of **episodic** plant community changes, as well as succession and seral stages. Community pathways can represent both linear and nonlinear plant community changes. A community pathway can be reversible in part by changes in natural disturbances, weather variation, or changes in management.

The **reference state** is the state where the functional capacities represented by soil/site stability, hydrologic function, and biotic integrity are functioning at a sustainable/resilient level under the natural disturbance regime (Figure 4). The reference state usually includes more than one community phase. This technical reference uses the community phases occurring within the natural disturbance regime of the reference state as the reference for assessments of rangeland health. Relative dominance of functional/structural groups may vary along the community pathways between these phases.

Shifts between states are referred to as **transitions** (Figure 4). Unlike community pathways, transitions are generally not easily reversible by simply altering the intensity or direction of factors that produced the change. Therefore, a transition from one state to another is often referred to as "crossing a **threshold**." Transitions among states in an ecological site are often caused by a combination of feedback mechanisms that alter soil and plant community dynamics (e.g., Schlesinger et al. 1990) and that contribute directly to a loss of state resilience (Caudle et al. 2013). Stringham et al. (2003) incorporated ecological processes into the transition concept by proposing that a transition occurs when one or more ecological processes are irreversibly changed and must be actively restored to return to the previous state. For example, as shrubs replace warm-season grasses in U.S. Southwest rangelands, runoff and erosion increase in shrub interspaces (see photographs in Section 7.4.10 Effects of Plant Community Composition and Distribution on Infiltration), further reducing soil and water resource availability for the remaining grasses (Schlesinger et al. 1990). Because of this loss of resilience, threshold reversal, or recovery to the previous state, if possible, requires new inputs such as revegetation or plant species/functional group removal. These practices are often expensive and difficult to apply.

Because all possible alternate states develop from the reference state, and transitions to alternate states are often irreversible (without management intervention), the reference state: (1) describes the ecological potential that can be used to help implement sustainable management practices and (2) maintains the most future management options.

Performing an IIRH assessment can provide clues about states and transitions and help interpret ecosystem changes. Kachergis et al. (2011) used the 17 indicators to develop a data-driven state-and-transition model for a claypan ecological site in northwest Colorado. The authors found that many of the indicators and their associated levels of departure from the reference state correlate with quantitative measures, suggesting that the 17 indicators can be used to approximate ecosystem functions associated with different states. They also used the indicators to identify a reference state that functions as expected for the claypan ecological site, plus four botanically and functionally distinct states, consistent with the theoretical concept of alternate states.

5.6 Resistance and Resilience

Understanding ecosystem **resistance** to disturbance and its **resilience** or ability to recover from disturbances (Seybold et al. 1999; Chambers et al. 2014; Chambers et al. 2017) is increasingly important to both scientists and land managers. Adequate ecological resilience is required for an ecological site to function within the natural range of variability, including the natural disturbance regime. Ecological **resilience**, as it applies to ecological sites and the three attributes of rangeland health (described in Section 4), is the capacity of the biotic and abiotic environment within an ecological site to regain fundamental structure, function, and processes when altered by disturbances like fire or land use changes (Holling 1973; Peterson et al. 1998).

Resistance is the capacity of the plants, animals, and abiotic environment to retain their fundamental structure, processes, and functions (or remain largely unchanged) despite stresses and disturbances, such as potential invasions of introduced species (sometimes referred to as novel species) (Folke et al. 2004; D'Antonio and Thomsen 2004), increased carbon dioxide, and climate change.

The resistance and resilience of community phases vary within a state. Consequently, the specific community phase that is the least resistant or resilient following a particular disturbance is the one that is most likely to proceed through a transition to another state (Figure 4).

5.7 Other Landscape Classification Systems

In countries where ecological site concepts have not been developed, soil/climate relationships similar to those found in ecological site descriptions could be developed using the best available information and tools, such as the Land-Potential Knowledge System (LandPKS) (Appendix 10). A consistent understanding and documentation of the community phases and the natural disturbance regime associated with the reference state must be developed and applied for the IIRH protocol to be used. The development of a consistent soil/climate-based reference is a priority task to apply the IIRH protocol. Because of the difficulty in determining a timeframe on which to base the natural range of variability and natural disturbance regime, the reference state may have to be based, in part, on current disturbance regimes and knowledge of changes to the ecological processes caused by current management and episodic events.

5.8 Indicators

Ecological processes are difficult to observe or measure in the field due to the complexity of rangeland ecosystems. As used in this technical reference, **indicators** are components of an ecosystem whose characteristics (e.g., presence or absence, quantity, distribution) are used as an index of an attribute (soil/site stability, hydrologic function, and biotic integrity) that is not feasible or is too expensive to measure. Just as the Dow Jones Industrial Average is used as an index to gauge the strength of a portion of the stock market, combinations of the 17 indicators found in this technical reference are used to gauge the attributes of soil/site stability, hydrologic function, and biotic integrity.

Indicators have historically been used in rangeland monitoring and resource inventories by land management and technical assistance agencies. These indicators focused on vegetation (e.g., production, composition, density) or soil stability as surrogates for rangeland condition or livestock carrying capacity. Such single attribute assessments are inadequate to determine rangeland health because they do not reflect the complexity of ecological processes. There is no single indicator of ecosystem health; instead, a suite of key indicators should be used for an assessment (Karr 1992). The IIRH protocol uses 17 indicators of rangeland health (Table 1) that are assessed and used to rate the 3 attributes of rangeland health.

5.8.1 Qualitative Assessment

All 17 indicators of rangeland health, with the exception of soil surface resistance to erosion (Herrick et al. 2001), can be assessed qualitatively (e.g., observed and rated relative to a reference state). Indicators are visually assessed for departure relative to the reference sheet based on observations, ratings, and descriptions of the condition or status of the indicators. Qualitative assessment allows rapid observation of multiple factors related to each indicator within the evaluation area. Qualitative assessments are often supported by, or sometimes used in conjunction with, quantitative assessment methods (see examples in Section 6). Quantitative measures are often used by evaluators to improve the consistency of indicator ratings (e.g., for training purposes); see Section 7.3 Step 3. Collect Supplemental Information.

5.8.2 Quantitative Assessment

Quantitative measurements and indicators are useful to support qualitative indicator assessments and also to allow direct comparisons between evaluation locations. Examples of quantitative data typically used to support IIRH assessments include, but are not limited to:

- Bare ground (indicator 4)
- Soil surface resistance to erosion (indicator 8)
- Litter cover and depth (indicator 14)
- Annual production (indicator 15)

At a minimum, quantitative measurements are required to train and calibrate evaluators to make ocular estimates, which are necessary for IIRH assessments.

Some ecosystem properties are more accurately assessed by qualitative indicators, while others are more effectively assessed by quantitative measurement (Rapport 1995). Evaluation of several of the 17 indicators of rangeland health can be supported by quantitative measurements (Figure 5 and Table 3). Pyke et al. (2002) provides a list of quantitative indicators and associated measurement methods that can potentially support interpretations of the 17 indicators of rangeland health. The specific quantitative indicator values associated with each departure class may vary significantly among ecological sites. For example, the amount of bare ground is often greater in arid environments than in mesic environments, which generally have a greater amount of vegetation cover.

Using quantitative measurements that correlate to multiple indicators and attributes is more efficient than attempting to measure quantitative indicators for each of the 17 qualitative indicators (Table 3). For example, quantitative indicators for bare ground and soil surface resistance to erosion are both good indicators of the attribute of soil/site stability in most ecological sites. The amount of bare ground is also related to hydrologic function, while soil surface resistance to erosion relates to all three attributes of rangeland health.

When collecting quantitative data, keep in mind that precision increases as the number of samples increases. The number of samples required depends on plot variability (see Appendix C in Herrick et al. 2009). Within-plot variability is usually lower in more homogenous systems such as shortgrass steppe, and therefore fewer samples are required to obtain a reliable estimate.

Example: Bare Ground

Reference:
Bare ground is 5-15%; bare patches are less than 20 cm in diameter and rarely connected.

quantitative measure
(line point intercept)
= 19% bare ground

+

qualitative assessment
that patches are < 20 cm in diameter and rarely connected

→ **slight to moderate departure**

Figure 5. Example of quantitative data supporting assessment of the bare ground indicator. In this example, both the quantitative measurement of total bare ground and a qualitative (ocular) assessment of the size and connectivity of bare patches is considered in order to assign an appropriate departure rating for the bare ground indicator.

Table 3. Key quantitative indicators and measurements relevant to each of the three attributes of rangeland health. Core methods of BLM and NRCS national monitoring programs are in bold: (1) NRCS 2006; (2) Herrick et al. 2017.

Attributes of Rangeland Health	Associated Indicator(s) of Rangeland Health[1]	Quantitative Indicators	Selected Measurements and References
Soil/Site Stability	Water flow patterns Bare ground Wind-scoured and/or depositional areas Litter movement Soil surface resistance to erosion Soil surface loss and degradation	Bare ground	**Line point intercept (2)**
		Proportion of soil surface covered by gaps longer than a defined minimum	**Canopy gap intercept (2)** Basal gap intercept (2)
		Soil aggregate stability in water	**Soil stability test (2)**
Hydrologic Function	Water flow patterns Bare ground Soil surface resistance to erosion Soil surface loss and degradation Effects of plant community composition and distribution on infiltration Litter cover and depth	Bare ground Litter cover Foliar cover composition	**Line point intercept (2)**
		Proportion of soil surface covered by gaps longer than a defined minimum	**Canopy gap intercept (2)** Basal gap intercept (2)
		Soil aggregate stability in water	**Soil stability test (2)**
Biotic Integrity	Soil surface resistance to erosion Soil surface loss and degradation Functional/structural groups Dead or dying plants or plant parts Litter cover and depth Annual production Invasive plants Vigor with an emphasis on reproductive capability of perennial plants	Soil aggregate stability in water	**Soil stability test (2)**
		Foliar cover and composition, including live vs. dead vegetation Litter cover Invasive plant cover	**Line point intercept (2)**
		Annual production	Total harvest (1) (Appendix 8) Weight units (1) (Appendix 8)

[1] Only the indicators of rangeland health associated with the selected measurements and quantitative indicators are identified here. Refer to Table 1 for the full list of indicators of rangeland health related to each attribute.

5.9 Annual Production, Foliar Cover, and Biomass

There are many considerations to be aware of when collecting and interpreting measurements of annual production, foliar cover, and biomass. These three related vegetation measurements are defined as follows:

Annual production: the net quantity of aboveground vascular plant material produced within a year. Synonym: net aboveground primary production.

Biomass (plants): the total amount of living plants above and below ground in an area at a given time (SRM 1999). As used in this technical reference, biomass refers only to parts of standing living plants (standing biomass) above ground, and not the roots.

Foliar cover: proportion of the soil surface covered by a vertical projection of a plant or plants. This is effectively the area that is protected from raindrops and the area in shade when the sun is directly overhead (Figure 6).

Both **foliar cover** and **biomass** correlate with **annual production**. However, these relationships vary by species, as well as among locations and both within and among years in a single location. Dominance rankings of species or functional/ structural groups may change depending on which vegetation measure is used. Consequently, uniform substitution of foliar cover or biomass for annual production is not appropriate. However, foliar cover and biomass may be used as surrogates for annual production where these relationships are well understood and documented. The amount of plant production and the kinds of plants are important factors in delineating an ecological site. Annual production by species has long been a measure of change in rangeland condition and is used to calculate the species composition found in many ecological site descriptions, although foliar cover is increasingly likely to be incorporated into ecological site descriptions based on data availability. While biomass data for ecological sites are currently scarce, and therefore unlikely to be used for IIRH, technological advances may make biomass data collection via remote sensing or other methods more feasible in the future.

Inconsistent comparisons can also arise when different methods are used to quantify or estimate standing biomass, foliar cover, or annual production. Annual production estimates (Appendix 8) include three components: (1) plant material produced within the growing season at the time of the evaluation, (2) plant material produced within the growing season that has been removed by herbivory, and (3) expected growth that will occur by the end of the growing season. Annual production is the total aboveground production (including stem growth) of all species. In ecosystems that have bimodal precipitation patterns that result in distinct growing periods within a year, it is necessary to include all plant material produced annually. Appendix 8 describes two methods and two sampling approaches designed to train evaluators to estimate total annual production. The "National Range and Pasture Handbook" (NRCS 2006) should be referred to for methods and sampling approaches to calculate species composition by weight.

Foliar cover measurements reflect the proportion of the soil surface covered by a vertical projection of a plant or plants. This is effectively the area that is protected from raindrops and the area in shade when the sun is directly overhead. In contrast, **canopy cover** includes the percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants (Figure 6). When measuring canopy cover, small openings within the canopy are included as cover; whereas, when measuring foliar cover, these small openings are excluded. Measuring canopy cover, as opposed to foliar cover, results in a higher estimate of "cover" particularly for stoloniferous grasses and for shrubs and trees with diffuse canopies (Godínez-Alvarez et al. 2009) and is also very difficult to standardize.

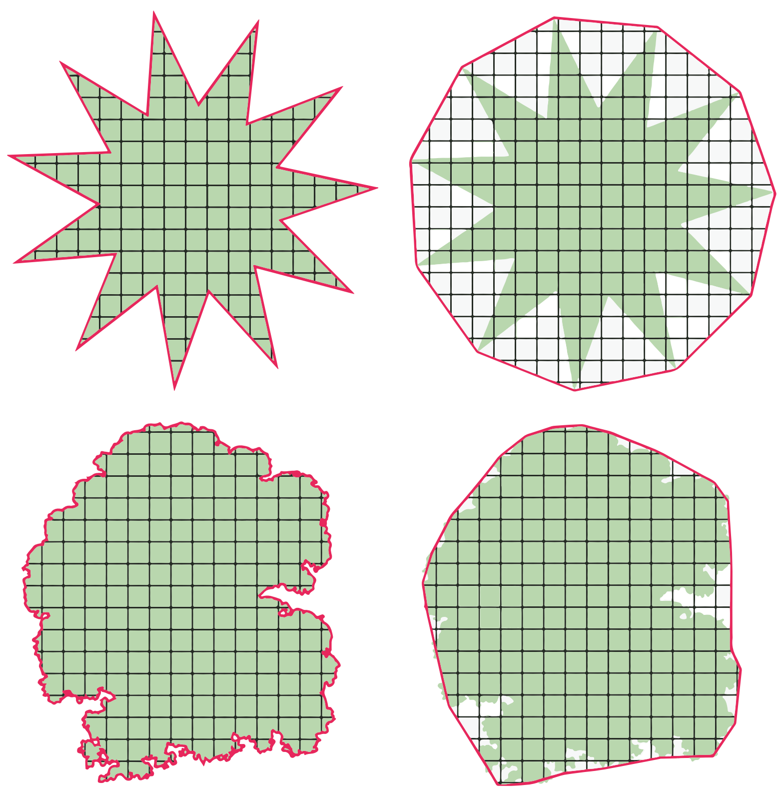


Figure 6. Comparisons of foliar cover on the left and canopy cover on the right. The hashed area shows the area that would be considered cover in each example.

Foliar cover measurements or estimates may be based on several methods including line point intercept and visual estimates. Visual estimates of cover are improved when observers first train themselves by collecting quantitative cover measurements. The line point intercept method (Herrick et al. 2017) is recommended because it measures the area actually covered by leaves, twigs, and stems and can be used to assess indicators that are generally more directly related to annual production, runoff, and erosion. The line point intercept method provides data on multiple canopy layers and can be used to calculate cover for bare ground, rock, biological soil crust, and litter cover. This method is among the easiest to standardize of all vegetation cover methods and is the preferred method to collect foliar cover for new ecological site descriptions. It is also the standardized method used in the BLM Assessment, Inventory, and Monitoring (AIM) Strategy (Toevs et al. 2011b) and the NRCS National Resources Inventory, so using this method allows data to be compared to very large datasets (around 50,000 plots as of the end of 2019).

Care must be taken in interpreting ecological site descriptions developed prior to 1997 when the NRCS transitioned to using foliar cover (NRCS 1997b) instead of canopy cover in these site descriptions. In addition, bare ground was often calculated differently than it is now, as small stones and biological soil crusts were often considered bare ground.

5.10 Soil Crusts

The surface of the soil can be modified by environmental events (e.g., rainfall), soil chemistry, or living organisms. The type of crust on the soil surface can differentially influence the ecological process of a site in positive or negative ways depending on the ecosystem and the type of crust. Therefore, it is important to understand the types of crusts when applying the IIRH protocol. Descriptions and visual examples (Figure 7) follow of biological, physical, and chemical soil crusts for consideration in evaluating rangeland health. One or more types of soil crust may coexist in a given location.

5.10.1 Biological Soil Crusts

Biological soil crusts consist of microorganisms (e.g., algae, cyanobacteria) and nonvascular plants (e.g., mosses, lichens) that grow on or just below the soil surface. Biological soil crusts may also be referred to as cryptogamic crusts. In the Western United States, Condon and Pyke (2019) examined 5,200 BLM AIM study plots and found that biological soil crusts are present in all plant communities. They are important as cover and in stabilizing soil surfaces (Bond and Harris 1964; Belnap and Gardner 1993; Eldridge and Greene 1994; Belnap and Lange 2001). The physical and chemical characteristics of soil, along with seasonal precipitation patterns, largely determine the dominant organisms comprising the biological soil crust. In some areas, depending on soil characteristics, they may increase or reduce the infiltration of water through the soil surface. They may also serve as a barrier to invasive species, such as cheatgrass in the Great Basin (Belnap et al. 2001; Reisner et al. 2013). Biological soil crusts tend to reduce sediment production in all types of rangelands (Belnap 2006). In general, the relative importance of biological soil crusts increases as annual precipitation and potential vascular plant cover decreases. If information on biological soil crusts is lacking in the ecological site description, **ecological reference areas** should be visited when developing the reference sheet to document expected types and amounts of these crusts (Appendix 1a and 1b).

Detecting algae and cyanobacteria is often difficult, while mosses and lichens are more visible in most ecosystems. Because of this, many data collection efforts record moss and lichen cover but do not include algae or cyanobacteria. Therefore, it is important to understand and document data collection and indicator reporting methods when collecting or utilizing these data.

Biological Soil Crusts

Moss that has been moistened to assist in distinguishing mosses from soil.

Lichen and moss biological crust showing increased surface roughness.

Physical Soil Crusts

Thick physical crust on soil surface.

Vesicular crust showing air pores in soil.

Chemical Soil Crusts

Chemical crust on abandoned agricultural field.

Figure 7. Examples of biological, physical, and chemical soil crusts.

5.10.2 Physical Crusts (Including Vesicular Crusts)

Physical crusts are thin surface layers induced by the impact of raindrops on bare soil causing the soil surface to seal and absorb less water. They can also be caused by the settling and drying of disturbed soils after they have been saturated. Physical crusts are more common on silt, clay, and loam soils. When present on sandy soils, they are relatively thin and weak. Physical crusts tend to have very low organic matter content or contain only relatively inert organic matter that is associated with low biological activity. As physical crusts become thicker and denser (Figure 7), infiltration rates are reduced and overland water flow increases. As a result of reduced infiltration, water can pond in flat crusted areas, increasing evaporation.

Physical crusts can be identified by lifting the soil surface with a pen or similar object and looking for cohesive layers at the soil surface that are not perforated by continuous pores or fissures and in which there is no apparent binding by visible strands of organic material, such as cyanobacteria.

Physical crusts may exert a positive influence on reducing wind erosion (see discussion in Section 7.4.6. Wind-Scoured and/or Depositional Areas (Indicator 6)). However, their function in stabilizing the soil surface against water erosion is generally negative. Although physical crusts also include **vesicular crusts**, which contain numerous small air pockets or spaces similar to a sponge, these soils are still resistant to infiltration due to the lack of pore continuity. In some ecological sites in arid environments (e.g., Mojave Desert), these crusts occur in undegraded sites due to the lack of organic matter inputs necessary for soil aggregation and pore formation. In other areas (e.g., some ecological sites in the Great Basin), they can reflect degradation associated with the loss of organic matter inputs where bunchgrasses have been lost from shrub interspaces (Pierson et al. 1994).

5.10.3 Chemical Crusts

Chemical crusts rarely form in rangelands, except on soils formed from saline or sodic substrates/parent materials (e.g., salt desert shrub communities) and in abandoned, irrigated agricultural fields where saline irrigation water was used or where irrigation resulted in the elevation of a saline water table nearer to the soil surface. Where they do occur, they can reduce infiltration and increase overland water flow similar to physical crusts.

Chemical crusts are usually identified by a white color on the soil surface. Consult with the appropriate **soil survey** to identify soils that have the potential to naturally form chemical crusts prior to developing a reference sheet or ecological site-specific evaluation matrix. Chemical crusts are a sign of soil surface degradation where they do not occur naturally or where they have increased relative to the appropriate reference.

5.11 Management Influences on Indicators

The benchmark for the assessment of each of the 17 indicators of rangeland health is the description of the natural range of variability associated with the natural disturbance regime in the reference state as described in the reference sheet ("none to slight" departure). It is recognized that managers may choose to manage for communities outside the natural disturbance regime or in an alternate stable state (e.g., a seeded forage state).

The ecological dynamics description in the ecological site description provides general examples of factors that contribute to the natural range of variability. Anthropogenic disturbances or management actions that can result either directly or indirectly in departures outside of the natural range of variability as determined by the natural disturbance regime include, but are not limited to (also see Appendix 4):

- Fire return intervals that are longer or shorter than what occurred naturally or changes in fire intensity due to modifications in fuel loading.
- Activities that disturb soil or vegetation (off-road vehicle use, recreational trails, etc.).
- Introduction of invasive plants.

- Livestock use that is dissimilar in timing, frequency, or intensity from natural herbivory.
- Land treatments (seeding, herbicide application, tree thinning, etc.).
- Roads, energy infrastructure, and urban/suburban development.

These anthropogenic disturbances or management actions may affect one or more of the 17 indicators to varying degrees. It is important to note that pre-European indigenous human influences on ecosystems in the United States included alteration of disturbance regimes and that these alterations are considered part of the natural range of variability of an area. Outside the United States, effects of indigenous human activities may also be incorporated into the natural range of variability.

5.12 Spatial Extrapolation to Regions, Landscapes, and Management Units

When selecting IIRH evaluation areas, it is important to consider how the resulting assessments may be aggregated to evaluate or report on condition of the larger landscape. Properly developed sample designs that incorporate randomized site selection and meet specific assessment objectives can allow assessment results to be extrapolated across larger landscape units (e.g., management unit, watershed, ecoregion). This can help identify areas where management actions may potentially have the greatest impact. In some cases, it may be possible to map assessment results (Figure 8).

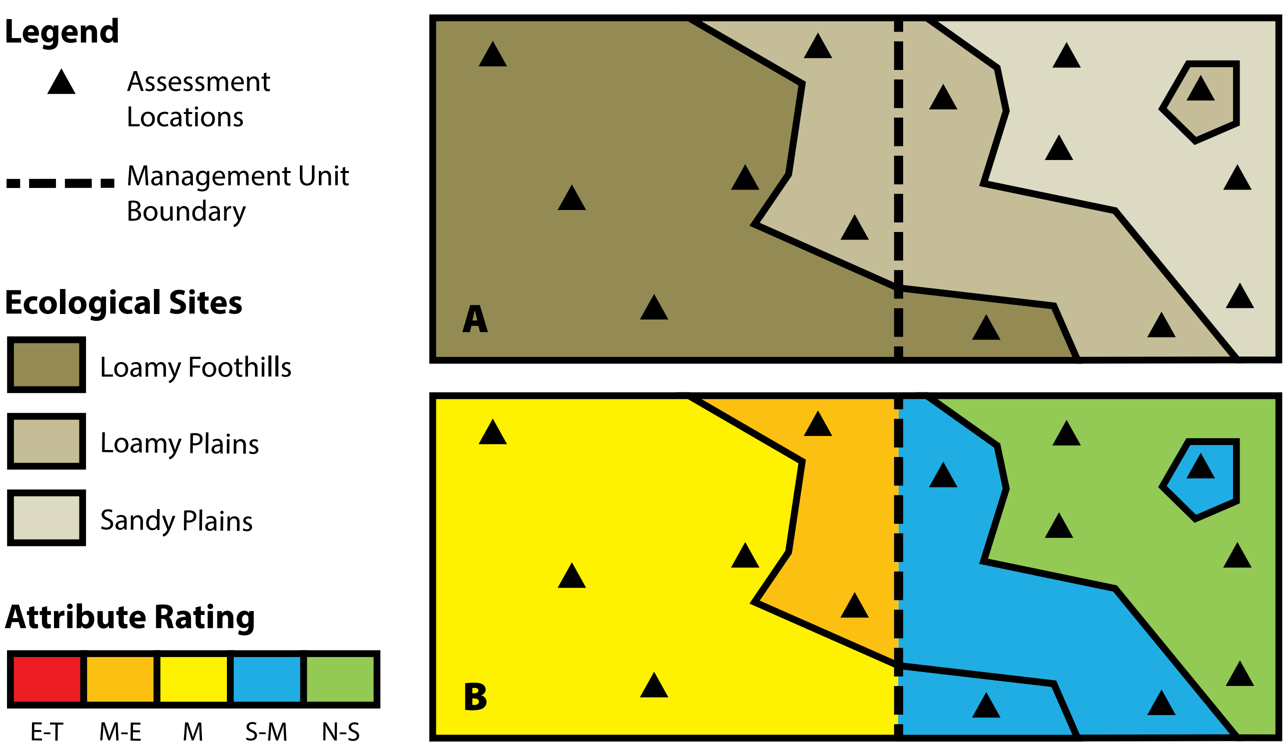


Figure 8. Example in which assessment locations were randomly chosen within previously mapped and verified ecological sites, enabling median attribute ratings to be mapped by ecological site and management unit boundaries. Note that this map is based on the assumption that the dominant ecological site (associated with the dominant soil map unit component of the soil map unit) actually comprises the majority of the area. This approach should be used with caution because, in many cases, the ecological site associated with the dominant soil map unit component in the soil map unit may represent less than 50% of the polygon.

Land managers may also choose to rely on professional knowledge to identify evaluation areas with specific resource or use concerns instead of using a randomized site selection process. This approach is useful for addressing questions or resource issues that are specific to those locations. However, this approach may incorporate bias, either unintentionally or intentionally, and thus limits the ability to aggregate and extrapolate evaluation results to a larger landscape. For example, **key areas** were often selected based on specific management objectives in land use or grazing plans that may not have been reflective of the rangeland health status of the entire management unit. Also, one of the criteria used to select key areas is the presence of a specific component of the plant community (e.g., key species) that may not be distributed evenly across the management unit. A key area may be an appropriate IIRH evaluation area in a management unit with uniform or well-understood livestock utilization and distribution.

Stratification, or dividing a landscape into different types, can be a useful tool for achieving assessment objectives when applied correctly. Stratification of samples using land types with similar ecological potential (e.g., dominant ecological sites or expected vegetation type) within the area of interest can ensure that landscape variability is captured in assessments (Figure 8). When stratifying by ecological site, soil survey maps are often used as one level of stratification. However, it is important to recognize that these maps generally only portray the dominant ecological site in each **soil map unit**. Because of the inherent uncertainty in these types of maps, it usually will be necessary to post-stratify assessment results based on the ecological site determination that is completed in the field.

When evaluating management outcomes is a key objective, stratification by management unit (e.g., grazing allotment or pasture) ensures that variability in management is also captured by assessments. This is especially important where grazing systems result in some pastures being grazed and others rested. Assessment results are extrapolated to the strata where they occurred (e.g., an ecological site within a management unit) (Figure 8). However, even within a stratum such as an ecological site, management influences on vegetation and soils (e.g., differential use associated with water points) may require additional stratification to capture variability in indicators and attributes across the management unit.

The IIRH protocol is being applied in many different areas to understand how rangeland health varies across regions, landscapes, and management units. For example, Miller (2008) assessed 500 locations to prioritize ecological sites for restoration at the Grand Staircase-Escalante National Monument using IIRH Version 3. The NRCS National Resources Inventory data report the proportion of private land area departing from reference conditions within large ecoregions, with a known degree of certainty (Herrick et al. 2010). The "Bureau of Land Management's Rangeland Resource Assessment—2011" reports similar results for public lands (Karl et al. 2016). Note that these proportional area estimates are possible because of the statistical sampling framework used with the NRCS National Resources Inventory and the BLM Landscape Monitoring Framework.

6. Applications of the IIRH Protocol and Relationship to Other Rangeland Assessment, Inventory, and Monitoring Protocols and Programs

6.1 Relationship to Other Rangeland Assessment, Inventory, and Monitoring Protocols and Programs

A number of other rangeland assessment protocols are applied throughout the world, often within the context of an agency's monitoring program. Chapter 3 of the National Research Council's book, titled "Rangeland Health: New Methods to Classify, Inventory, and Monitor Rangelands," summarizes some protocols commonly used in the United States prior to its publication (NRC 1994). All of these protocols are still in use today, although use has declined with increasing adoption of IIRH and the standardized core monitoring methods. Most of the earlier methods emphasize plant species composition, although some include soil erosion indicators. Many protocols also focused on livestock forage production.

The following protocols and programs may be related to, or incorporate, the IIRH protocol.

6.1.1 Similarity Index

The similarity index was used historically for rangeland assessments (West et al. 1994). It is an index of the current plant community composition in relation to a single plant community phase in the reference state or to a desired plant community for the ecological site. Total annual production, annual production by species, and species presence/absence (Mueller-Dombois and Ellenberg 1974) are used to calculate the similarity index. These production estimates are quantitative and are computationally similar to two indicators of rangeland health—functional/structural groups and annual production—both of which can be rated qualitatively. In contrast, the IIRH protocol compares relative dominance of plant functional/structural groups within an evaluation area to the appropriate community phase within the reference state on the ecological site being evaluated.

6.1.2 Apparent Trend

Apparent trend is an assessment of the perceived direction of successional change occurring over time in a plant community and soils in relation to a community phase in the reference state or a desired plant community (NRCS 2006). Apparent trend uses seedling and young plant abundance, perceived changes in plant composition, plant litter, plant vigor, and condition of the soil surface (erosion) in determining if the site is appearing to move toward or away from the desired plant community. Many of these indicators are similar to those in the IIRH protocol. Changes in apparent trend indicators can assist managers in speculating the direction of change in the plant community. The IIRH protocol is not designed to be used to determine apparent trend.

6.1.3 Landscape Function Analysis

The landscape function analysis developed in Australia (Tongway 1995; Tongway and Hindley 2004) was one of the first protocols to focus on rangeland ecological processes. The IIRH protocol adopts a similar functional approach. The IIRH protocol is distinct from landscape function analysis and other international protocols because of its use of a unique reference for each group of similar soils or ecological sites. Unlike the IIRH protocol, landscape function analysis does not include an explicit reference state other than measured baseline conditions. Landscape function analysis can be a useful assessment tool where reference state information is not available for the land unit of interest. Additionally, landscape function analysis is a valuable monitoring tool, especially where there are changes in vegetation structure and soil surface hydrology.

6.1.4 NRCS National Resources Inventory Rangeland Resource Assessment

The National Resources Inventory provides information on the trends of land, soil, water, and related resources on the nation's nonfederal lands (NRCS 2015). The NRCS includes IIRH assessments along with quantitative data collection using the standard methods described in Herrick et al. (2017). A spatially balanced, randomly located sampling design (see discussion on spatial extrapolation in Section 5.12) can provide land area estimates for attribute ratings of rangeland health and quantitative indicators. Many quantitative indicators associated with the 17 qualitative indicators can be measured (e.g., bare ground) (refer to Table 3) allowing these indicators to be monitored over time. Results are reported to Congress as part of the Resource Conservation Assessment and used to support the development and improvement of ecological site descriptions. The results are also increasingly being analyzed and reported in other publications (e.g., Herrick et al. 2010).

6.1.5 BLM Assessment, Inventory, and Monitoring Strategy

The BLM uses the same standard methods as National Resources Inventory (Herrick et al. 2017) to monitor rangelands as part of the BLM Assessment, Inventory, and Monitoring (AIM) Strategy (Toevs et al. 2011b). This strategy includes collecting standard, quantitative soil and vegetation data relevant to livestock and wildlife habitat management and soil and water conservation, most often using a randomized sampling design (see discussion on spatial extrapolation in Section 5.12). The AIM Strategy was designed to inform the BLM of resource status, condition, and trend at multiple spatial scales ranging from management units (e.g., allotments, treatment areas) to national-level assessments (e.g., landscapes, watersheds) (Karl et al. 2016). IIRH assessments are complementary to and can be completed as a part of terrestrial AIM projects. AIM data are captured electronically in the field and managed electronically, which helps ensure data quality and facilitates centralized data storage, analysis, and reporting.

6.1.6 Proper Functioning Condition

Several widely applied qualitative assessment methods are available to evaluate riparian systems. The most widely applied riparian assessment in the United States is the proper functioning condition (PFC) method for lotic (flowing water) ecosystems (Dickard et al. 2015) and for lentic (nonflowing) ecosystems (Prichard et al. 2003). Development of the PFC protocol began in 1988 and similar to the IIRH protocol, PFC is based on the assumption that ecosystems need to sustain ecological processes and retain adequate structural and functional vegetation components to resist invasive species and be resilient to disturbances. Proper function is a prerequisite for achieving desired conditions.

6.2 Selected Applications of the IIRH Protocol

The IIRH protocol consists of a five-step process (Figure 9) that is designed to provide the status of three attributes of rangeland health relative to the reference state. The following are examples of applications that use the IIRH protocol's five-step process.

6.2.1 BLM Rangeland Health Assessments

Standards of rangeland health that conform to the fundamentals of rangeland health (43 CFR 4180.1) have been adopted at state or district levels for application on BLM-managed lands. The BLM is required to review the status of land health periodically through the rangeland health assessment and evaluation process. The specific components required to complete a rangeland health assessment depend on the BLM rangeland health standards that apply within the evaluation area. Field evaluations using the IIRH protocol are often an important component of understanding the current status of upland ecological conditions. IIRH assessments can be used in the rangeland health evaluation process to assist in determining whether applicable standards related to upland watershed, soil, and vegetation conditions are being met. However, other available information should also be used to assess upland rangeland health conditions and trends, such as long-term monitoring data, ecological site inventory, and species-specific habitat assessments (Kachergis et al. 2020). Management interpretations and decisions are made within the context of historical and recent land management and disturbances including their effect on current conditions.

6.2.2 Assessment of Road Impacts on Rangeland Health

Linear disturbances associated with on- and off-road vehicle use on rangelands is increasing due in part to increased recreational use and mineral and energy development. Duniway and Herrick (2013) developed a simple stratification system to apply the IIRH protocol to successfully identify where increased degradation is associated with the presence or use of roads. The IIRH protocol is sensitive to identifying both direct and indirect impacts of transportation activities and is especially sensitive to determining the status of soil/site stability and hydrologic function rangeland health attributes.

6.2.3 Integrated Grazing Land Assessment

The integrated grazing land assessment approach expands on the strengths of the IIRH protocol and the pasture condition scoring method to provide a detailed assessment of the ecological attributes of an area, assess how an area is being managed, and whether livestock management can be optimized (Toledo et al. 2016). The integrated approach is based on attributes of rangeland health, as well as an attribute related to grazing land management. These foundational attributes include soil/site stability, hydrologic function, biotic integrity, and livestock carrying capacity. These attributes assess ecosystem services, such as forage/fodder production, soil carbon sequestration, nutrient cycling, and prevention of soil erosion (Nelson 2012).

6.3 Modified Applications of the IIRH Protocol

This section describes several applications that use components of the five-step IIRH protocol to provide information other than the status of the three attributes of rangeland health. For example, the value of the IIRH protocol as a communication tool to better understand the status of rangeland ecological processes has long been recognized (see Section 3. Intended Applications of Version 5). The process of rating the 17 indicators can be a useful communication framework for recognizing and discussing land health issues and identifying potential solutions on a land unit with managers and the public. In some situations, these communication goals may be met without completing the full five-step IIRH protocol and rating the attributes of rangeland health. The following are examples of applications that use a modified IIRH protocol.

6.3.1 Ecologically Based Invasive Plant Management

Ecologically based invasive plant management provides land managers a practical framework for managing degraded or invasive plant-dominated rangelands (Sheley et al. 2011). This successional management tool includes methods to assess ecological processes using the 17 indicators from the IIRH protocol and a conceptual model, which together help managers identify appropriate strategies to promote desired changes in plant communities. Successional management identifies three general drivers of plant community change—site availability, species availability, and species performance—which are assessed using combinations of the 17 indicators. The result is a starting point in the identification of ecological processes in need of repair and the selection of management strategies to facilitate their recovery.

6.3.2 NRCS Ranch Planning

The NRCS works with ranchers to develop conservation plans for their lands. The 17 indicators are rated using the standard protocol during the inventory phase of the conservation planning process. Information from the individual indicators (rather than the three attributes of rangeland health) is used to help identify resource concerns and to inform specific alternatives, including land treatments or changes in management. The indicator ratings provide a communication tool to identify problem areas and develop a plan to correct the problems.

6.3.3 Ecological Health Index

This is a short-term monitoring approach applied in the Patagonia region in Argentina to detect ecological health and land productivity (Xu et al. 2019). It is intended to assist ranchers to annually monitor grazing lands and determine the effects of management on ecological processes and ecosystem function. The protocol includes a modified evaluation matrix similar to the IIRH evaluation matrix, many of the 17 indicators, and the reference area concept.

7. IIRH Protocol Instructions and Steps

An **assessment of rangeland health** using the five-step IIRH protocol provides information on the functional status of ecological processes relative to the reference state for an ecological site or other functionally similar unit. An IIRH assessment provides an indication of the status of the three attributes of rangeland health at an "evaluation area" (i.e., the area where the rangeland health assessment is conducted) at a particular moment in time. Interest in an evaluation area may be based on concerns about current conditions, lack of information on conditions, or public perceptions of conditions. Evaluation areas may also be selected as part of a broader sampling design or assessment strategy.

Timing is also a factor in planning assessments. Although IIRH is a point-in-time assessment, it should be conducted when the indicators are accessible and readily observed. During, or soon after the growing season, is generally the optimal time to conduct an assessment. Knowledge of local phenology patterns can assist evaluators in conducting the assessment when plant species are still recognizable (e.g., forbs) and their potential for reproduction can be rated.

The following instructions provide a step-by-step guide for users, including directions to complete each step. The flow chart in Figure 9 illustrates the entire IIRH process and can be used to help identify steps to complete and the sequence of those steps. It is important to note that the initial steps may be iterative. It is useful to have local input, such as recent weather, management actions, and disturbance history, for steps 2 and 3 prior to going to the field (see Appendix 3. Checklists for the IIRH Protocol).

7.1 Step 1. Select the Evaluation Area(s), Identify the Soil, and Determine the Ecological Site

7.1.1 Select the Evaluation Area(s)

Management objectives help frame issues and assist managers in identifying areas of concern. This helps inform where to locate evaluation areas. Stratification of evaluation areas enables assessments to describe landscape variability (e.g., how rangeland health attributes vary by ecological sites or between management units). Depending on the scale of interest, ecological sites, groups of ecological sites, or ecoregions may all be appropriate strata. Locating evaluation areas randomly within strata enables extrapolation of assessment findings to broader landscape units (see Section 5.12 Spatial Extrapolation to Regions, Landscapes, and Management Units). However, locating evaluation areas nonrandomly may be appropriate in some cases, such as when questions are focused on a particular location or a disturbance or disturbance gradient that is clearly apparent (e.g., a relatively small recreational impact area). Finally, select the number of evaluation areas needed within each stratum; the greater the confidence needed, the more evaluation areas should be assessed.

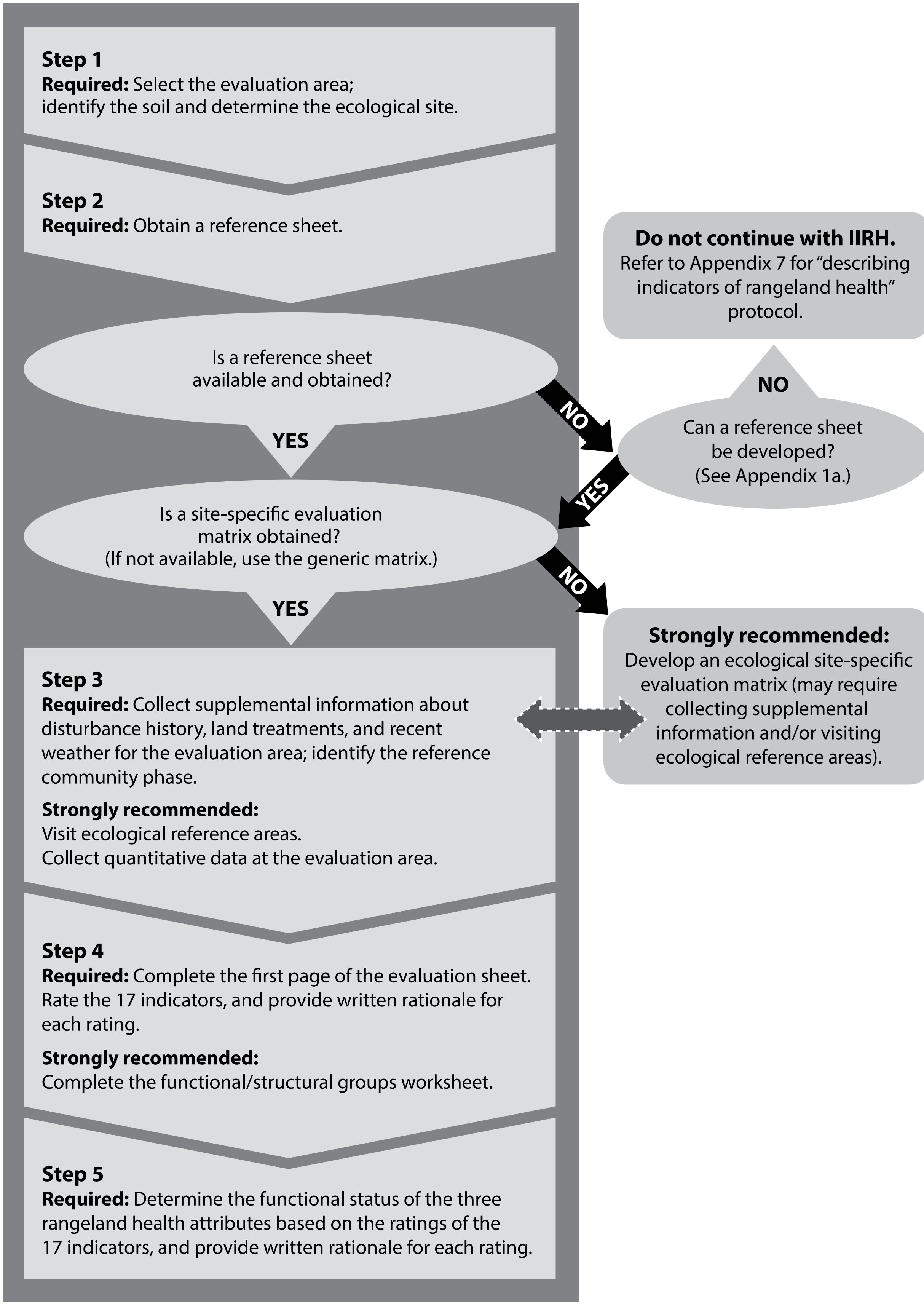


Figure 9. Flowchart for completing an assessment of rangeland health using the IIRH protocol. See the checklists in Appendix 3 for tasks typically completed before going to the field and those completed at the evaluation area and necessary references, equipment, and forms.

For further assessment planning considerations, as well as information on combining assessments with monitoring, see the Landscape Toolbox website (Appendix 10). Volume II of the "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems" (Herrick et al. 2009) also includes some general guidance.

Each evaluation area should be within a single ecological site, relatively uniform (in terms of slope, aspect, disturbances, etc.) and large enough to accurately evaluate all indicators (usually 0.5 to 1 acre (0.2 to 0.4 hectares)). An acre is approximately the size of an American football field without the end zones. When conducting the IIRH protocol in conjunction with quantitative data collection efforts, the evaluation area should coincide with the plot boundary.

Upon arrival at the location, the evaluator(s) should use observations of landscape position and soil profile characteristics to determine the ecological site (see Section 7.1.2 and Appendix 5). Because assessments are conducted on an ecological site basis, it is preferable to select evaluation areas that do not encompass more than one ecological site. If there are small components of other ecological sites within the evaluation area, do not include them as part of the IIRH assessment. However, if more than one major ecological site occurs in an evaluation area, complete a separate assessment for each ecological site (Figure 10). Once the evaluation area has been identified, clearly (temporarily) mark the perimeter of the evaluation area prior to starting the assessment.

Figure 10. Example of an evaluation area (black border) with two distinct ecological sites characterized by big sagebrush (outside of the yellow polygons) and low sagebrush (inside of the yellow polygons). In this situation, a separate IIRH assessment would be conducted in each ecological site. Each ecological site that is assessed must be large enough to comprise an adequate evaluation area.

7.1.2 Determine the Ecological Site and Characterize the Evaluation Area

The reference sheet that corresponds to the ecological site in the evaluation area is required to conduct an IIRH assessment. This requires determining the ecological site in the evaluation area. Characterizing the evaluation area also provides context for the assessment and assists with future interpretations.

Soil maps and electronic mapping applications (e.g., Web Soil Survey, Ecosystem Dynamics Interpretive Tool) (Appendices 5 and 10) help predict soils and therefore ecological sites that are more likely to be found in the evaluation area. However, soil maps cannot be used to identify the soil and ecological site without confirming with a soil pit for three reasons:

(1) Most **soil map units** are comprised of more than one **soil map unit component** (Figure A5.1 and Appendix 5).

(2) **Soil inclusions** or soils representing a relatively small proportion of each **soil map unit** (generally less than 15%) are found in the vast majority of soil map units in the United States and may not even be listed in the NRCS **soil survey**.

(3) Soil maps represent the best available information, but due to their coarse scale, they may be inaccurate.

Therefore, multiple ecological sites can be found within a soil map unit (Duniway et al. 2010). Finally, note that a single **soil series** may be assigned to more than one **soil map unit** due to the variability in the soil series properties, including slope and soil surface texture. This variability can result in more than one ecological site being assigned to a single soil series.

Instructions for completing page 1 of the evaluation sheet, including documenting the ecological site description, site location, basic site characteristics, and reference sheet versions used are included in Appendix 4. A step-by-step process to determine the ecological site at an evaluation area is described in Appendix 5.

Electronic applications, such as the Database for Inventory, Monitoring, and Assessment (DIMA) available on the Landscape Toolbox website and the Land-Potential Knowledge System (LandPKS) (Appendix 10), can also be used to record evaluation area characteristics. LandPKS is a mobile app that includes tools to assist land managers in collecting site-specific soil and vegetation data and provides access to several global databases on soils, climate, and topography (Herrick et al. 2017).

ACTIONS TO TAKE IF SOIL AND/OR ECOLOGICAL SITE INFORMATION IS NOT AVAILABLE

An IIRH assessment cannot be completed without a reference sheet, and a reference sheet cannot be generated without an ecological site or equivalent unit with which it is associated. See Appendix 7 to help determine whether an IIRH assessment can be completed. If not, complete a protocol called “describing indicators of rangeland health” (DIRH) (Appendix 7) to document information on the soil profile and the current status of IIRH indicators (Herrick et al. 2019). The DIRH protocol is designed to be used in two ways. First, where the DIRH protocol is completed on what are believed to be relatively undegraded lands based on other evidence (e.g., knowledge of historic disturbance regimes), data from similar intact locations in the same ecological site can be combined and used to help develop or revise the reference sheet. Second, DIRH data can be collected on land with no known reference, regardless of its level of degradation, and then used at a later date to support completion of an IIRH assessment after a reference sheet has been developed.

7.2 Step 2. Obtain a Reference Sheet and Evaluation Matrix

7.2.1 Obtain a Reference Sheet (Required)

The reference sheet (Appendix 1a) describes the range of expected spatial and temporal variability of each indicator within the natural disturbance regime based on each ecological site (or equivalent unit) and is required to conduct an IIRH assessment. Reference sheets are incorporated into most ecological site descriptions. If a reference sheet is not available, one must be developed using the checklist in Appendix 1a.

Before developing or revising a reference sheet, refer to the EDIT (Ecosystem Dynamics Interpretive Tool) website (*https://edit.jornada.nmsu.edu/*), and contact the NRCS state rangeland management specialist to determine if a final or draft reference sheet is available.

Development of the reference sheet requires more expertise than is usually required to conduct the IIRH protocol. The input of multiple individuals is particularly critical in the development of a reference sheet for each ecological site. Reference sheet development also requires knowledge of the natural range of spatial and temporal variability and disturbance responses associated with a particular ecological site. Memory of similar sites, professional opinion of what the site could be, visits to ecological reference areas, or reviews of old range or ecological site descriptions that do not contain reference sheets are not adequate substitutes for a properly developed or revised reference sheet. However, all of these information sources, as well as existing or new monitoring data, may be used in the development of the reference sheet. See Appendix 1a and 1b for more complete instructions on developing reference sheets. If a reference sheet cannot be developed, the DIRH protocol (Appendix 7) can be used, and the information may assist in the future development of a reference sheet.

7.2.2 Obtain an Evaluation Matrix (Required)

The generic evaluation matrix (Appendix 2) can be used to conduct an IIRH assessment using the ecological site classification system, as well as other landscape-scale classification systems, if appropriate reference information associated with the 17 indicators is available. This matrix provides general descriptions of key characteristics and degrees of departure, forming a relative scale from "none to slight" to "extreme to total" departure for each of the 17 indicators. The descriptor for "none to slight" comes from the reference sheet (Appendix 1a) and reflects the effects of the natural disturbance regime within the natural range of variability of each indicator in the reference state.

It is strongly recommended to obtain or develop an ecological site-specific evaluation matrix for each ecological site because it can more accurately describe the possible range of variation for each indicator compared to the generic evaluation matrix. Instructions for developing an ecological site-specific evaluation matrix are included in Appendix 2, and an example is provided in Table 4.

For some ecological sites, conditions described in the reference sheet for an indicator may resemble one of the other departure categories in the generic evaluation matrix. For example, in sites that naturally have a high amount of bare soil and large, connected bare ground patches (e.g., Mancos shale in the Colorado Plateau, see photo in Section 7.4.1 Rills), the reference state descriptor for bare ground may resemble the generic matrix's moderate departure rating. Development of ecological site-specific evaluation matrix descriptors should be prioritized in these situations to better rate indicator departure. Development of ecological site-specific matrix descriptors should be completed prior to going to the field to complete an assessment.

Once ecological site-specific descriptors are developed for any indicator(s), these modified descriptions should be used for subsequent

Table 4. Example of an evaluation matrix with ecological site-specific and generic descriptors for bare ground in a New Mexico ecological site.

Indicator 4. Bare Ground	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
Ecological Site-Specific Descriptor	Greater than 75% bare ground with bare ground patches connected; only occasional areas where ground cover is contiguous; ground cover mostly patchy and sparse.	51-75% bare ground; bare ground patches are large (> 24" diameter) and usually connected.	31-50% bare ground; bare ground patches are 12-24" and sporadically connected.	20-30% bare ground; bare ground patches greater than 12" diameter but rarely connected; bare ground patches associated with surface disturbance are larger and are rarely connected.	Less than 20% bare ground occurring in patches less than 10" diameter; larger bare ground patches also associated with ant mounds and small mammal disturbances.
Generic Descriptor	Substantially higher than expected. Bare ground patches are large and frequently connected.	Much higher than expected. Bare ground patches are large and occasionally connected.	Moderately higher than expected. Bare ground patches are moderate in size and sporadically connected.	Slightly higher than expected. Bare ground patches are small and rarely connected.	Reference sheet narrative inserted here.

evaluations on the same ecological site and forwarded to the person maintaining ecological site descriptions (usually the NRCS state rangeland management specialist). This will ensure these modifications are considered during revisions of reference sheets in ecological site descriptions.

7.3 Step 3. Collect Supplemental Information

Supplemental information improves an evaluator's ability to conduct an informed and accurate assessment. Local knowledge is a valuable source of much of this supplemental information, which includes: (1) recent weather, including precipitation for the past 2 years; (2) land treatment records; (3) disturbance history; and (4) information about wildlife, livestock, recreation, or other uses. As much of the supplemental information as possible should be collected prior to the IIRH assessment.

Supplemental information can be summarized on page 1 of the evaluation sheet. Appendix 4 provides more detailed instructions and a completed example of page 1 of the evaluation sheet.

It is also strongly recommended to visit ecological reference areas (step 4 in Appendix 1a) to take photos and collect quantitative data (Appendix 3) to assist in understanding the effects of recent weather, uses, and disturbances on the natural range of variability of the ecological site on which the IIRH assessment will be conducted. The IIRH protocol can be used to assist in identifying areas that meet the criteria for an ecological reference area. Although a reference area may show some departure for individual indicators, all three attribute ratings should be in the "none to slight" category. The information on page 1 of the evaluation sheet can also be helpful in future evaluations, since ecological site descriptions can have a range of properties that should be accounted for in the assessments.

7.3.1 Recent Weather (Required)

Knowledge of recent weather (past 2 years) in the evaluation area is needed to understand effects of weather on the temporal range of variability of the indicators. For example, during drought, reduced plant vigor may be within the natural range of variability for that area. Water flow patterns may be more prominent shortly after an intense rainstorm. Weather station records and local knowledge are potential sources of information about recent weather, which can be recorded on page 1 of the evaluation sheet.

7.3.2 Land Treatments and Disturbance History (Required)

Before going to the field, check records and/or ask landowners about natural disturbances and land treatments in or near the evaluation area. Wildfire is an example of a natural disturbance that can be expected to drive plant community changes at an evaluation area. Other natural disturbances that may be documented include, but are not limited to, insect or rodent population increases/decreases, native herbivore use, droughts, and wet periods.

Land treatments include a wide range of vegetation and soil manipulations, such as use of mechanical equipment, herbicides, prescribed fire, or seeding. Dates, types of treatments (including seed mixtures if applicable), results from monitoring studies (if available), and treatment polygons all provide context for conducting an assessment. Agency or landowner records may provide this information. For example, the U.S. Geological Survey maintains the Land Treatment Digital Library (Appendix 10), which contains information on land treatments implemented on public lands managed by the BLM.

7.3.2.1 IDENTIFY THE REFERENCE COMMUNITY PHASE (REQUIRED)

Land treatment and disturbance history are used to select the appropriate reference community phase to be used as the basis for an assessment. Compare the evaluation area's land treatment and disturbance history to the narrative in the appropriate ecological site description sections that explain the disturbance and community dynamics within the reference state. The reference plant community phase is not selected by simply choosing the phase that most resembles the vegetation composition in the evaluation area. Additional instructions are provided in the functional/structural groups worksheet section of Appendix 4. If the functional/structural groups worksheet is not being used, the expected relative dominance is described in the supplemental information section of the evaluation sheet.

7.3.3. Wildlife, Livestock, Recreation, or Other Uses (Recommended)

In areas grazed by livestock, it is useful to understand the timing and amount of grazing that has occurred in the evaluation area during the year the assessment is completed. This information, along with knowledge of types and amounts of recreation use and wildlife use of the area, helps to provide context in conducting the assessment, as well as any subsequent interpretations. Other observations, such as signs of wildlife (e.g., tracks, scat), may be also recorded.

7.3.4 Photographs (Strongly Recommended)

Taking photographs of the evaluation area and keeping them with the evaluation sheet (or in an electronic file) is strongly recommended. When taking photographs, include at least two general views (Figure 11) in different directions (include some skyline for future point of reference) and photographs that illustrate important indicator values or anomalies. The time, date, orientation, and location of each photo may be recorded using a photo ID card (Herrick et al. 2017) or electronic applications.

Figure 11. Example of a landscape photo with documentation at an evaluation area.

7.3.5 Quantitative Data (Strongly Recommended)

Collecting quantitative data in the evaluation area is strongly recommended to help train evaluators in rating some indicators and, if needed, to support assessments. Table 5 provides examples of qualitative indicators and associated measurement methods that can be used to collect related quantitative indicator values (also see Table 3 and Pyke et al. 2002). The stick method provides an option to collect quantitative data without specialized equipment (Riginos and Herrick 2010).

7.4 Step 4. Rate the 17 Indicators in the Evaluation Sheet (Required)

The recommended protocol to conduct an IIRH assessment is for the evaluator(s) to complete a general reconnaissance of the evaluation area to determine how much variability exists for each indicator on the site. This enables the evaluator(s) to become familiar with the plant species, relative dominance of functional/structural groups, soil surface features, rangeland health indicators, and variability associated with the ecological site in the evaluation area. When completing the IIRH protocol as an interdisciplinary team, indicators are rated using a consensus approach.

The reference sheet describes the range of expected spatial and temporal variability for each indicator within the natural disturbance regime for an ecological site. The rating of each indicator in the evaluation area is based on that indicator's degree of departure from the "none to slight" category, which is taken from the appropriate reference sheet (Appendix 1a). When indicator conditions match the description for the reference, the indicator is rated "none to slight."

Table 5. Selected indicators of rangeland health and associated measurement methods that are commonly used to collect related quantitative indicator values.

Rangeland Health Indicator	Measurement Method[1]	Quantitative Indicator Value
Bare ground (indicator 4)	**Line point intercept**	Bare ground percent
	Gap intercept	Size of intercanopy or basal gaps
Soil surface resistance to erosion (indicator 8)	**Soil stability test**	Soil surface stability values
Effects of plant community composition and distribution on infiltration (indicator 10)	Production by species[2]	Functional/structural group composition by weight
	Line point intercept	Functional/structural group composition by cover
Functional/structural groups (indicator 12)	Production by species[2]	Functional/structural group composition by weight
	Line point intercept	Functional/structural group composition by cover
Dead or dying plants or plant parts (indicator 13)	**Line point intercept**	Proportion of dead plants or plant parts intercepted
	Belt transect	Proportion or density of dead or dying plants
Litter cover and depth (indicator 14)	**Line point intercept**	Litter cover
Annual production (indicator 15)	Total harvest[2] Weight units[2]	Total annual production
Invasive plants (indicator 16)	Production by species[2]	Invasive plant composition by weight
	Line point intercept	Cover of invasive species
	Belt transect	Density of invasive plants

1 Core methods are bold.

2 Note that the protocol outlined in Appendix 8 provides a measurement of total annual production. Refer to the "National Range and Pasture Handbook" (NRCS 2006) for protocols to determine species composition by weight.

Refer to the evaluation matrix (Appendix 2) or ecological site-specific evaluation matrix (if available) to determine which descriptor best describes the departure from the "none to slight" descriptor, and enter that rating on page 2 of the evaluation sheet (Appendix 4). The narrative descriptors for each indicator form a relative scale from "none to slight" to "extreme to total" departure.

The evaluation matrix often includes several short sentences describing characteristics of the departure of an indicator. Not all indicator departure descriptors will match indicator conditions observed in the evaluation area, particularly when using the generic evaluation matrix. Evaluators should select the departure rating for which the majority of the descriptors best describe the departure of the indicator (e.g., use a "best fit" approach) while strongly considering those descriptors that fall in greater departure rating categories (Table 6). Each indicator rating should be supported with comments in the spaces provided on page 2 of the evaluation sheet (Appendix 4).

Table 6. Example of a "moderate to extreme" rating for gullies for an evaluation area on a sandy ecological site. Due to the sandy nature of soils in the evaluation area, nickpoints and headcuts ("moderate" in this example) are more likely to be muted; therefore, the observers place more weight on the vegetation and gully size characteristics that fall in the "moderate to extreme" departure category and decide to rate the indicator as "moderate to extreme."

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
5. Gullies	Sporadic or no vegetation on banks and/or bottom. Numerous nickpoints. Significant active bank and bottom erosion, including downcutting. Substantial depth and/or width. Active headcut(s) may be present.	Intermittent vegetation on banks and/or bottom. Nickpoints common. Moderate active bank and bottom erosion, including downcutting. Significant width and/or depth. Active headcut(s) may be present.	Occasional vegetation on banks and/or bottom. Occasional nickpoints and/or slight downcutting. Moderate depth and/or width. Active headcuts absent.	Vegetation on most banks and/or bottom. Few nickpoints and/or minimal downcutting. Minimal gully depth and/or width. Headcuts absent.	Reference sheet narrative inserted here.

IMPORTANT CHARACTERISTICS OF THE INDICATORS

1. The 17 indicators consider many important characteristics of rangeland ecological processes and function. It is this multiple-characteristic approach to assessment that makes the IIRH protocol a useful rangeland health assessment tool.
2. None of the indicators are new to rangeland assessment and management. All have been used previously to evaluate rangeland resources. However, the IIRH protocol organizes these indicators into a system that collectively provides information about their associated attributes of rangeland health (soil/site stability, hydrologic function, and biotic integrity).
3. There is some redundancy built into the indicators so that similar questions about rangeland health are asked in different ways. For example, the indicators bare ground, litter movement, and effects of plant community composition and distribution on infiltration help determine whether an evaluation area is more susceptible to loss of soil/site stability from runoff and soil erosion than would be indicated by just one of these indicators.

Descriptions of each of the 17 indicators used to evaluate rangeland health are provided in Section 7.4.1 through 7.4.17. For each indicator, the following information is provided: (1) background information, (2) description of how to identify the indicator in the field, (3) instructions for rating the indicator, (4) generic evaluation matrix, (5) associated quantitative measurements, (6) the attribute(s) with which the indicator is associated, and (7) photographic examples.

Summaries of the interpretation of indicators relative to each attribute are provided in Tables 26 (soil/site stability), 27 (hydrologic function), and 28 (biotic integrity). The information in these tables can assist in applying the preponderance of evidence approach for rating the attributes of rangeland health and documenting the rationale for those ratings. Additional information on many of the soil-related indicators can be found in the NRCS Rangeland Soil Quality Information Sheets (NRCS 2001) (see Appendix 10 for website information).

▶ 7.4.1 Rills (Indicator 1)

Indicator Description and Assessment

Rills are small, intermittent watercourses with steep sides, usually only several centimeters deep (SSSA 1997). They are generally linear erosion features that mostly run parallel to the slope. For most soils and ecological sites, the potential for rill formation increases as the degree of disturbance (loss of cover) and slope increases. Rills usually end at a concentrated water flow pattern, a terracette, or an area where the slope flattens and deposition occurs. Rills may connect into a drainage and erosion network on some sites, but for most sites, rills will not be connected. See the text box at the end of this indicator description for guidance on distinguishing rills from water flow patterns and gullies.

Some soils have a greater potential for rill formation than others (Bryan 1987; Quansah 1985). The potential for rill formation also depends on types and amounts of vegetation and recent weather (e.g., storm timing and intensity relative to vegetation). Therefore, it is important to establish the degree of natural versus accelerated rill formation by using interpretations based on the soil survey, ecological site description, or ecological reference areas. For example, rills are common and part of the site potential in arid and semiarid sites where soils are formed by weathered shale bedrock (e.g., Mancos shale in the Colorado Plateau) (Figure 12).

Rating this indicator involves comparing the number, distribution, depth, width, and length of rills to the reference ("none to slight" departure). Table 7 provides generic descriptors of the five departure categories in the evaluation matrix for rills.

Figure 12. Example of a Mancos shale landscape in the Western U.S. where rills are a component of the natural range of variability.

Table 7. Generic descriptors of the five departure categories in the evaluation matrix for rills.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
1. Rills	Numerous and frequent throughout. Nearly all are wide, deep, and long. Occur in exposed and vegetated areas.	Moderate in number at frequent intervals. Many are wide, deep, and long. Occur in exposed areas and in some adjacent vegetated areas.	Moderate in number at infrequent intervals. Moderate width, depth, and length. Occur mostly in exposed areas.	Scarce and scattered. Minimal width, depth, and length. Occur in exposed areas.	Reference sheet narrative inserted here.

Measurements

Rills are not frequently measured in association with the IIRH protocol. Rills may be counted over a defined distance across (perpendicular to) a slope. Additionally, these counts can be stratified based on slope ranges (e.g., 0–3%, 3–15%, > 15% slope). The length, width, and depth of rills can also be measured.

Relationship to Attributes of Rangeland Health

Soil/site stability: Although rills are small, if present in high densities, they can transport significant amounts of soil that may be lost from or redistributed on the site.

Hydrologic function: The channels formed by rills facilitate rapid water movement on slopes causing water to be lost from or redistributed on the site. Formation of rills greater than expected for a site may indicate a reduction in infiltration capacity.

Biotic integrity: Not applicable.

DISTINGUISHING RILLS FROM WATER FLOW PATTERNS AND GULLIES

Rills and water flow patterns are sometimes difficult to distinguish from each other. Generally, rills are small erosional channels where water and soil movement are concentrated in a linear pattern, while water flow patterns are typically much wider than they are deep, yielding a more diffuse and irregular pattern due to plant, litter, or rock obstructions (e.g., they follow the microtopography). Short, linear sections of water flow patterns may be present and are usually distinguished from rills by the lack of downcutting on both sides of the erosion path. In this situation, rate the feature as a water flow pattern. Water flow patterns can transition to rills where slopes increase or if water becomes concentrated causing downcutting on both sides of the linear erosion feature. If unsure whether an erosional feature is a water flow pattern or a rill, rate it as one or the other, but never as both. Document the rationale in the comment section on page 2 of the evaluation sheet (Appendix 4). Rate the departure for both indicators, if both are present.

Distinguishing between rills and gullies can also be difficult. Using the definition provided by Selby (1993), rills are less than 1 ft (30 cm) wide and 2 ft (61 cm) deep, whereas gullies exceed these limits. It is important to rate an observed erosional feature as either a gully or a rill, but never as both, with documentation in the comments section on page 2 of the evaluation sheet (Appendix 4).

Indicator 1 Example Photos

Rills in disturbed areas on a steep slope.

Rills are generally linear with sidecutting on both edges. Edges may become muted over time.

▶ 7.4.2 Water Flow Patterns (Indicator 2)

Indicator Description and Assessment

Water flow patterns are the paths that water takes as it moves across the soil surface during periods when surface water from rain or snowmelt exceeds soil infiltration capacity. This process is commonly referred to as **sheetflow** or **overland flow**. Water flow patterns follow the natural microtopography of the landscape. These patterns are generally evidenced by litter, soil or gravel redistribution, or pedestalling of vegetation or stones that break or divert the flow of water (Morgan 1986). Length, width, and number of water flow patterns are influenced by the number and kinds of obstructions to water flow provided by basal intercepts of living or dead plants, biological soil crusts, persistent litter, or rocks. They may be continuous or appear and disappear as the slope, perennial plant density, and microtopography change. Soils with inherently low infiltration capacity may have a large number of natural water flow patterns. Generally, as slope increases and ground cover decreases, water flow patterns increase (Morgan 1986). See the text box at the end of Section 7.4.1 for guidance on distinguishing water flow patterns from rills and gullies.

This indicator's rating includes: (1) density, width, and length of water flow patterns; (2) the connectivity of water flow patterns (e.g., do small water flow patterns merge into larger water flow patterns, or are they short and not connected?); and (3) the degree of erosion (depositional and cut areas) associated with water flow patterns. These features may be muted depending on the time since the last storm event or the type of vegetation (e.g., sod grasses may make water flow patterns difficult to see). Table 8 provides generic descriptors of the five departure categories in the evaluation matrix for water flow patterns.

Table 8. Generic descriptors of the five departure categories in the evaluation matrix for water flow patterns.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
2. Water Flow Patterns	Extensive. Long and wide. Erosional and/or depositional areas widespread. Usually connected.	Widespread. Longer and wider than expected. Erosional and/or depositional areas common. Occasionally connected.	Common. Lengths and/or widths slightly to moderately higher than expected. Minor erosional and/or depositional areas. Infrequently connected.	Scarce. Length and width nearly match expected. Some minor erosional and/or depositional areas. Rarely connected.	Reference sheet narrative inserted here.

Measurements

Due to the variability in width and depth that may occur within a single water flow pattern and difficulty in consistently determining the length, these features are not usually measured directly. Water flow patterns can be counted within a set distance along a slope or can be recorded using the continuous line intercept method. Tongway (1994) describes a semiquantitative protocol that addresses water flow. Basal cover, measured using line point intercept, can be negatively correlated with water flow pattern connectivity and continuity because plant bases slow water movement. Basal gaps, measured using basal gap intercept, may be positively correlated with water flow patterns because water gains energy as it moves across larger gaps unobstructed. These measurements may help gauge an evaluation area's susceptibility to water flow pattern formation but do not directly inform the rating of this indicator because gaps in vegetation can exist without water flow pattern development.

Relationship to Attributes of Rangeland Health

Soil/site stability: There is an indication of increased soil movement within and possibly off a site when: (1) water flow patterns connect into a drainage network and (2) occurrence of water flow patterns is greater in number, length, and width than what has been defined as expected for the site in the reference state. Interrill erosion caused by overland flow has been identified as the dominant sediment transport mechanism on rangelands (Tiscareño-Lopez et al. 1993).

Hydrologic function: There is an indication of increased water movement within and possibly off a site when (1) water flow patterns connect into a drainage network and (2) occurrence of water flow patterns is greater in number, length, and width than what has been defined as expected for the site in the reference state. Shorter water flow patterns indicate that water movement is intermittently slowed or stopped. Water flow patterns can occur when water moves across the soil surface with little evidence of erosion (e.g., lack of depth of flow pattern, pedestals/terracettes).

Biotic integrity: Not applicable.

Indicator 2 Example Photos

Defined water flow pattern in sagebrush steppe.

Diffuse water flow pattern with litter movement indicating the high degree of overland water flow.

Water flow pattern with incised bank on one side.

Water flow pattern that is narrow and defined in the upper half of the photo, becoming wide and diffuse in the lower half of the photo.

▶ 7.4.3 Pedestals and/or Terracettes (Indicator 3)

Indicator Description and Assessment

Pedestals indicate the movement of soil by water or wind from the base of plants or from around rocks or persistent litter, giving them the appearance of being elevated. Accelerated erosion is likely to be occurring on a site when the amount of pedestals is more than what is defined as expected for the site in the reference state (within the natural disturbance regime). In some cases, plant roots may be exposed due to this accelerated erosional process.

Nonerosional processes, such as frost heaving and soil or litter deposition on and around plants (Hudson 1993), can create features around plants that are similar in appearance to erosional pedestals (but are not included when rating this indicator). Frost heaving is not common under reference conditions in temperate rangelands; where it does occur, it usually is associated with finer soils and plants with less developed root systems. Frost heaving potential is strongly dependent on soil texture, with silts and clays being more likely to heave than coarser soils (Kaplar 1974).

Terracettes are "benches" of soil deposition that form behind or between obstacles, such as rocks, plant bases, or large litter, when soil and other materials are redistributed by water movement. As the degree of soil movement by water increases, terracettes may become more numerous, and the area of soil deposition becomes larger. The relatively higher elevation of the soil on the upslope side of a terracette is an indication of soil deposition by moving water or of soil erosion below the terracette.

Terracettes formed by livestock or wildlife trails on hillsides are not considered erosional terracettes and are not included when rating this indicator. These terracettes can influence soil stability and hydrologic function by concentrating water flow or changing infiltration and may be associated with soil compaction. However, these effects are captured through assessment of other indicators associated with these attributes (e.g., water flow patterns, compaction layer, or soil surface loss and degradation).

The pedestals and/or terracettes indicator is rated based on the increases in number of pedestals or terracettes and the frequency of exposed plant roots in plant pedestals relative to the "none to slight" descriptor. Note, pedestals may occur in an evaluation area without terracettes and vice versa. In this situation, rate this indicator based on the features (pedestals or terracettes) that occur in the evaluation area. Table 9 provides generic descriptors of the five departure categories in the evaluation matrix for pedestals and/or terracettes.

Table 9. Generic descriptors of the five departure categories in the evaluation matrix for pedestals and/or terracettes.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
3. Pedestals and/or Terracettes	Pedestals extensive; roots frequently exposed. Terracettes widespread.	Pedestals widespread; roots commonly exposed. Terracettes common.	Pedestals common; roots occasionally exposed. Terracettes uncommon.	Pedestals uncommon; roots rarely exposed. Terracettes scarce.	Reference sheet narrative inserted here.

Measurements

Pedestals and terracettes are not easily measured. However, belt transects may be used to measure or document the density (i.e., number in a defined area) of these features. Additionally, these counts can be stratified based on slope ranges (e.g., 0–3%, 3–15%, > 15% slope).

Relationship to Attributes of Rangeland Health

Soil/site stability: Pedestals are important indicators of soil movement by water and wind, while terracettes (Hudson 1993) are important indicators of soil movement by water (Anderson 1974; Morgan 1986; Satterlund and Adams 1992).

Hydrologic function: Pedestals and terracettes caused by water erosion can be important indicators of water movement across a site (Anderson 1974; Morgan 1986; Satterlund and Adams 1992; Hudson 1993). If wind erosion is the primary factor in pedestal development, these pedestals should not be considered when evaluating hydrologic function. Be sure to document the cause of pedestal formation, if known, in the comments section on page 2 of the evaluation sheet (Appendix 4).

Biotic integrity: Not applicable.

Indicator 3 Example Photos

Severe wind caused plant pedestalling as evidenced by exposed roots.

Small rocks on pedestals as a result of water erosion.

Terracette formed behind vegetation obstructions in a water flow pattern.

Pedestaled shallow-rooted bunchgrasses associated with water erosion.

▶ 7.4.4 Bare Ground (Indicator 4)

Indicator Description and Assessment

Bare ground is exposed mineral soil not covered by vegetation (live or dead and basal and canopy cover), gravel/rock, visible biological soil crusts, or litter. These ground surface cover materials intercept raindrops, reduce soil particle detachment (raindrop splash erosion), and reduce soil movement by water and wind (Weltz et al. 1998).

The amount and distribution of bare ground is an important contributor to soil/site stability; therefore, bare ground is a direct indication of site susceptibility to accelerated wind or water erosion (Smith and Wischmeier 1962; Morgan 1986; Benkobi et al. 1993; Blackburn and Pierson 1994; Pierson et al. 1994; Gutierrez and Hernandez 1996; Cerda 1999).

A **bare ground patch** is an area where bare ground is concentrated. Bare ground patches may include some ground cover (e.g., plants, litter, rock, and visible biological soil crusts) within their perimeter, but there is proportionally much more bare soil than ground surface cover. In general, a site with bare ground concentrated in a few large patches will be less stable than a site with the same ground cover percentage in which the bare soil is distributed in many small patches, especially if these patches are not connected (Gould 1982; Spaeth et al. 1994; Puigdefábregas and Sánchez 1996).

The amount, size, and connectivity of bare ground patches can vary seasonally, with changes in vegetation canopy (foliar) cover and litter amount. Bare ground patches vary in response to weather-driven plant production, consumption, and trampling by herbivores (Gutierrez and Hernandez 1996; Anderson 1974). Natural disturbances, such as ant mounds and rodent burrows, can create bare ground patches that are often part of the natural range of variability on many ecological sites.

This indicator is rated based on increases in both the amount of bare ground and the size and connectivity of bare ground patches as compared to what is described in the reference sheet. Decreases in amount of bare ground, or size and connectivity of bare ground patches relative to the description in the reference sheet, are not considered to be a departure for this indicator. Table 10 provides generic descriptors of the five departure categories in the evaluation matrix for bare ground.

Table 10. Generic descriptors of the five departure categories in the evaluation matrix for bare ground.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
4. Bare Ground	Substantially higher than expected. Bare ground patches are large and frequently connected.	Much higher than expected. Bare ground patches are large and occasionally connected.	Moderately higher than expected. Bare ground patches are moderate in size and sporadically connected.	Slightly higher than expected. Bare ground patches are small and rarely connected.	Reference sheet narrative inserted here.

Measurements

Bare ground is measured using line point intercept or another vertical point-intercept-based method. Size of bare ground patches can be hard to quantify due to variability in cover and the difficulty in placing a finite boundary around bare ground patch perimeters. Canopy gap intercept provides an indication of the extent to which plant cover is aggregated, which can help define, but not fully account for, the spatial extent of bare ground patches.

Bare ground is what remains after accounting for ground surface covered by vegetation (basal and foliar cover), litter, standing dead vegetation, gravel (> 5 mm in diameter)/rock, and visible biological soil crust. To calculate percent bare ground from line point or step point intercept data, count the total number of points that have bare ground, and divide the total number of bare ground hits by the total number of pin drops (Herrick et. al 2017).

Relationship to Attributes of Rangeland Health

Soil/site stability: Occurrence of bare ground at a higher percentage and bare ground patches with greater size and connectivity than expected both increase (1) the potential for water erosion due to raindrop impact and soil particle disaggregation and movement or (2) wind erosion due to soil saltation. When soils lack protective cover of vegetation, biological soil crusts, and rocks, water is more likely to move across the soil surface prior to infiltration, thus leading to accelerated soil erosion.

Hydrologic function: When soils lack protective cover of vegetation (especially as bare ground patch size increases), biological soil crusts, and rocks, water is more likely to move across the soil surface prior to infiltration, leading to accelerated water loss.

Biotic integrity: Not applicable.

Indicator 4 Example Photos

Desert grassland in near reference state condition that would have minimal bare ground and small, rarely connected bare ground patches.

Degraded desert grassland site with large and connected patches of bare ground.

Bare ground is not protected from raindrop impact by vegetation, litter, visible biological soil crusts, and rocks/gravel greater than 5 mm in diameter (diameter of the coin is 23 mm). Gravel less than 5 mm in diameter is considered bare ground.

Bare ground patch in grassland community around an ant mound (e.g., within the natural range of variability for this site).

▶ 7.4.5 Gullies (Indicator 5)

Indicator Description and Assessment

Gullies are well-defined channels cut into the soil by ephemeral water flow that normally follow natural drainage channels. Gullies can develop from enlarged rills; however, gully formation may be much more complex and usually involves an interrelationship between the: (1) volume, speed, and type of runoff; (2) susceptibility of the soil to erosion; and (3) changes in ground cover caused by inappropriate land uses and treatments (Morgan et al. 1997). See the text box at the end of Section 7.4.1 for guidance in distinguishing gullies from rills and water flow patterns.

Soils with weak cementation, poor consolidation, and low cohesion (alluvium, colluvium, loess, ocean, or lake deposits) are especially susceptible to gully formation, as are soils with a high salt content (Heede 1976).

Concentrated water flow may initiate the formation of a gully where runoff accumulates: (1) due to rills or water flow patterns having formed a drainage network, (2) at the base of a slope, or (3) on the downslope side of exposed bedrock. Once water has been captured by a gully, the energy associated with the moving water may extend the gully up- and downslope, cut the channel deeper, and incise the channel sides widening the gully. The linear extent or depth of a gully may be limited by bedrock, but a gully may continue to erode upslope and along its sides. For most soils and ecological sites, the risk of gully formation increases as the degree of disturbance, loss of cover, and slope increases.

Upslope erosion can result in **headcuts** when water undercuts the upslope walls, creating a drop in the gully bottom, which often results in plunge pools (Poesen et al. 2002). Active headcuts may be a sign of accelerated erosion in a gully even if the rest of the gully shows signs of healing (Morgan 1986).

Gullies are a natural feature of very few landscapes and ecological sites; in most cases, current or historical management (e.g., grazing, vegetation removal, recreation vehicles, or road drainages) have caused gullies to form or expand (Morgan 1986). Gullies can be caused by offsite influences that can affect site function in the evaluation area. Document these offsite influences on page 1 of the evaluation sheet and in the comments section for this indicator on page 2 (Appendix 4).

Because of the magnitude to which a single gully can affect an evaluation area, gullies are assessed by observing the severity of erosion in individual gullies. The occurrence of deeper, wider, or more actively eroding gullies than what has been defined as expected for a site in its reference state (within the natural disturbance regime) indicates accelerated soil erosion and water loss. General signs of active erosion (e.g., incised sides along a gully or headcuts) are indicative of a current erosional problem, while a healing gully is characterized by rounded banks, vegetation growing in the bottom and on the sides (Anderson 1974), and a reduction in gully depth (Martin and Morton 1993). Table 11 provides generic descriptors of the five departure categories in the evaluation matrix for gullies.

Table 11. Generic descriptors of the five departure categories in the evaluation matrix for gullies.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
5. Gullies	Sporadic or no vegetation on banks and/or bottom. Numerous nickpoints. Significant active bank and bottom erosion, including downcutting. Substantial depth and/or width. Active headcut(s) may be present.	Intermittent vegetation on banks and/or bottom. Nickpoints common. Moderate active bank and bottom erosion, including downcutting. Significant depth and/or width. Active headcut(s) may be present.	Occasional vegetation on banks and/or bottom. Occasional nickpoints and/or slight downcutting. Moderate depth and/or width. Active headcuts absent.	Vegetation on most banks and/or bottom. Few nickpoints and/or minimal downcutting. Minimal gully depth and/or width. Headcuts absent.	Reference sheet narrative inserted here.

Measurements

Gully width and depth can be measured at random or regular points along the reach of the gully. Similarly, the slope angle and proportion of incised banks along a set reach of a gully can be measured. Depth and width of headcuts associated with gullies can also be measured. Vegetation in the bottom or on gully banks can be measured using line point intercept, although the meandering nature of gullies may make these measurements difficult to collect.

Relationship to Attributes of Rangeland Health

Soil/site stability: Considerable amounts of soil may be lost from the sides and headcuts of gullies. The amount of soil loss via a gully is generally greater than via water flow patterns or rills, and the effects are more concentrated and visible. Gullies are associated with accelerated erosional processes and with landscape instability (Morgan et al. 1997). Gullies can also affect physical soil properties at a site (Poesen et al. 2003).

Hydrologic function: Gullies increase the volume of water that will move offsite. The amount of water transport via a gully is generally greater than via water flow patterns or rills, and the effects are more concentrated and visible. Gullies can also affect water table levels at a site (Poesen et al. 2003).

Biotic integrity: Not applicable.

Indicator 5 Example Photos

Formation of a gully from runoff from a large rill off the road. Note the beginning of the gully at the headcut near the shovel.

Large gully with active side and bed cutting.

Gully with some active side and bed cutting and some vegetation on sides and bottom.

A network of gullies with multiple nickpoints and active bank erosion.

▶ 7.4.6 Wind-Scoured and/or Depositional Areas (Indicator 6)

Indicator Description and Assessment

Wind-scoured areas, including blowouts, are formed as finer particles of the topsoil are blown away, sometimes leaving residual gravel, rock, or exposed roots on the soil surface (Anderson 1974). **Blowouts** are defined as "a hollow or depression of the land surface, which is generally saucer or trough-shaped, formed by wind erosion, especially in an area of shifting sand, loose soil, or where vegetation is disturbed or destroyed" (SSSA 1997). Blowouts are included within the following discussion of wind-scoured areas and within the assessment of this indicator. **Depositional areas** are locations where windblown soil accumulates; the deposited soil may originate from either on- or offsite. Soil deposition due to water movement is not included when assessing this indicator.

The following conditions increase the susceptibility of the soil to wind erosion: (1) a reduction in plant cover, soil surface crusts (physical, chemical, or biological), and litter that results in more bare soil or bare ground patches; (2) a decrease in the amount of soil organic matter that causes decreased soil aggregate stability (see Section 7.4.8 Soil Surface Resistance to Erosion (Indicator 8)); and (3) long, unsheltered, smooth soil surfaces that are exposed to wind (NRCS 2001).

Wind-scoured areas, including blowouts, are generally found in areas where bare soil is concentrated (e.g., bare ground patches) (Chepil 1946; Gillette et al. 1972). They usually occur in plant interspace areas with a close correlation between soil cover, bare ground patch size, **soil texture**, and the degree of accelerated erosion (Morgan 1986). Wind-scoured areas appear to be swept or scoured smooth by wind action, and subsurface **soil horizons** may be exposed. In areas where the wind has removed soil particles and litter, gravel or rock may be left on the soil surface (gravel pavement), or plant roots may be exposed.

Soil crusts (see Section 5.10) are extremely important in protecting the soil surface from wind erosion on many rangelands with low vegetation cover. The degree of wind erosion may increase as surface crusts are impacted by disturbance or worn away through abrasion because the exposed soil beneath these surface crusts is often weakly consolidated and vulnerable to movement via wind (Chepil and Woodruff 1963). As wind velocity increases, soil particles begin bouncing against each other in the **saltation** process. This abrasion leads to suspension of fine particles in the windstream where they may be redistributed or transported off the site (Chepil 1946; Gillette et al. 1972; Gillette et al. 1974; Gillette and Walker 1977; Hagen 1984).

Depositional areas usually occur under plant canopies and on the downwind side of plants or other obstructions, sometimes forming a hummock-like landscape. Deposition of suspended soil particles is often associated with vegetation structure, which slows the wind velocity and allows soil particles to settle from the windstream. Taller vegetation slows the wind and captures soil particles (Pye 1987); thus, shrubs and trees are likely sinks for deposition (e.g., mesquite dunes) (Gibbens et al. 1983; Hennessy et al. 1983). As windblown soil is redistributed, accumulation areas (e.g., deposits around plants or sand dunes) increase in size and area of coverage as the degree of wind erosion increases (Anderson 1974). Like sedimentation (soil deposited by water), wind-deposited soil particles can originate from offsite locations and affect the function of the depositional area by modifying soil surface texture (Hennessy et al. 1986; Morin and van Winkel 1996) and burying soil crusts and parts of plants. In this situation, soil deposition would also be considered as degradation and incorporated in the rating of indicator 9, soil surface loss and degradation.

Some soil deposition immediately following a wildfire may be within the natural range of variability. However, wildfires in the same area within a shorter timeframe than that expected under the natural disturbance regime may cause a cumulative increase in soil deposition that would not be expected in the reference state.

Wind-scoured and/or depositional areas are rated based on the distribution and extent of the areas. In addition, wind-scoured areas are rated based on their connectivity. Amount of deposited soil is also considered when rating this indicator. Document the relative proportion of the evaluation area that is affected by wind-scoured and/or depositional areas and record the depth and distribution of deposited soils in the comment section on page 2 of the evaluation sheet (Appendix 4). Table 12 provides generic descriptors of the five departure categories in the evaluation matrix for wind-scoured and/or depositional areas.

Table 12. Generic descriptors of the five departure categories in the evaluation matrix for wind-scoured and/or depositional areas.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
6. Wind-Scoured and/or Depositional Areas	Extensive. Wind scours usually connected. Large soil depositions around obstructions.	Common. Wind scours frequently connected. Moderate soil depositions around obstructions.	Occasionally present. Wind scours infrequently connected. Minor soil depositions around obstructions.	Infrequent and few. Wind scours rarely connected. Trace amounts of soil deposition around obstructions.	Reference sheet narrative inserted here.

Measurements

The proportion of the evaluation area affected by wind-scoured areas may be measured by recording these features using the continuous line intercept method. Because low amounts of ground cover and/or large gaps in vegetation indicate susceptibility to wind erosion, line point intercept and canopy gap intercept data can be used to assess susceptibility to wind scouring. Deposition is difficult to measure consistently at the scale of an evaluation area due to the variability in distribution and extent.

Relationship to Attributes of Rangeland Health

Soil/site stability: Wind-scoured and/or depositional areas outside the natural disturbance regime within the natural range of variability for an ecological site are signs of site degradation due to wind erosion. Soil/site stability is decreased when the soil surface is removed by wind erosion, exposing subsurface soils, which are typically less resistant to further erosion. Newly deposited soil may be also be unstable and therefore susceptible to erosion.

Hydrologic function and biotic integrity: Not applicable.

Indicator 6 Example Photos

Wind-scoured area (rocks on soil surface) and an area with deposited sand in bottom of picture.

Mesquite dune formation on former desert grassland facilitating wind scouring and deposition.

Grass seedling damaged by wind erosion and soil deposition.

Bunchgrass that has been partially buried due to deposition of windblown soil.

▶ 7.4.7 Litter Movement (Indicator 7)

Indicator Description and Assessment

Litter is the uppermost layer of organic debris on the soil surface—essentially the freshly fallen or slightly decomposed vegetal material (SRM 1999). In this technical reference, litter includes dead plant material, including leaves, stems, and branches, that are detached from the plant. Duff (dead plant material that is decomposed so that leaves, stems, and branches are difficult to recognize) is not included in the litter movement indicator.

Litter movement refers to the change in location of litter due to water or wind. The distance, amount, and size of litter being moved are signs of the extent to which water or wind erosion may be occurring. Litter movement resulting from wildlife, insects, and anthropogenic activities, such as effects of livestock or recreational vehicles, is not evaluated by this indicator.

Litter movement on a site is a function of slope and obstructions, including vegetation. For example, alluvial fans and floodplains are active surfaces over which water and sediments move in response to major storm events. The amount of litter movement due to water flow varies from large to small depending on the amount of interspace gaps typical of the plant community, slope, and intensity of the storm (e.g., Thurow et al. 1988a; Chartier and Rostagno 2006). The amount of litter movement by wind depends on the size of plant interspace gaps, as well as the height of vegetation (Raupach et al. 1993; Whicker et al. 2002).

The size, distance, and amount of litter moved by wind or water relate to the degree of litter redistribution and therefore the degree of erosion and redistribution of organic matter (Debano and Conrad 1978; Abrahams et al. 1995; Shen et al. 2011; Yan et al. 2016). In general, the greater the distance that litter is moved from its point of origin and the larger the size and amount of litter moved, the more the site is being influenced by accelerated erosional processes and nutrient redistribution (Debano and Conrad 1978; Abrahams et al. 1995). For example, movement of detached shrub branches is a more significant indicator of erosion than movement of forb or grass stems or leaves, as it takes more energy to move woody material (Kumada et al. 2009; Yan et al. 2016). Litter often concentrates in areas where wind or water slows or in areas with obstructions. Looking for such accumulations is a good approach for detecting litter movement in an evaluation area. Excess litter accumulations under shrubs may be related to litter movement due to wind, while litter concentrated around obstructions in interspaces may be associated with water movement.

This indicator is rated by considering the size classes of litter moved, distance of movement, and distribution of litter accumulations relative to the reference sheet. Table 13 provides generic descriptors of the five departure categories in the evaluation matrix for litter movement.

Table 13. Generic descriptors of the five departure categories in the evaluation matrix for litter movement.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
7. Litter Movement (Wind or Water)	Extreme movement of all size classes (including large). Significant accumulations around obstructions or in depressions.	Moderate to extreme movement of small to moderate size classes. Moderate accumulations around obstructions or in depressions.	Moderate movement of mostly small size classes. Small accumulations around obstructions or in depressions.	Slight movement of small size classes. Minimal or no accumulations around obstructions or in depressions.	Reference sheet narrative inserted here.

Measurements

Measuring litter movement is difficult under natural field conditions and better suited to experimental studies (e.g., rainfall manipulation, marking litter pieces). The distance of movement is difficult to measure because it is often problematic to identify where the litter originated. Line point intercept data may be analyzed to quantify amounts and patterns of litter accumulation based on the spatial distribution of litter hits on the line together with vegetation cover pattern. The size (e.g., length, width) and amount (e.g., weight, cover) of litter moved can be measured directly, particularly in areas where moving litter accumulates.

Relationship to Attributes of Rangeland Health

Soil/site stability: Litter movement from a point of origin is an indicator that water or wind erosion may be occurring. In a study in the Edwards Plateau in Texas, litter concentration was shown to be the variable most closely correlated with interrill erosion. The same study showed that bunchgrass litter represented significant obstructions to runoff, thereby causing sediment transport capacity to be reduced and a portion of the sediment to be deposited (Thurow et al. 1988a).

Hydrologic function and biotic integrity: Not applicable.

Indicator 7 Example Photos

Fine litter movement due to wind.

Fine litter movement in water flow pattern. Note plant pedestals.

Movement of larger size classes of litter in a water flow pattern.

▶ 7.4.8 Soil Surface Resistance to Erosion (Indicator 8)

Indicator Description and Assessment
This indicator assesses the resistance of the soil surface to erosion by water. Resistance depends on soil stability and on the spatial variability in soil stability relative to vegetation and microtopographic features (Morgan 1986). Soil surfaces may be stabilized by: (1) soil organic matter that has been fully incorporated into aggregates at the soil surface; (2) adhesion of decomposing organic matter to the soil surface; and (3) biological soil crusts (Wills et al. 2017). The presence of one or more of these factors is a positive indicator of soil surface resistance to erosion (Blackburn et al. 1992; Pierson et al. 1994). **Soil texture** (especially clay content and sand size) and clay mineralogy affect potential stability: coarse sandy soils have inherently lower stability. This indicator is more highly correlated with water erosion (Blackburn and Pierson 1994; Pierson et al. 1994) than with wind erosion. However, susceptibility to wind erosion also declines with an increase in soil organic matter (Fryrear et al. 1994) and biological soil crust cover (Belnap and Gillette 1998).

When soil surface resistance is high, soil erosion on some soils may be minimal even with rainfall intensities of more than 5 inches/hour (Goff et al. 1993). For example, on a Loamy Upland ecological site in Arizona, Holifield Collins et al. (2015) found a strong negative correlation between sediment yield and runoff and soil aggregate stability. In this study, soil aggregate stability thresholds that indicated an increased risk of erosion were identified. Conversely, the presence of highly erodible materials at the soil surface can dramatically increase soil erosion by water, even where there is high vegetative cover (Morgan et al. 1997). Soil aggregate stability and resistance to erosion will vary depending on soil characteristics of the site (e.g., soils with coarser textures will generally form less stable aggregates than soils with finer textures).

This indicator is rated by testing the stability or cohesion of small soil surface samples when they are submerged in water and comparing the values to those provided in the reference sheet. See the Measurements section and Figure 13 for additional information about this soil stability test.

Soil surface resistance to erosion in arid and semiarid ecosystems is often higher under perennial plant canopies than in interspaces. Where the site potential is different under plant canopies, both canopy and interspace values should be reported in the reference sheet (Appendix 1a), and stability should be evaluated under plants and in interspaces. In areas with a low amount of vegetative cover, soil stability in plant interspaces is particularly important.

In areas where there is little to no soil present due to the presence of natural rock cover (nearly 100% surface cover by stones) or there is continuous open water (e.g., marshes in the Southeast), this indicator should be rated as "none to slight." Guidance for setting soil aggregate stability scores to determine the correct departure category rating is provided in the text box in this section. Table 14 provides generic descriptors of the five departure categories in the evaluation matrix for soil surface resistance to erosion.

DEFINING DEPARTURE CATEGORIES FOR SOIL SURFACE RESISTANCE TO EROSION

When defining the departure category, it is necessary to take into account the potential range of variability using the following steps:

(1) Set the minimum stability class rating ("extreme to total"). Most temperate soils will degrade to an average stability of 1-1.5. Some highly weathered tropical soils (e.g., Oxisols) are inherently more stable and may only degrade to a stability of 2-4.

(2) Set the maximum stability class rating ("none to slight") based on data from reference sites and an understanding of the processes previously discussed. Most soils with textures other than coarse sands and coarse loamy sands have a potential stability of at least 5, and most soils developed under perennial grass have a potential stability of 5.5-6.

(3) Assign the intermediate ratings based on a linear distribution (e.g., if "extreme to total" is rated 1-2 and "none to slight" is rated 4-5, then "slight to moderate" is 3.5-4.5, "moderate" is 2.5-3.5, and "moderate to extreme" is 1.5-2.5).

Table 14. Generic descriptors of the five departure categories in the evaluation matrix for soil surface resistance to erosion.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
8. Soil Surface Resistance to Erosion	Extremely reduced throughout.	Significantly reduced in most interspaces or plant canopies and moderately reduced throughout.	Significantly reduced in at least half of plant interspaces or plant canopies or moderately reduced throughout.	Some reduction in plant interspaces or plant canopies or slightly reduced throughout.	Reference sheet narrative inserted here.

Measurements

Soil surface resistance to erosion is evaluated quantitatively using the soil stability test (Herrick et al. 2017), which reflects differences in the susceptibility of soil aggregates to a loss of structure (slaking) in water (Herrick et al. 2001; Herrick et al. 2017).

This method involves collecting small soil surface samples and, when dry, dipping them in deionized water following a specific timing protocol. Each soil sample is given a score between 1 and 6 based on an established set of criteria. Figure 13 provides an overview of using the soil stability kit.

Use the most recent version of the "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems," Volume 1 (Herrick et al. 2017) to conduct the soil stability test to rate this indicator. Ensure that the most recent field forms and instructions are taken to the field to conduct an assessment.

Twelve to 18 random surface soil aggregate samples (half from under canopy and half from interspace locations) will usually provide a relatively precise estimate at an evaluation area. Average the sample values separately from under canopy and interspace locations for an evaluation area. Converting these values to a plot-level average requires calculating a weighted average based on plant cover. As the number of samples increases, precision increases. Number of samples required depends on plot variability. A study showed that 4-20 samples (median 12; a full box includes 18 samples) were required to detect a 1-unit difference in 8 different plant communities on 4 different ecological sites in the Chihuahuan

Desert (Herrick et al. 2017). Within-plot variability is expected to be lower (fewer samples required) in more homogenous systems, such as shortgrass steppe or the Mojave Desert.

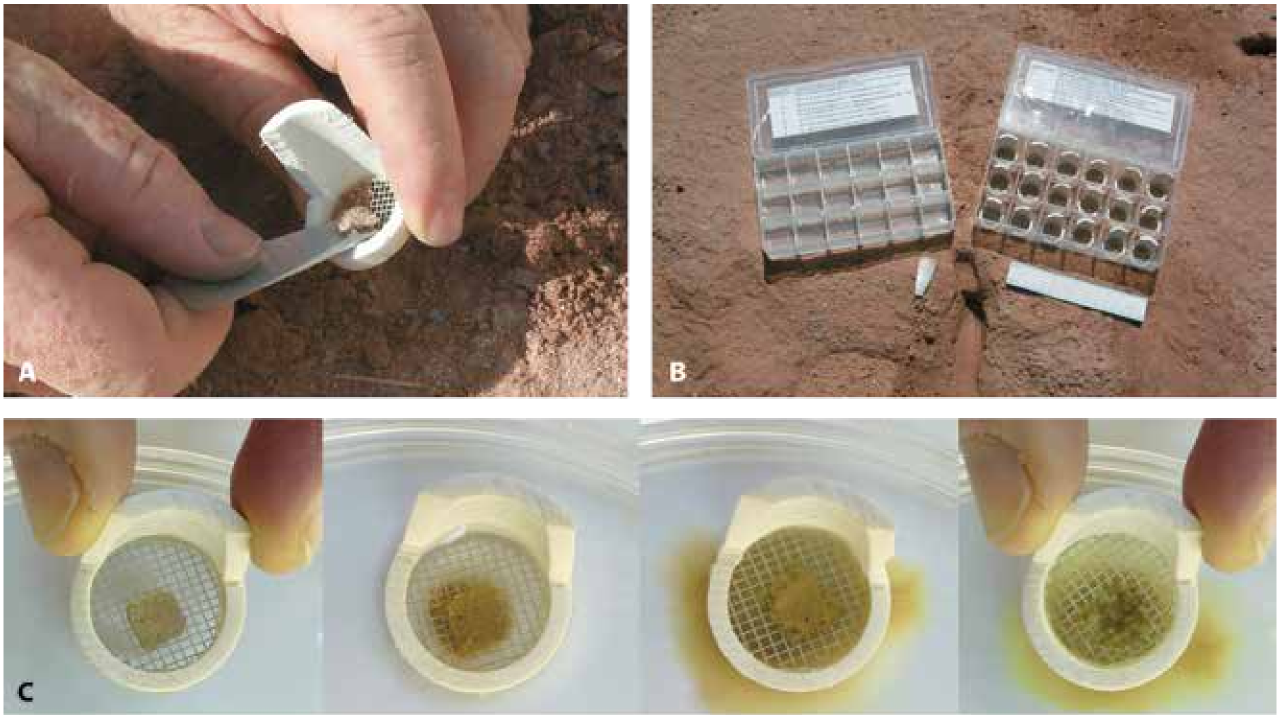


Figure 13. Overview of the soil stability test. See Herrick et al. 2017 for comprehensive instructions.

A. Collection of a soil surface sample into a soil stability testing sieve.
B. A complete soil stability kit with 18 soil samples collected.
C. Example of a soil sample "melting" after submersion and dipping in water.

The bottle cap test is another option to determine soil aggregate stability, but it is not as accurate or as repeatable as the soil stability test and is only recommended if a soil stability kit is not available. See Appendix 9 for the bottle cap test.

Relationship to Attributes of Rangeland Health

Soil/site stability: Higher soil aggregate stability means soil particles are more strongly "glued" to each other and are less likely to be detached by raindrop impact, overland flow, or wind. If soil surface aggregate stability values are less than what is described for the reference state for an ecological site in any part of the evaluation area (e.g., under plant canopies or canopy interspaces), the site may have an increased potential for runoff and erosion.

Hydrologic function: Higher soil aggregate stability indicates that individual soil particles (especially clays) are less likely to be dispersed in water. Dispersed particles may form physical soil crusts, which limit infiltration, while higher stability helps maintain high infiltration. If soil surface aggregate stability values are less than what is described for the reference state for an ecological site in any part of the evaluation area (e.g., under plant canopies or canopy interspaces), the site may have a reduced potential for infiltration.

Biotic integrity: Biological soil processes are necessary to both form and maintain stable aggregates. Litter decomposition, which requires soil microorganisms and microinvertebrates, and biological soil crusts increase soil surface resistance to erosion through their positive impacts on soil aggregate stability. Reduced soil surface stability usually reflects lower soil biotic integrity because of the disruption of soil organic matter inputs and biological decomposition processes.

▶ 7.4.9 Soil Surface Loss and Degradation (Indicator 9)

Indicator Description and Assessment

The soil surface is an important component of a site because it often controls water infiltration and available plant nutrients. The soil surface horizon is where seed germination and plant establishment occur. The soil at and near the surface has the highest organic matter and nutrient content in most ecological sites. Soil organic matter generally controls the maximum rate of water infiltration into the soil and is essential for successful seedling establishment (Wood et al. 1982). Therefore, loss or degradation of the soil surface can lead to reduced infiltration, increased runoff, additional soil erosion, and limitations to seed germination, plant establishment, and soil water holding capacity.

Soil surface loss and degradation is the reduction in soil surface depth, organic matter, porosity, and structure as a result of wind or water erosion, and it is indicative of long-term change in rangeland health. The loss or degradation of part or all of the soil surface layer or horizon is an indication of a loss in site potential (Dormaar and Willms 1998; Davenport et al. 1998). A departure for this indicator often persists after vegetation has recovered. The degree of soil surface loss and degradation may determine whether a site has the capability to recover ecosystem function or whether a physical threshold has been crossed (Figure 1.1 in Whisenant 1999).

As erosion increases, the potential for loss of soil surface organic matter increases, resulting in further degradation of soil structure. Historical soil erosion may result in complete loss of the soil surface layer (Satterlund and Adams 1992; O'Hara et al. 1993). In areas with limited slope, where wind erosion does not occur, the soil may remain in place, but all characteristics that distinguish the surface from the subsurface layers may be lost due to degradation. Except in soils with a clearly defined soil horizon immediately below the surface (e.g., argillic horizon), it is often difficult to distinguish between the loss and degradation of the soil surface. When rating this indicator, the objective is to determine to what extent the functional characteristics of the surface layer have been degraded by considering surface loss and degradation collectively. Evidence of soil surface loss and degradation includes reduced thickness of, or deposition over, the soil surface horizon and changes in soil color and structure (Karlen and Stott 1994).

Soil deposition over the surface horizon can also degrade the soil surface. Soil deposition can have both positive and negative impacts, depending on the nature of the deposited material relative to the original soil surface. Positive examples include sand deposition over loam or clay that increases infiltration capacity and deposits rich in organic matter that increase nutrient availability. However, deposition of coarse sand (low water holding capacity) can reduce seedling establishment, and deposition of any unconsolidated material often reduces soil stability. Some soil deposition immediately following a wildfire may be within the natural range of variability. However, more wildfires in the same area within a shorter timeframe than expected under the natural disturbance regime may cause a cumulative increase in soil deposition that would not be expected in the reference state.

Observations of soil surface loss and degradation should be made at multiple locations throughout the evaluation area, not just in a single soil pit. Observations under canopy and from interspace locations will usually provide a better representation of the evaluation area.

The criteria to assess this indicator include:

1. **Thickness of surface horizon:** Reductions in thickness of the surface horizon can be identified by comparing the soil surface horizon to the horizon description for the appropriate soil map unit component of the evaluation area. Transitions between soil surface horizons are identified by changes in color, texture, or structure. Evaluation areas located in the flatter, wetter end of the range of a soil map unit component will have thicker soil surface horizons, while those in steeper, drier slopes (e.g., south-facing) or ridge tops will have

thinner soil surface horizons. Note that on some evaluation area soils, the surface horizon may have been nearly or totally lost. Soil deposition can also degrade the soil surface due to altering the thickness, color, texture, or structure of the soil surface horizon(s).

2. **Change in soil color:** Soil organic matter content is frequently observed as a darker color of the soil, although high amounts of oxidized iron (common in humid climates) can obscure organic matter. Evaluation areas located in the flatter, wetter end of the range of a soil map unit component will generally have darker colors, while those in steeper, drier slopes may have lighter colors. In arid soils, where organic matter contents are low, this accumulation can be quite faint. The use of a mister to wet the soil profile can help make these layers more visible. Comparing interspaces and protected areas within the same ecological site can also provide a reference for changes in soil organic matter content, as well as the continuity of that soil organic matter throughout an evaluation area.

   Soil colors are described in three components: hue, value, and chroma. Official soil series descriptions can be used as a reference to provide soil color values by horizon if the expected range of color values are not included in the reference sheet or soil map unit component description. The soil color is most conveniently measured by comparison with a soil color reference, such as the Munsell soil color chart. Care must be taken to ensure evenly distributed light without sun glare and that the correct dry or moist colors are compared.

3. **Changes in structure:** Soil structural degradation is reflected by a reduction in the number, length, or size diversity of soil pores or peds (Satterlund and Adams 1992; O'Hara et al. 1993). Number, length, and size of soil **micropores** are not measurable in the field; **macropores** (larger pores that promote water movement) are easily visible, but not easily measured. Soil surface structure or the shape of small pieces of soil can also be described (see Appendix 6 and Table A6.1 for examples of soil structure types). Compared to the reference sheet or ecological reference areas, lighter soil colors, different structure, and fewer macropores that promote water movement all suggest degradation. Soil structural degradation is reflected by the loss of clearly defined structural characteristics or aggregates between depths of < 1/8 inch and 3 to 4 inches. In soils with good structure, pores of various sizes are visible within the aggregates. Structural degradation is reflected in more massive, homogeneous soil surface horizons that are associated with a reduction in infiltration rates (Warren et al. 1986). In soils with high clay content, degradation may also be reflected by more angular structural units. Table 15 provides generic descriptors of the five departure categories in the evaluation matrix for soil surface loss and degradation.

Table 15. Generic descriptors of the five departure categories in the evaluation matrix for soil surface loss and degradation.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
9. Soil Surface Loss and Degradation	Soil surface horizon very thin to absent throughout. Soil surface structure similar to or more degraded than subsurface. No distinguishable difference between surface and subsurface organic matter content.	Severe soil loss or degradation throughout. Minor differences in soil organic matter content and structure between surface and subsurface layers.	Moderate soil loss or degradation in plant interspaces with some degradation beneath plant canopies. Soil organic matter content is markedly reduced.	Slight soil loss or degradation, especially in plant interspaces. Minor change in soil organic matter content.	Reference sheet narrative inserted here.

Measurements

Measurements of soil surface horizon depth can be made in soil pits. Identification of soil surface horizon boundaries is important when measuring horizon depth. Depth of soil deposition can be measured.

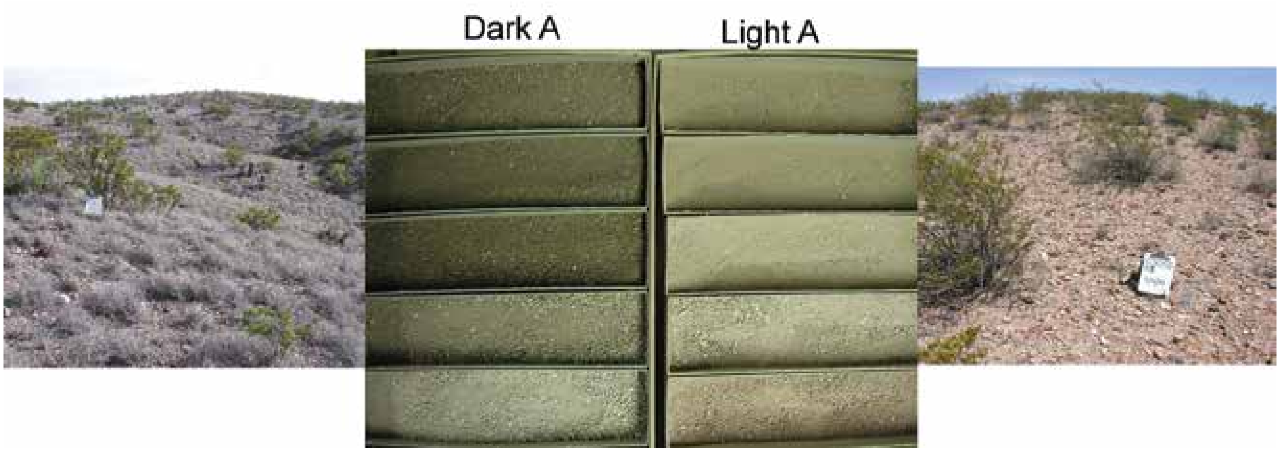
Relationship to Attributes of Rangeland Health

Soil/site stability: This indicator provides information on both past erosion or degradation and future susceptibility to erosion or degradation. While the loss of soil surface is certainly an indication of past erosion, degradation by loss of organic matter and soil structure indicates susceptibility to further degradation.

Hydrologic function: Maximum and minimum potential infiltration rates are controlled by soil texture, while the current infiltration rate is determined by soil surface structure. Loss of soil organic matter and degradation of soil surface horizon structure decrease infiltration rates and water holding capacity, thereby increasing runoff.

Biotic integrity: The soil surface provides the environment for germination and establishment of plant species. It also provides the environment for soil microorganisms that enhance soil fertility, water holding capacity, and stability.

Indicator 9 Example Photos



Differences in soil color between near reference (left) and degraded desert (right) soils.

Soil deposition has buried the root crown of this perennial bunchgrass 2 inches below soil surface.

Soils from four horizons in a soil pit. The surface horizon soil on the left is darker than soils in the subsurface horizons due to relatively higher organic matter content. Inset: Comparing a soil sample to a standard soil color chart.

▶ 7.4.10 Effects of Plant Community Composition and Distribution on Infiltration (Indicator 10)

Indicator Description and Assessment

This indicator reflects effects of vegetation composition and spatial distribution on the infiltration capacity of the soil within the evaluation area and the amount of time water is retained on the soil surface. The term **infiltration** for this indicator encompasses both the entry of water into soil and the movement of water into the soil profile. In Version 4, runoff was included as a component in rating this indicator but has been removed from consideration in rating this indicator because runoff is assessed, in part, using the soil/site stability indicators of rills, water flow patterns, pedestals and/or terracettes, gullies, and litter movement. Vegetation composition and distribution are strongly related to spatial and temporal variability in infiltration on rangelands throughout the United States, including Nevada (Blackburn 1975; Blackburn and Wood 1990), Idaho (Johnson and Gordon 1988; Blackburn and Wood 1990), Texas (Wood and Blackburn 1984; Thurow et al. 1988a, 1988b), and New Mexico (Devine et al. 1998).

The ability of a site to capture and store precipitation can be positively or negatively influenced by changes in plant community composition and distribution. Plant rooting patterns, litter production and associated decomposition processes, height, basal area, and spatial distribution can all affect infiltration. Examples of composition changes that have effects on infiltration include conversion of desert grasslands to shrub-dominated communities (Schlesinger et al. 1990; Spaeth et al. 1996) and shifts between bunchgrass and short grasses in the Edwards Plateau in Texas (Thurow et al. 1986, 1988a, 1988b).

Infiltration is negatively affected when sagebrush steppe is converted to a juniper-dominated system in the Great Basin. Where juniper dominates, snow melts earlier and more water is lost to evapotranspiration compared to sagebrush-dominated areas. Sagebrush-dominated areas capture larger snow depths that persist longer, prolonging summer-season streamflow in some locations and late season shrub and herbaceous species productivity (Kormos et al. 2017). Conversion of sagebrush steppe to a nonnative annual grass-dominated plant community may still provide adequate soil surface protection and rainfall infiltration. However, this type of vegetation conversion may reduce snow entrapment, thereby reducing infiltration when the snow melts and decreasing soil water storage.

Care must be exercised in interpreting this indicator in different ecological sites or ecosystems, as the same species or functional group may have different effects in different locations. For example, Perlinski et al. (2017) found that although four ecological sites in a semiarid watershed in southeast Wyoming had similar infiltration rates and volumes of runoff after precipitation events, the amounts and intensities of rainfall required to generate runoff, timing of overland flow, and peak runoff rates differed among the ecological sites.

This indicator is rated based on changes in functional/structural groups, their spatial distribution, and how those changes affect infiltration. As previously noted, water runoff indicators are not used to rate this indicator; it is assumed that decreased infiltration causes a corresponding increase in runoff. Rate this indicator by comparing the functional/structural groups and their associated species composition and distribution in the evaluation area with the appropriate reference state community phase in the functional/structural groups indicator description (Appendix 1b). Record the degree to which changes in functional/structural groups and their associated species composition and distribution are expected to negatively affect infiltration in the evaluation sheet (Appendix 4).

All species present in the evaluation area are considered when rating this indicator. If an invasive species belongs to a functional/structural group that is expected for the site, include it in this group when rating this indicator (see

Section 7.4.12 for more information). If an invasive species that belongs to a functional/structural group that is not expected for the ecological site is present in the evaluation area, consider its expected effects on infiltration in the rating of this indicator. Document the situation by describing how the unexpected functional/structural groups are likely to affect infiltration in the comments section on page 2 of the evaluation sheet. Table 16 provides generic descriptors of the five departure categories in the evaluation matrix for this indicator.

Table 16. Generic descriptors of the five categories in the evaluation matrix for effects of plant community composition and distribution on infiltration.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
10. Effects of Plant Community Composition and Distribution on Infiltration	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in a severe reduction in infiltration.	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in greatly decreased infiltration.	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in a moderate reduction in infiltration.	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in a slight reduction in infiltration.	Reference sheet narrative inserted here.

Measurements

Plant community or functional/structural group composition can be quantified with either line point intercept or annual production measurements. Functional/structural group composition is most commonly calculated using species-based production methods (NRCS 2006) (the annual production methods in Appendix 8 are not generally robust enough to determine species composition for most of the plants in the evaluation area). Plant distribution can be inferred from canopy or basal gap intercept data.

Relationship to Attributes of Rangeland Health

Hydrologic function: Plant community composition and distribution relative to infiltration is used to reflect the unique contributions of functional/structural groups and their associated species to changes in water infiltration. An example is conversion of mixed-grass prairie vegetation to sod-bound blue grama (Printz and Hendrickson 2015), which facilitates surface water movement with minimal soil erosion.

Soil/site stability and biotic integrity: Not applicable.

Indicator 10 Example Photos

Desert grassland community that facilitates infiltration.

Degraded desert grassland dominated by shrubs resulting in reduced infiltration.

New Mexico grassland with high infiltration capacity.

Juniper encroachment and subsequent loss of grassland species has significantly reduced infiltration.

Dominance of sod-forming grass has reduced the water infiltration rate, resulting in water loss for the site.

▶ 7.4.11 Compaction Layer (Indicator 11)

Indicator Description and Assessment

A **compaction layer** is a near-surface layer of dense soil caused by impact on or disturbance of the soil surface. A compaction layer can be caused by application of weight or pressure at or below the soil surface. Compaction layers restrict water percolation (Willat and Pullar 1984; Thurow et al. 1988a), plant growth (Wallace 1987), and nutrient cycling (Hassink et al. 1993), potentially reducing infiltration and increasing runoff and changes in plant composition and production. Compaction layers known as "plow pans" can occur at the bottom of a tillage layer in abandoned agricultural fields. Farm machinery, trampling by large herbivores (Willat and Pullar 1984; Warren et al. 1986; Chanasyk and Naeth 1995), recreational and military vehicles (Webb and Wilshire 1983; Thurow et al. 1988a), foot traffic (Cole 1985), brush removal, seeding equipment, or any other activity or equipment that exerts pressure on the soil surface can cause a compaction layer to develop. Moist soil is more easily compacted than dry or saturated soil (Hillel 1998). Recovery processes (e.g., earthworm activity and frost heaving) may be sufficient to limit compaction by livestock in many upland systems (Thurow et al. 1988a). On desert grasslands, increasing grass cover can result in a long-term reduction in compaction layers and an increase in water infiltration (Castellano and Valone 2007).

Compaction layers can be detected and evaluated by digging holes (generally less than 1 foot, or 30 cm, deep) and observing the soil structure and root morphology. Plant root penetration can be restricted, and roots may be found growing laterally at the upper boundary of the compaction layer. Changes in soil structure (e.g., from blocky to massive) may also be indicative of a compaction layer. Once a compaction layer has been observed, the spatial extent of the layer may be estimated by simply probing the soil with a sharp rod or shovel and feeling for the compaction layer (Barnes et al. 1971). Differences in compaction are often observed in plant interspaces and under perennial plant canopies, particularly shrub canopies.

A compaction layer resulting from land uses should not be confused with soil moisture changes along the soil profile or naturally occurring restrictive layers, resulting from changes in soil **texture** (e.g., clay accumulation) or chemical content (e.g., calcium carbonate layer). These naturally occurring layers are generally described in the soil survey description associated with the site.

Rate this indicator by identifying the presence or absence of a compaction layer, distribution of the layer across the evaluation area, and the degree of development (e.g., density and thickness) of the layer relative to what is described in the reference sheet. Table 17 provides generic descriptors of the five departure categories in the evaluation matrix for compaction layer.

Table 17. Generic descriptors of the five departure categories in the evaluation matrix for compaction layer.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
11. Compaction Layer	Extensive and/or strongly developed (thickness and density); may severely restrict root penetration.	Widespread and/or moderately to strongly developed (thickness and density); may greatly restrict root penetration.	Moderately widespread and/or moderately developed (thickness and density); may moderately restrict root penetration.	Not widespread and/or weakly developed (thickness and density); may weakly restrict root penetration.	Reference sheet narrative inserted here.

Measurements
A qualitative assessment is usually appropriate for rating this indicator. However, thickness of the compaction layer may be measured. The proportion of the evaluation area affected by a compaction layer can be determined by digging holes at regular intervals along a transect. While soil compaction layers may be indirectly measured with a penetrometer or by measuring bulk density, these methods are both highly variable and may also be influenced by other factors (e.g., soil moisture content and rocks).

Relationship to Attributes of Rangeland Health

Soil/site stability: Soil stability is negatively impacted when a compaction layer reduces infiltration to the point that surface runoff increases, which increases the potential for water erosion.

Hydrologic function: Compaction layers may restrict infiltration of water through the soil profile, thus negatively impacting hydrologic function. Compaction also reduces pore space and affects soil structure, affecting soil aeration and water holding capacity.

Biotic integrity: Compaction layers can restrict the distribution of plant roots (especially fibrous roots) through the soil, limiting the ability of vegetation to extract nutrients and moisture from the soil profile.

Indicator 11 Example Photos

Compaction layer below the knife blade.

Roots unable to penetrate a strong compaction layer causing lateral root growth.

Platy soil structure in a compaction layer that is near the soil surface.

▶ 7.4.12 Functional/Structural Groups (Indicator 12)

Indicator Description and Assessment

Functional/structural groups are plant species (including nonvascular plants such as visible biological soil crusts) that are grouped together on the basis of similar growth forms or ecophysiological roles. Plant community resistance to invasive plants and resilience to disturbances are enhanced through a mixture of functional and structural plant groups (Pokorny et al. 2005; Chambers et al. 2017) and biological soil crusts (Belnap et al. 2001; Reisner et al. 2013). Function and structure may be interrelated as evidenced by effects of plant canopy and rooting structure on precipitation capture and infiltration (amount and depth).

Function typically refers to the ecophysiological role that plants and biological soil crusts play on a site. This may include the plant's life cycle (e.g., annual, monocarpic perennial, or perennial), phenology, photosynthetic pathway, nitrogen fixer associations, sprouting ability, and water infiltration (including biological soil crusts).

Structure refers to plant growth forms (e.g., trees, vines, shrubs, grasses, forbs, and nonvascular plants, such as visible biological soil crusts) within the community. Structure may be subdivided to group species with similar growth forms based on height, growth patterns (bunch, sod-forming, or spreading through long rhizomes or stolons), root structure (fibrous or tap), rooting depth, or sprouting ability (Figure 14).

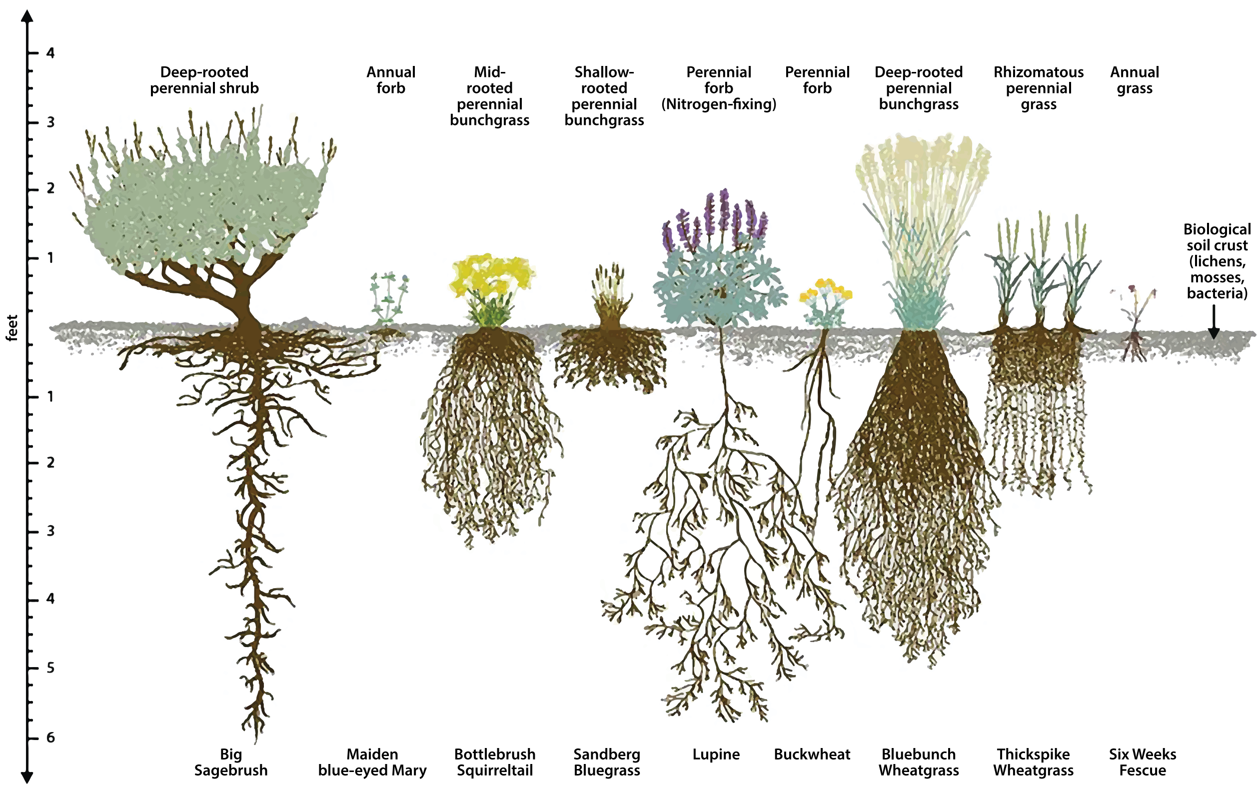


Figure 14. Root morphology of common plants in a sagebrush steppe ecosystem (adapted from Sage Grouse Initiative 2016). Refer to Natura (1995) for a similar diagram of root morphology of common plants in a mixed prairie ecosystem.

The functional/structural groups indicator assesses shifts in expected types and proportions of functional/structural groups within the context of the plant community phases that are described for an ecological site under the natural disturbance regime. Both the presence of functional/structural groups and the number of species (or life forms for biological soil crust) within the groups have a significant positive effect on ecosystem processes (Tilman et al. 1997). Additionally, reductions in the numbers of species in functional/structural groups (particularly the expected dominant and subdominant groups) may indicate loss of biotic integrity (Chambers et al. 2017).

Therefore, changes in expected functional/structural groups and their composition are evaluated through assessment of four subindicators, which include:

(1) Relative dominance among expected functional/structural groups.

(2) Occurrence and dominance of functional/structural groups not expected at the ecological site.

(3) Number of expected functional/structural groups.

(4) Number of species within expected dominant and subdominant functional/structural groups.

Rating the Functional/Structural Groups Indicator

A functional/structural groups table is a required part of the reference sheet (Appendix 1a and 1b) and must be used to rate this indicator. This table describes the expected functional/structural groups, relative dominance, and number of species in each community phase within the natural disturbance regime of the natural range of variability. If a reference sheet does not include a completed functional/structural groups table, contact the NRCS state rangeland management specialist to determine if one is being developed. Instructions for developing this table are included in Appendix 1b. If a table is developed or modified, it should be submitted to the NRCS state rangeland management specialist for incorporation into the reference sheet for the ecological site.

Using the functional/structural groups worksheet (Appendix 4) is strongly recommended to increase ease and consistency of rating this indicator. A functional/structural groups worksheet is completed at each evaluation area and includes a list of species and functional/structural groups observed in the evaluation area. The completed worksheet documents the observations used to rate the indicator and assists in future interpretation of the compared assessment. Each completed worksheet should be attached to or stored with the associated evaluation sheet. Appendix 4 includes detailed instructions and an example of a completed functional/structural groups worksheet.

If the functional/structural groups worksheet is not used, the reference community phase of the evaluation area is documented on page 1 of the evaluation sheet, including the relative dominance of the functional/structural groups expected for the site based on the time since or effects of disturbances or treatments.

Step 1. Identify the reference phase. The first step is to identify the most appropriate reference plant community phase in the evaluation area from the phases described in the functional/structural groups narrative and table in the reference sheet. Compare the disturbance and land treatment history information of the evaluation area to the descriptions of disturbance and community dynamics associated with the natural disturbance regime of the natural range of variability for the ecological site. For example, if an evaluation area burned 15 years prior, the reference phase representing this post-fire timeframe should be used. The reference plant community phase is not selected by simply choosing the phase that most resembles the vegetation composition in the evaluation area. However, observations in the evaluation area should be used to corroborate the collected disturbance history information before making the final reference phase selection.

When an assessment in an evaluation area is completed at the lower or upper timeframe of the chosen reference community phase, the plant community may be between two adjacent reference community phases. Scientific literature, monitoring data, and local experience with plant community dynamics following disturbances may be used to make adjustments to the expected relative dominance in these situations. For example, Moffet et al. (2015) developed a recovery curve to model the time required for mountain big sagebrush stands to recover after a wildfire to the prefire value of 30% cover. This type of information, combined with an appropriate state-and-transition model (see Figure 4; specifically, the pathway (arrow) between community phase 1.1 and 1.2 in state 1), can help identify when sagebrush will transition from a trace, minor, or subdominant to a dominant functional/structural group.

Step 2. Observe species and functional/ structural groups at the evaluation area. Next, make observations (including measurements, if applicable) of the plant community composition in the evaluation area. Species in the evaluation area should be categorized by functional/structural group to evaluate the four subindicators.

- Nonnative (including invasive) species found in the evaluation area are assigned to functional/ structural groups using the same criteria as native species and are generally included in the same functional/structural group as natives with similar function and structure (see Appendix 1b).
- If an invasive species is part of a functional/ structural group that is not expected for the ecological site, it is rated using the criteria in 12b (Table 18).

Step 3. Determine relative dominance of functional/structural groups. Using the same metric as the reference sheet (annual production or cover), determine the relative dominance of the functional/structural groups observed in the evaluation area. More than one functional/ structural group may be assigned to each relative dominance category. The relative dominance categories used for the IIRH protocol are described in the text box in this section. Refer to Appendix 1b for instructions for calculating relative abundance from quantitative data.

Step 4. Rate the four subindicators.

- Subindicator 12a is rated by comparing the relative dominance of functional/structural groups in the evaluation area to the expected relative dominance of functional/structural groups for the selected reference community phase.
- Subindicator 12b is rated by determining if any functional/structural groups not expected in the selected reference phase are present within the evaluation area. If no unexpected groups are present, the rating is "none to slight." If one or more groups not expected for the site are present, select the departure rating that best fits the observed relative dominance of the unexpected group(s) in the evaluation area.
- Subindicator 12c is rated by comparing the list of functional/structural groups expected for the site in the reference community phase to the expected groups present within the evaluation area. Note that the expected dominant, subdominant, and minor groups must be "functionally present" in the evaluation area in order to be counted (see explanation in box on the next page).
- Subindicator 12d is rated by adding the total number of species (or life forms for biological soil crust) expected in the dominant and subdominant functional/structural groups for the selected reference plant community phase and comparing it to the total number of species within those groups in the evaluation area.

Step 5. Select the overall indicator rating. Of the four subindicator ratings, the one with the greatest departure is chosen as the final rating.

FUNCTIONAL/STRUCTURAL GROUP DOMINANCE CATEGORIES

For purposes of this technical reference, relative dominance of a functional/structural group is defined as size per unit area with size based on production or cover (or less commonly on biomass) as follows:

dominant: species or functional/structural groups with the greatest size per unit area in the plant community; elimination or reduction of these species or groups from the community would have a major impact on the relative dominance of the remaining groups.

subdominant: species or functional/structural groups within a plant community with less size per unit area than dominant plants and generally greater than 10% of the community composition; elimination of these species or groups from the community would have a relatively major impact on composition of the remaining groups.

minor: species or functional/structural groups within a plant community with less size per unit area than subdominant plants and generally greater than 1% and less than 10% of the community composition; elimination of these species or groups from the community would have a minor impact on the composition of the remaining groups.

trace: species or functional/structural groups that represent rare contributions to the measurable plant community composition (e.g., less than 1% of the composition); elimination of these species or groups from the community would have little impact on the composition of the remaining groups.

▼▲▼▲▼▲▼▲▼

Generally, if only a few individuals in a functional/structural group are present in an evaluation area, that functional/structural group is no longer considered "**functionally present**." When a functional/structural group that is expected to be dominant, subdominant, or minor is reduced in the evaluation area to a few remnant individuals, the group is no longer considered functionally present for purposes of evaluating the number of expected functional/structural groups on the site. This is because the ecological role of that group has been diminished to the degree that it is essentially providing little to no ecological function or reproductive capability. Functionally present also applies to indicator 17 (vigor with an emphasis on reproductive capability of perennial plants). This concept does not apply to trace functional/structural groups because they represent less than 1% of the composition.

Table 18. Generic descriptors of the five departure categories in the evaluation matrix for the four subindicators of functional/structural groups.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
12. Functional/ Structural (F/S) Groups	Indicator rating is based on the greatest departure of the four subindicators.				
12a. Relative dominance	All expected dominant F/S groups are now minor, trace, or missing.	Dominant F/S group(s) has become minor or trace, or a minor or trace group is now dominant.	Dominant F/S group(s) has become subdominant.	Subdominant F/S group has become minor or trace, or a minor or trace F/S group has become subdominant.	Resembles expected relative dominance.[1]
12b. F/S groups not expected	F/S group(s) not expected is now dominant.	F/S group(s) not expected is now subdominant.	F/S group(s) not expected is now minor.	F/S group(s) not expected is now trace.	None.
12c. Number of expected F/S groups[2]	Severely reduced (missing ≥ 76% of expected F/S groups).	Greatly reduced (missing 51-75% of expected F/S groups).	Moderately reduced (missing 26-50% of expected F/S groups).	Slightly reduced (missing ≤ 25% of expected F/S groups).	All expected F/S groups are present.[1]
12d. Total combined number of species expected in dominant and subdominant F/S groups	Severely reduced (missing ≥ 76%).	Greatly reduced (missing 51-75%).	Moderately reduced (missing 26-50%).	Slightly reduced (missing 10-25%).	Missing less than 10% of expected number of species in dominant and subdominant F/S groups.[1]

[1] For the appropriate reference community phase.

[2] Must be functionally present.

Measurements

The species inventory method (Herrick et al. 2017) provides a consistent protocol for developing a species list for the functional/structural groups worksheet. Functional/structural group composition is most commonly calculated using species-based production methods (NRCS 2006) or foliar cover from line point intercept, noting that cover is not equivalent to production (see Section 5.9). Thus, functional/structural group composition should be based on the measurement used in the reference sheet. Note the annual production methods in Appendix 8 are not generally robust enough to determine species composition for all plants in the evaluation area.

Relationship to Attributes of Rangeland Health

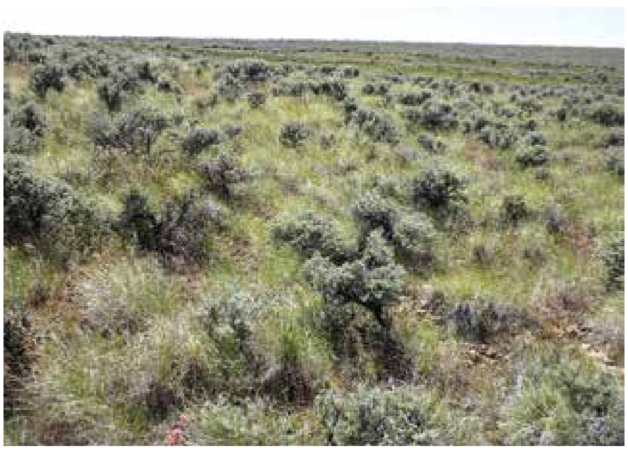
Soil/site stability and hydrologic function: Not applicable.

Biotic integrity: A change in the relative dominance or number of species in functional/structural groups may have a negative effect on ecosystem processes. A diversity of functional/structural groups appropriate to a site can promote community resistance to invasive plants and resilience to disturbances (Pokorny et al. 2005; Chambers et al. 2014).

Indicator 12 Example Photos

Tallgrass praire dominated by warm-season perennial grasses (reference state).

Tallgrass prairie dominated by short sod-forming grasses (outside reference state).



Sagebrush steppe plant community co-dominated by non-resprouting shrubs and deep-rooted perennial bunchgrasses (reference state).

Sagebrush steppe plant community dominated by annual grass with non-resprouting shrubs in a subdominant category (outside reference state).

Biological soil crusts covering the soil surface between perennial plants. When biological soil crusts are an expected component of the reference community phase, they should be included when rating this indicator.

▶ 7.4.13 Dead or Dying Plants or Plant Parts (Indicator 13)

Indicator Description and Assessment

Dead or dying plants and dead or dying stems, branches, leaves, etc., are a natural phenomenon in all perennial plant communities. For example, many perennial bunchgrasses tend to develop a dead center with live leaves and stems forming an outside ring as the grasses age. Likewise, a shrub may have dead branches, although most of the plant is alive.

Note that the name of this indicator in Version 4 was "**plant mortality** and decadence." The name of this indicator is now "dead or dying plants or plant parts" and more directly describes the components of this indicator, whereas decadence refers to the natural aging process that eventually results in mortality of the plant.

The natural disturbance regime affects plant lifespans and may also affect the ratio of dead to live plant parts. For example, a multiyear drought may result in more dead or dying plants or plant parts than during periods of average precipitation. Improper management during drought periods can increase the amount of dead or dying plants or plant parts above the natural range of variability expected to occur during a drought (Thurow and Taylor 1999). However, little is known about the lifespan of many plant species under the natural disturbance regime (Svejcar et al. 2014), which makes it difficult to determine departure from the expected condition described in the reference sheet. Ecological reference areas in the same ecological site can provide a point of comparison to determine expected dead or dying plants or plant parts given recent weather at the time of an assessment.

Follow the process in the text box in this section to rate this indicator and indicator 17 (vigor with an emphasis on reproductive capabilty of perennial plants). In addition to the process in the text box, the following bullets apply specifically to rating this indicator:

- Dormant plants are not considered dead or dying unless there are obvious signs that parts of the plants are dead.
- Only rate the perennial plants (including dead plants) that are physically present in the evaluation area (document this observation in the comments section on page 2 of the evaluation sheet).
- Vigor and reproductive capability of perennial plants are rated under indicator 17 and thus are not considered when rating this indicator.
- Invasive species listed for indicator 16 in the reference sheet are not included in the rating of this indicator.

INSTRUCTIONS FOR RATING INDICATORS 13 (DEAD OR DYING PLANTS OR PLANT PARTS) AND 17 (VIGOR WITH AN EMPHASIS ON REPRODUCTIVE CAPABILITY OF PERENNIAL PLANTS)

Indicators #13 and 17 are rated by species within the functional/structural groups to which they are assigned. The following steps and guidelines apply:

1. Refer to information about the reference community phase for the expected functional/structural groups and their relative dominance (this is recorded on page 1 of the functional/structural groups worksheet). Observe the condition of the species in the expected dominant, subdominant, and minor perennial functional/structural groups (not annuals) that are present within the evaluation area. Species within functional/structural groups not expected for the site are not assessed. Nonnative invasive species listed in the reference sheet (indicator 16) are also excluded, even if they fall within an expected functional/structural group. It is important to understand the effects of recent weather, natural disturbances, herbivory, and management actions (see Section 5.11 Management Influences on Indicators) when rating these indicators.

2. In the comment section on page 2 of the evaluation sheet, document the departure rating for species in each expected dominant, subdominant, and minor functional/structural group that has a departure greater than "none to slight" (see reference sheet). Expected trace functional/structural groups are not included when rating these two indicators, given the relatively small effect they have on the function of ecological processes.

3. Record the overall indicator rating in the evaluation sheet using a preponderance of evidence approach for dominant, subdominant, and minor functional/structural groups with departure ratings greater than "none to slight" (see bullet 2). If departures from reference sheet descriptions are concentrated in one or more of the expected dominant or subdominant groups, this presents a greater concern than if species from an expected minor group are affected. For example, if one or more species in the expected dominant functional/structural group (e.g., deep-rooted, cool-season perennial grasses in the sagebrush steppe ecosystems) has a "moderate" departure rating and species in all other functional/structural groups have a "slight to moderate" rating, an overall "moderate" rating could be justified. Provide rationale for the final rating in the comments section.

   The condition of expected dominant and subdominant groups is important to resilience and therefore biotic integrity. When a species in an expected dominant functional/structural group has declined and also shows reductions in vigor and reproductive capability and/or increased dead or dying plants or plant parts, recruitment of that species is less likely to occur during favorable weather conditions and may eventually lead to the functional/structural group's reduction in dominance. This reduces the resilience of a site (see Section 5.6 Resistance and Resilience) and ultimately biotic integrity (see Table 28).

Table 19. Generic descriptors of the five departure categories in the evaluation matrix for dead or dying plants or plant parts.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
13. Dead or Dying Plants or Plant Parts (dominant, subdominant, and minor functional/ structural groups	Extensive mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Widespread mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Moderate mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Occasional mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Reference sheet narrative inserted here.

Measurements

The ratio of dead to live plant parts can be measured using line point intercept; record the hits on dead plant parts separately from live plant hits. The ratio of dead to live plants (entire plant) can be measured using a density technique in which dead and live plants are counted separately.

Relationship to Attributes of Rangeland Health

Soil/site stability and hydrologic function: Not applicable.

Biotic integrity: This indicator is an important component of plant population dynamics. If dead or dying plants or plants parts are increasing outside the natural range of variability and causing a reduction in recruitment potential, stand integrity is expected to decline, and undesirable plants (e.g., weeds or invasive plants) may increase (Pyke 1995; Svejcar et al. 2014).

Indicator 13 Example Photos

Dead grass plant.

Grass plant with dead or dying plant parts.

Dead and dying branches and leaves on sagebrush.

▶ 7.4.14 Litter Cover and Depth (Indicator 14)

Indicator Description and Assessment

Litter is the uppermost layer of organic debris on the soil surface—essentially the freshly fallen or slightly decomposed vegetal material (SRM 1999). In this technical reference, it includes dead plant material, including leaves, stems, and branches, that is detached from the plant. Stems and seed heads that are dead or dormant but still attached to the plant are considered dead plant parts, not litter (sometimes referred to as "standing dead"). Litter may be in varying degrees of decomposition, but it is still composed of recognizable plant parts (e.g., leaf of grass). If dead plant material is so decomposed that the plant parts cannot be recognized, it is considered duff, which is not evaluated when rating this indicator.

Litter provides a source of soil organic material and raw materials for onsite nutrient cycling (Whitford 1988, 1996), helps moderate the soil microclimate, provides food for microorganisms, and plays a role in enhancing erosion resistance by dissipating the energy of raindrops and obstructing overland flow (Hester et al. 1997; Thurow et al. 1988a, 1988b).

The potential cover and depth of litter is related to the productivity and decomposition rates of a given ecological site. Both productivity and decomposition are influenced by weather conditions (primarily precipitation), with more litter being produced in wet years and less during dry years. The cover, depth, and kind of litter are also affected by the plant community composition. For example, a grass and forb community with similar annual production as a shrub-dominated community will return more litter to the soil surface because leaves, flower stalks, and stems generally detach from the plant within 1 to 2 years; this material also decomposes more rapidly than woody litter. In contrast, the shrub community stores part of its annual growth as woody stems that may remain on the plant for many years. However, woody shrub litter is usually more persistent.

To evaluate this indicator, the cover and depth of herbaceous and woody litter present is compared to the cover and depth that would be expected for the same recent weather conditions in the reference state under a natural disturbance regime. After wet years, a larger amount of herbaceous litter may be expected. In contrast, less litter would be expected the first growing season after a wildfire that was part of the natural disturbance regime. The amount of litter present at a site can be reduced by recent disturbances or uses, such as livestock grazing or off-road vehicles.

While most attention is given to a reduction of litter (cover and depth), sites that have undergone a plant community change can produce and accumulate more litter cover and at a greater depth than expected. For example, a large increase in invasive annual grasses in a perennial grass/shrub-dominated community can result in a large increase in the amount of litter cover and depth. Litter cover and depth in excess of that described in a reference sheet is a departure. Both the overall cover and depth of litter are considered when assessing this indicator, especially in mesic or arid environments in which litter cover may exceed what is expected and litter depth may be minimal. For example, if litter cover is greatly increased relative to the reference sheet and the depth is only slightly more than expected, this indicator could be rated "slight to moderate" if the depth of litter does not have an appreciable effect on either hydrologic function or biotic integrity in the evaluation area. Table 20 provides generic descriptors of the five departure categories in the evaluation matrix for litter cover and depth.

Table 20. Generic descriptors of the five departure categories in the evaluation matrix for litter cover and depth.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
14. Litter Cover and Depth	Largely absent with minimal depth or extensive with much greater depth relative to site potential and recent weather.	Greatly reduced or greatly increased cover and/or depth relative to site potential and recent weather.	Moderately more or less cover and/or depth relative to site potential and recent weather.	Slightly more or less cover and/or depth relative to site potential and recent weather.	Reference sheet narrative inserted here.

Measurements
Litter cover can be measured using line point intercept. Litter depth can be measured directly at multiple points distributed across the evaluation area.

To calculate percent litter cover from line point or step point intercept data, count the total number of points that have litter recorded in any layer, and divide the total number of litter hits by the total number of pin drops. Litter is counted whether it occurs under plant canopies or in interspaces.

Relationship to Attributes of Rangeland Health

Soil/site stability: Not applicable.

Hydrologic function: Litter affects hydrologic function by intercepting raindrops, obstructing overland flow, promoting infiltration, reducing evapotranspiration, and reducing erosion (Hester et al. 1997; Pierson et al. 2007; Thurow et al. 1988a, 1988b).

Biotic integrity: Variations in litter amount affect biotic integrity through effects on nutrient cycling (Whitford 1988, 1996), microclimate, and seedling recruitment.

Indicator 14 Example Photos

High litter cover (top photo) with minimal litter depth (bottom photo).

Low litter cover and zero litter depth due to sparse vegetation.

High litter cover (top photo) with thick litter depth (bottom photo) in an annual grassland community.

▶ 7.4.15 Annual Production (Indicator 15)

Indicator Description and Assessment
Annual production represents the energy captured by plants through the process of photosynthesis, given recent weather conditions. This is the only indicator that is directly linked to the ecological process of energy flow.

Annual production, as used in this technical reference, is the net quantity of aboveground vascular plant material produced within a **growing season**. It is not a measurement or estimate of total standing biomass (which includes the previous growing season production). It is an indicator of the energy captured by plants and its availability for secondary consumers in an ecosystem, given recent weather conditions. Annual production potential changes with plant communities or ecological sites (Whittaker 1975), biological diversity (Tilman and Downing 1994), and latitude (Cooper 1975).

Comparisons to the reference sheet are based on total annual (growing season) production, no matter when the site is assessed. If utilization of vegetation has occurred, plants are in early stages of growth, or there is a bimodal growing season, estimate the annual production removed or expected when determining the total annual production (Appendix 8). Additional methods are described in the "National Range and Pasture Handbook" (NRCS 2006).

Do not include **standing dead vegetation** (produced in previous growing seasons) or live tissue (woody stems) not produced in the current year's growing season(s) as annual production. Standing dead plants produced during the current growing season (e.g., annuals) are included in the annual production evaluation. All species (e.g., native, seeded, and invasive species) that are or were alive in the growing season of the evaluation are included in determining total annual production.

Rate this indicator by comparing the total annual production estimate in the evaluation area with the total annual production in the "none to slight" category in the evaluation matrix (Table 22 and Appendix 2). Most ecological site descriptions include an annual production range based on variation in precipitation amount and timing (Table 21). Select the appropriate total annual production value based on knowledge of the growing season conditions (includes combination of precipitation and temperatures as they affect plant production) for the current year (see Section 7.3 Step 3. Collect Supplemental Information).

PURPOSE OF ANNUAL PRODUCTION ESTIMATE (APPENDIX 8)
The instructions provided in Appendix 8 are intended to provide relatively quick methods to train evaluators to estimate total annual production on ecological sites. The goal of training is for evaluators to become proficient in estimating total annual production within the 20% increments required to rate the departure from the expected annual production described in the reference sheet. Evaluators are not expected to apply the methods at every evaluation area once they have the ability to adequately estimate annual production for a particular ecological site. The annual production methods in Appendix 8 are generally not robust enough to determine the relative abundance of functional/structural groups (see NRCS 2006 for protocols to determine relative abundance).

Table 21. Example of values from an ecological site description used to determine the departure rating for annual production.

	Low	Representative Value*	High
Pounds/Acre	500	800	1,100

* The representative value is the total annual production expected for a "normal" growing season. It represents the modal concept of the growing conditions for the ecological site that includes a combination of precipitation timing and amount and temperature ranges that characterize the ecological site.

Use Table 21 for the following example. Evaluators estimate annual production in an evaluation area to be 450 lb/acre. The growing conditions (precipitation and temperatures) during the production year would be expected to produce the representative value of 800 lb/acre. Dividing 450 lb/acre (observed value) by 800 lb/acre (expected value) equals 56%, which falls in the "moderate" departure category in the evaluation matrix (Table 22 and Appendix 2). Enter the departure rating and the estimated annual production in the evaluation sheet (Appendix 4).

Greater than expected total annual production is not considered a departure when rating this indicator. However, evaluators are strongly encouraged to record the total annual production estimated in the evaluation area in the evaluation sheet to document this factor. This situation is most prevalent where native plant communities have been replaced by invasive annual grasses that are highly responsive to above average spring precipitation in terms of total annual production (McLeod et al. 2016). The ecological impacts of annual production greater than the range described in the reference sheet are captured in the functional/structural groups and invasive plants indicators.

Table 22. Generic descriptors of the five departure categories in the evaluation matrix for annual production.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
15. Annual Production*	20% or less of potential production based on recent weather.	21-40% of potential production based on recent weather.	41-60% of potential production based on recent weather.	61-80% of potential production based on recent weather.	Reference sheet narrative inserted here (annual production > 80% of potential).

* When developing an ecological site-specific evaluation matrix, use these same percentage categories.

Measurements

Evaluators need to be comfortable in estimating total annual production before conducting a rangeland health assessment (see sidebar note in this section).

Three common procedures to determine annual production include double sampling (combination of harvesting and estimating), total harvest, and weight units (NRCS 2006). Appendix 8 describes in detail the total harvest and weight unit methods, which are the recommended methods to train evaluators to be able to estimate total annual production in order to rate this indicator. Appendix 3 includes a list of equipment, forms, and resources to assist evaluators in estimating total annual production.

Relationship to Attributes of Rangeland Health

Soil/site stability and hydrologic function: Not applicable.

Biotic integrity: Solar energy is converted into chemical energy by photosynthesis. It is important to note that the amount of solar energy captured in primary production (e.g., energy flow) represents the total amount of energy available for utilization by animals. Reductions in annual production indicate reduced ability of a site to capture energy.

Indicator 15 Example Photos

Measuring annual production with clipping and weight units.

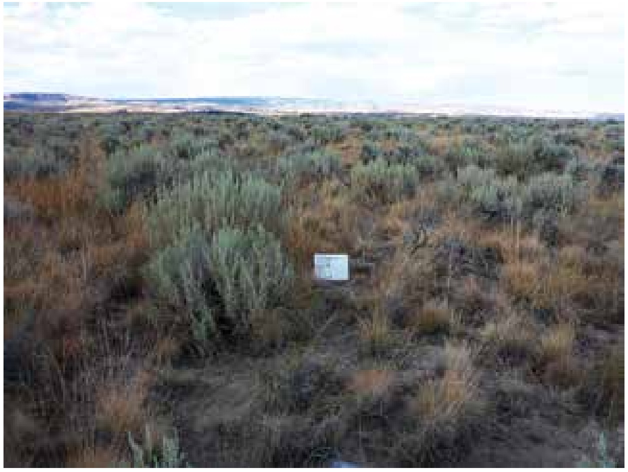
A. A 9.6 ft^2 plot is usually most appropriate for clipping less dense rangeland vegetation, such as bunchgrasses and shrubs.

B. Clipping vegetation in a 1.92 ft^2 plot, which is an appropriate size for homogenous, relatively dense vegetation, such as that in meadows, plains, and prairies.

C. Weighing a weight unit of grass with a spring scale.

D. Weighing clipped vegetation in paper bags.

Indicator 15 Example Photos (continued)



Annual production in an intact sagebrush grassland.

Sagebrush site with reduced annual production due to a reduction in the bunchgrass component.

Annual production may exceed expected amount in sites dominated by annual grasses. The annual production indicator is rated as "none to slight" when annual production is higher than expected.

▶ 7.4.16 Invasive Plants (Indicator 16)

Indicator Description and Assessment

Invasive plants (for purposes of the IIRH protocol) are plant species that are typically not found on the ecological site or should only be in the trace or minor categories under the natural disturbance regime and have the potential to become a dominant or codominant species on the site if their establishment and growth are not actively controlled by natural disturbances or management interventions. A primary characteristic of invasive plant species is their ability to persist on an ecological site and influence ecological processes (Chambers et al. 2014). Some invasive plants (e.g., knapweed) are capable of invading undisturbed, climax bunchgrass communities (Lacey et al. 1990), further emphasizing them as an indicator of ecosystem stress. Even some highly diverse, species-rich plant communities are susceptible to exotic species invasion (Stohlgren et al. 1999).

The following guidance is applied when developing the reference sheet and assessing the invasive plants indicator:

- **Ruderal plants are not included.** Plant species that become dominant for only 1 to several years (e.g., short-term response to drought or wildfire) are not included in this indicator. For example, Russian thistle often increases after a disturbance but rarely dominates over time.
- **Noxious weeds are sometimes included.** The state noxious weeds list should be consulted when identifying invasive species for a specific ecological site; however, the species should only be included in evaluating this indicator if it fits the previously stated definition of an invasive plant. Plants that are invasive on an ecological site may or may not be **noxious** (i.e., any plant designated by a federal, state, or county government to be injurious to public health, agriculture, recreation, wildlife, or any public or private property) (Sheley et al. 1999).
- **Introduced desirable plants may be included.** Plants that have been purposefully introduced to an ecological site and that do not spread into and become dominant in areas where they were not planted are not considered invasive on that ecological site. However, introduced species are considered invasive on ecological sites when they have or could potentially spread into and dominate areas where they were not sown. An example is crested wheatgrass, which is not particularly invasive in the warm and dry portions of the Great Basin but may be invasive in parts of the northern Great Plains.
- **Native plants may be included.** Some native plants that may be present in minor or trace amounts of the reference state's expected plant composition may become dominant and control ecological processes on the ecological site when the natural disturbance regime changes (e.g., juniper or mesquite increasing in absence of fire). These native plants are considered invasive plants in the assessment. Figure 15 shows an example in which western juniper now dominates a sagebrush ecological site due to the absence of fire.

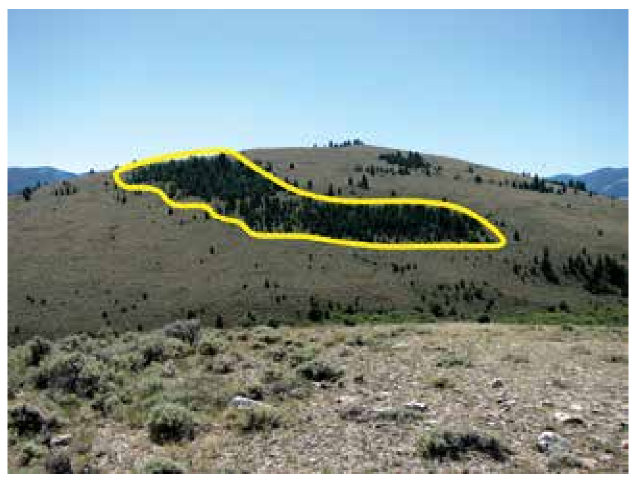


Figure 15. Juniper-dominated area in a sagebrush ecological site.

Assess this indicator by selecting the best fit departure descriptor in the evaluation matrix (Table 23 and Appendix 2). It is important to document the invasive species by name and the relative abundance of each invasive species in the evaluation area in the comment section on page 2 of the evaluation sheet (Appendix 4). Any noxious weeds encountered during an assessment should be reported to the appropriate land management entity, whether or not they are considered invasive for the ecological site.

Table 23. Generic descriptors of the five departure categories in the evaluation matrix for invasive plants.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
16. Invasive Plants	Dominant throughout.	Common throughout.	Scattered throughout.	Uncommon.	Nonnative invasive plants not present. If native invasive species are present, composition matches that expected for the ecological site.

Measurements

Invasive plants can be quantified by measuring foliar cover using line point intercept or by measuring plant density using belt transects. Species-based annual production data may also be used to calculate abundance of invasive species. The annual production methods in Appendix 8 are generally not robust enough to determine relative abundance of invasive species (see NRCS 2006 for protocols that are appropriate for this purpose).

Relationship to Attributes of Rangeland Health

Soil/site stability and hydrologic function: Not applicable.

Biotic integrity: Invasive plants may impact an ecosystem's composition and abundance of species, community dynamics, and the processes by which energy and nutrients move through the ecosystem. These impacts can influence both biological organisms and physical properties of the site (Olson 1999). These impacts may range from slight to severe depending on the species involved and their degree of dominance. Invasive species may adversely affect a site by increased water usage (e.g., salt cedar/tamarisk in riparian areas) or rapid nutrient depletion (e.g., high nitrogen use by cheatgrass).

Indicator 16 Example Photos

Invasive plants include native plants that can increase and become dominant plants that persist without management intervention. A 1952 photo (left) from southern Idaho shows juniper expansion into sagebrush, and the same site in 2004 (right) shows the continued expansion in the absence of a fire or other treatment.

Cheatgrass is an invasive annual grass that has greatly increased wildfires in the Great Basin and dominates the landscape unless managers intervene.

Yellow star-thistle, an exotic forb, can invade and dominate plant communities if not controlled.

▶ 7.4.17 Vigor with an Emphasis on Reproductive Capability of Perennial Plants (Indicator 17)

Indicator Description and Assessment
Plant **vigor** relates to the robustness of a plant in comparison to other individuals of the same species. Vigor is reflected primarily by the size of the plant and its parts in relation to the plant's age and the local environment in which it is growing (SRM 1999). A plant's reproductive capability is dependent on having adequate vigor and the ability to reproduce given the constraints of climate and herbivory. Inflorescence (e.g., seed stalks) and flower production are basic measures of reproductive potential for sexually reproducing plants and clonal production (e.g., tillers, rhizomes, or stolons) for vegetatively reproducing plants.

Adequate seed production maintains plant populations when sexual reproduction is the primary mechanism of individual plant replacement at a site; however, annual seed production of perennial plants is highly variable (Harper 1977). Seed production is related to plant vigor since healthy plants are better able to produce adequate quantities of **viable seed** than are plants that are stressed or dying (Hanson and Stoddart 1940; Goebel and Cook 1960). Similarly, the production of tillers, rhizomes, or stolons may decline in density and size as plant vigor declines (Goebel and Cook 1960).

With the exception of hyperarid ecosystems (e.g., Arabian Peninsula and northern Atacama Desert), nearly all rangelands have the potential to support perennial plants (Whitford 2002). A plant community that lacks perennial plants is rarely included in the reference state. Since the vigor of perennial plants is closely related to reproductive capability, nonreproductive characteristics of perennial grasses, forbs, and shrubs may be used as a surrogate for reproductive capability if reproductive structures are not developed at the time of the assessment. Useful nonreproductive characteristics include leaf or stem color, size of a plant crown or basal diameter, leaf or twig length and density, and current plant production.

If reproductive structures are present, they are evaluated in relation to what would be expected under the natural disturbance regime, especially recent weather conditions. Ecological reference areas on the same ecological site can provide a point of comparison to determine expected vigor and reproductive capability given recent weather at the time of an assessment.

Rate this indicator according to the steps and guidelines in the text box in Section 7.4.13 (indicator 13) by evaluating the vigor and reproductive capability of the perennial species within their functional/structural groups. Rate the indicator using the expected relative dominance of functional/structural groups (only dominant, subdominant, and minor), and use a preponderance of evidence approach. In addition, the following guidelines apply:

- **Recruitment** is not assessed with this indicator since plant recruitment from seed is an episodic event on many rangeland ecological sites. Evidence of recruitment (seedlings, young plants, or vegetative spread) of perennial native or seeded plants should be recorded in the comment section on page 2 of the evaluation sheet but is not considered in rating the reproductive capability of perennial plants.
- Base the indicator rating on the visible perennial plants occupying the site at the time of the evaluation. Don't increase the departure rating for this indicator to account for plants in a functional/structural group that are no longer present in the evaluation area.
- In situations in which all plant species in an expected dominant, subdominant, or minor functional/structural group(s) are no longer visibly present in the evaluation area, the rating is "extreme to total." If only a few perennial plants are visibly present in an expected dominant, subdominant, or minor functional/structural group(s) in the evaluation area, that functional/structural group(s) may no longer be functionally present. In this situation, the rating for the functional/structural group(s) would also be "extreme to total."

- The indicator rating should not be adjusted to reflect expected effects of future management actions in an evaluation area. For example, if vigor and reproductive capability of species in functional/structural groups are reduced within a pasture in a rotation grazing system, conduct the assessment based on current status in the evaluation area; do not make projections about how vigor and reproductive capability may change based on future scheduled rest.
- Vigor is influenced primarily by the size of a plant and its parts (SRM 1999), so the presence of dead or dying plants or plant parts may affect this indicator. Only live plants should be included in the rating of this indicator; assess dead plants in indicator 13 (dead or dying plants or plant parts).

Table 24. Generic descriptors of the five departure categories in the evaluation matrix for vigor with an emphasis on reproductive capability of perennial plants.

Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants (dominant, subdominant, and minor functional/ structural groups)	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/ structural group(s) are extremely reduced, or functional/ structural group(s) is no longer functionally present.	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/ structural group(s) are greatly reduced.	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/ structural group(s) are moderately reduced.	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/ structural group(s) are slightly reduced.	Reference sheet narrative inserted here.

Measurements

This indicator can be measured in various ways. Mueggler (1975) recommends comparing seed stalk numbers or culm length on grazed and ungrazed bluebunch wheatgrass plants as a measure of plant recruitment potential. Goebel and Cook (1960) include flowering stalk height, leaf length, stem growth, and number of **viable seeds** per flowering stalk in assessing the vigor of intermountain perennial grasses and forbs. Bilbrough and Richards (1993) use number and length of leaders (e.g., shoots), biomass, and node production (flowering and shoot) as indicators of the vigor of two common Intermountain shrubs. Basal area of perennial grasses is another variable related to plant vigor, which can be determined using line point intercept.

Relationship to Attributes of Rangeland Health

Soil/site stability and hydrologic function: Not applicable.

Biotic integrity: Plant community composition and therefore resiliency are dependent on the availability of plants with the capability to reproduce and for recruitment to occur (Svejcar et al. 2014). Plant vigor and reproductive capability are key components in ensuring that, when favorable recent weather conditions are present, recruitment can occur to balance plant mortality.

Indicator 17 Example Photos

Native sagebrush community with good vigor and reproductive capability relative to site potential and recent weather.

Native sagebrush community with reduced vigor and reproductive capability relative to site potential and recent weather. Growing season for the perennial grasses is over so seed production potential is minimal. Sagebrush reproductive capability is also reduced on live branches.

Native shrub (bitterbrush) with good vigor and reproductive capability.

Native shrub (bitterbrush) with poor vigor and reduced reproductive capability due to heavy browsing.

▶ 7.4.18 Optional Indicators

The 17 indicators of rangeland health previously described must be assessed on all sites. These indicators are not intended to be all inclusive for all rangelands. Additional indicators may be added to improve sensitivity in detecting changes in soil/site stability, hydrologic function, and biotic integrity. However, optional indicators must significantly improve the quality of the evaluation by providing additional information about ecological function of the system(s) being evaluated, relative to at least one of the three attributes.

Optional indicators must be ecologically, not management, focused. For example, an indicator of suitability for livestock, wildlife, or special status species is not an appropriate indicator to determine the health of a land unit. It may be important in an allotment or ranch evaluation, but it is not relevant in determining the status of the attributes of rangeland health.

For example, a biological soil crust indicator may be applied in ecological sites where these crusts play a particularly important biological or physical role (e.g., for nitrogen fixation or soil stabilization). A generic evaluation matrix for this optional indicator is shown in Table 25.

Other examples of optional indicators that may be applied in some ecological sites are **slumps** (a landslide involving a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface (SSSA 1997)) or **mass movement** (the dislodgement and downslope transport of soil and rock material as a unit under direct gravitational stress (SSSA 1997)). These indicators may be appropriately applied in areas that have an inherent risk for slumps, rockslides, or debris flows.

The benefits of maintaining a consistent protocol should be weighed against the expected improvement in assessments when considering the development and use of optional indicators. Prior to conducting an assessment, document the relationship of the optional indicator(s) to the three attributes of rangeland health. Coordinate the development of optional indicators with the NRCS state rangeland management specialist.

Table 25. Generic descriptors of the five departure categories for the optional indicator of biological soil crusts.

Optional Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
Biological Soil Crusts	Occurring only in protected areas; very limited suite of life forms.	Largely absent in plant interspaces; occurring mostly in protected areas.	Occurring in protected areas and with a minor component in interspaces.	Occurring throughout the site but continuity is broken.	Largely intact and nearly matches site potential.

7.5 Step 5. Determine the Functional Status of the Three Attributes of Rangeland Health (Required)

The IIRH protocol relies on the collective experience and knowledge of the evaluator(s) to classify each indicator and then to interpret the collective rating of the indicators into one summary rating of departure for each attribute of rangeland health. This protocol is intended for use by experienced, knowledgeable evaluators who are encouraged to assist those with less experience or training as part of an interdisciplinary team.

The interpretation process is the critical link between indicator observations and determining the status of each rangeland health attribute. Therefore, evaluators should complete the attribute ratings before leaving the evaluation area.

There is some redundancy built into the indicators so that similar questions about rangeland health are asked in different ways. For example, the indicators bare ground, litter movement, and effects of plant community composition and distribution on infiltration help determine whether an evaluation area is more susceptible to loss of soil/site stability from runoff and soil erosion than would be indicated by just one of these indicators. This helps address two challenges: (1) some indicators may, at times, be difficult to observe (e.g., pedestals may be trampled and therefore muted after intensive grazing) and (2) some indicators are less sensitive to changes on some ecological sites (e.g., gullies in a playa or other concave area, spatial distribution of vegetation in a tallgrass prairie).

Use the **preponderance of evidence** approach to select the appropriate departure category for each attribute. This selection is based, in part, on where the majority of indicators for each attribute fall under the five departure categories. For example, if four of the soil/site stability indicators are in the "moderate" departure category and six are in the "slight to moderate" departure category, the soil/site stability attribute departure would be rated as "slight to moderate," assuming that interpretation of knowledge of ecological site properties and processes, other information, and local experience supports this rating. However, if one or two of the four indicators in the "moderate" category are particularly important, based on knowledge of ecological site properties and processes, a rating of "moderate" may be supported.

Rating all 17 indicators is required to determine the degree of departure for the three attributes of rangeland health. However, consider whether indicators rated "none to slight" have the possibility of occurrence in the evaluation area (e.g., it is nearly impossible for rills to develop in a playa). When it is nearly impossible for an indicator to occur, the associated "none to slight" rating may be given a lower weight when rating the attributes and should be described in the attribute rationale.

Record justification for the attribute ratings at the bottom of page 2 of the evaluation sheet (Appendix 4).

Use Tables 26, 27, and 28 for information about the interrelationships between the indicators as they relate to each attribute. Patterns in the indicator ratings may be used in the preponderance of evidence approach when rating an attribute. For example, the indicators displaying "moderate" or greater departure relative to soil/site stability might all be related to wind erosion, indicating that the evaluation area has greatly increased susceptibility to wind erosion, whereas the area's total erosion susceptibility might be lower if the indicators displaying departure are related to both wind and water erosion.

Table 26. Interrelationships of the indicators associated with the soil/site stability attribute rating.

Indicator	Relationship to the Soil/Site Stability Attribute Rating
1. Rills	Increased occurrence of rills is indicative of loss of soil stability and accelerated erosion by water. Rills can transport significant amounts of soil, which may be lost from or redistributed on the site.
2. Water Flow Patterns	Increased occurrence of water flow patterns indicates accelerated water erosion resulting in soil movement within (and possibly off) a site. Water flow patterns are visual evidence of interrill erosion caused by overland flow, which has been identified as the dominant sediment transport mechanism on rangelands (Tiscareño-Lopez et al. 1993).
3. Pedestals and/or Terracettes	Increased occurrence of pedestals indicates accelerated soil erosion by water or wind. Increased occurrence of terracettes is evidence of reduced soil stability resulting in accelerated erosion by water. Erosional pedestals within a site may be associated with soil surface loss and degradation where soil has eroded around numerous plant or rock pedestals.
4. Bare Ground	Increased bare ground leaves soil more vulnerable to water erosion resulting from raindrop impact, splash erosion, and soil particle disaggregation and to wind erosion resulting from saltation of soil particles. When soils lack protective cover of vegetation, biological soil crusts, and rocks, water or wind may move across the soil surface leading to accelerated soil erosion. Bare ground found in large patches may contribute to a greater amount of soil erosion than the same amount of bare ground found in many small patches.
5. Gullies	Gullies are concentrated areas of soil loss from accelerated water erosion. They are a natural feature of very few landscapes and are usually indicative of significant landscape instability. Considerable amounts of soil may be lost from sides and headcuts of gullies. The amount of loss of soil and water through a gully can be greater than from rill and interrill erosion, and the effects are more concentrated. Gullies can also affect physical soil properties at a site (Poesen et al. 2003).
6. Wind-Scoured and/or Depositional Areas	Increased incidence of wind-scoured areas indicates reduced soil and site stability resulting in soil loss by wind erosion. Once wind erosion has begun, soil material below the surface layer that may have been protected by litter or soil crusts may be more susceptible to erosion. Increased incidence of depositional areas is indicative of wind erosion that may be occurring within the evaluation area or in adjacent areas. Soil is usually deposited as disaggregated particles, which may be more susceptible to subsequent wind or water erosion.
7. Litter Movement	Litter movement from the point of origin indicates that water or wind erosion may be occurring. Litter concentration has been shown to be closely correlated with interrill erosion (water flow patterns).
8. Soil Surface Resistance to Erosion	Soil stability is directly tied to the soil surface's resistance to water erosion. Higher soil aggregate stability means soil particles are more strongly "glued" to each other and therefore less likely to be detached by raindrop impact, overland flow, or wind. Soil surface resistance to erosion may have a spatial relationship with other indicators such as bare ground, which also influences soil/site stability. Reduced soil surface resistance to erosion is associated with reduced infiltration rate, increased runoff, and increased erosion.
9. Soil Surface Loss and Degradation	Soil surface loss and degradation indicates past erosion. Signs of soil degradation, including structure changes and reduction of organic matter, may also increase susceptibility to future erosion. Soil surface loss and degradation is an indicator of long-term change in rangeland health and often persists after vegetation cover has recovered. The degree of soil surface loss and degradation may help determine whether a site has the capability to recover ecosystem function or whether a physical threshold has been crossed.
11. Compaction Layer	Soil stability may be impacted when the compaction layer reduces infiltration to the point that surface runoff increases, which increases the potential for water erosion.

Table 27. Interrelationships of the indicators associated with the hydrologic function attribute rating.

Indicator	Relationship to the Hydrologic Function Attribute Rating
1. Rills	Rills concentrate and facilitate rapid water movement on slopes causing water to be lost from or redistributed on the site. Increased occurrence of rills indicates reduced hydrologic function resulting from decreased infiltration.
2. Water Flow Patterns	Increase in number, length, depth, and width and connectivity of water flow patterns indicates increased water movement (overland flow) on (and possibly off) a site. Increases in size and connectivity of water flow patterns are likely associated with an increased size and number of bare ground patches. Connected water flow patterns can form a drainage network which may connect to rills or gullies. When the soil surface is stable, but infiltration is reduced, overland flow may form water flow patterns with minimal evidence of erosion; however, these features are indicative of reduced hydrologic function.
3. Pedestals and/or Terracettes	Increased occurrence of pedestals and/or terracettes is indicative of reduced hydrologic function. Pedestals caused by water erosion and terracettes are indicators of reduced infiltration resulting in greater overland water flow, sediment transport, and deposition. Pedestals may also be caused by wind erosion, but the resultant soil loss may subsequently impact hydrologic function. Soil surface loss and degradation is likely to be observed around erosional pedestals.
4. Bare Ground	When soils lack protective cover of vegetation, biological soil crusts, litter, and rocks, water is more likely to move across the soil surface prior to infiltration, affecting hydrologic function due to accelerated water loss from a site. Increases in bare ground and bare ground patch size and connectivity can also increase a site's vulnerability to erosion and promote further declines in hydrologic function.
5. Gullies	Gullies are indicative of loss of hydrologic function because they can channel large amounts of water offsite. The amount of loss of water through a gully is generally greater than through water flow patterns or rills, and the effects are more concentrated. Gullies can also affect water table levels at a site (Poesen et al. 2003).
8. Soil Surface Resistance to Erosion	Reduced soil surface resistance to erosion is associated with reduced infiltration rate, increased runoff, and increased erosion. Reductions in soil stability values indicate that soil particles are more likely to be dispersed in water. Dispersed particles may form physical crusts, which limit infiltration and thus impact hydrologic function. Soil surface resistance to erosion may have a spatial relationship with other indicators such as bare ground, which also influences hydrologic function.
9. Soil Surface Loss and Degradation	Potential infiltration rates are controlled by soil texture, while the actual infiltration rate is controlled by soil surface structure and porosity. Hydrologic function is impacted when loss of soil organic matter or degradation of surface horizon structure decrease infiltration rates and water holding capacity. Soil surface loss and degradation is an indicator of long-term change in rangeland health and often persists after vegetation cover has recovered. The degree of soil surface loss and degradation may help determine whether a site has the capability to recover ecosystem function or whether a physical threshold has been crossed.
10. Effects of Plant Community Composition and Distribution on Infiltration	Plant community composition and distribution relative to infiltration reflects the unique contributions of functional/structural groups and their associated species in modifying infiltration. Plant rooting patterns, litter production and associated decomposition processes, height, basal area, and spatial distribution can all affect infiltration. Changes in vegetation composition and distribution can also affect hydrologic function by modifying evapotranspiration, soil water storage, and snow entrapment.
11. Compaction Layer	Compaction layers may negatively impact hydrologic function by restricting water infiltration through the soil profile. In some cases, the compaction layer reduces infiltration to the point that surface runoff increases.
14. Litter Cover and Depth	Litter influences hydrologic function by intercepting raindrops, obstructing overland flow, promoting infiltration, reducing evapotranspiration, and reducing erosion (Hester et al. 1997; Pierson et al. 2007; Thurow et al. 1988a, 1988b). Reductions in litter cover may be associated with increases in bare ground. Thick, contiguous litter mats may intercept moisture from small precipitation events, reducing infiltration.

Table 28. Interrelationships of the indicators associated with the biotic integrity attribute rating.

Indicator	Relationship to the Biotic Integrity Attribute Rating
8. Soil Surface Resistance to Erosion	Biotic factors, including biological soil crust and vegetation composition and cover, litter composition and decomposition, and root growth, all influence soil aggregate stability. Reduced soil surface stability usually reflects lower soil biotic integrity because soil biological processes depend on organic matter inputs and biological decomposition processes to form and maintain stable soil aggregates. These changes, in turn, affect biotic integrity because a stable soil surface provides the environment necessary for most germination and establishment of plant species.
9. Soil Surface Loss and Degradation	Soil surface loss and degradation reflect changes in biotic integrity because of the role of soil biotic activity in creating and maintaining soil structure. These changes, in turn, affect biotic integrity because the soil surface provides the environment for most germination and establishment of plant species. It also provides the environment for soil microorganisms that enhance soil fertility, water holding capacity, and stability. In most sites, the soil at and near the surface has the highest organic matter and nutrient content. Soil organic matter generally controls the maximum rate of water infiltration into the soil and is essential for successful seedling establishment (Wood et al. 1997). Soil surface loss and degradation is an indicator of long-term change in rangeland health and often persists after vegetation cover has recovered. The degree of soil surface loss and degradation may help determine whether a site has the capability to recover ecosystem function or whether a physical threshold has been crossed. The loss or degradation of part or all of the soil surface layer or horizon is an indication of a loss in site potential (Dormaar and Willms 1998; Davenport et al. 1998).
11. Compaction Layer	Compaction layers can restrict the distribution of plant roots, especially fibrous roots, through the soil, limiting the ability of vegetation to extract nutrients and moisture from the soil profile. Compaction layers can also reduce soil water holding capacity, decreasing moisture availability for plant growth. Compaction can also reflect a reduction in biotic integrity because it indicates that the factors that cause compaction are not balanced by recovery processes, including plant root growth.
12. Functional/ Structural Groups	A mixture of plant functional and structural groups appropriate to a site can promote community resistance to plant invasions and resilience to disturbances (Pokorny et al. 2005; Chambers et al. 2014). A change in the relative dominance or number of species in functional/structural groups may have a negative effect on ecosystem processes and overall biotic integrity. Both the presence of functional/structural groups and the number of species (or life forms for biological soil crusts) within these groups have a significant positive effect on ecosystem processes (Tilman et al. 1997).
13. Dead or Dying Plants or Plant Parts	Plant mortality and recruitment are two processes that drive changes in plant populations and communities. This indicator addresses mortality, while indicator 17 indirectly addresses recruitment. If plant mortality exceeds recruitment, biotic integrity of the stand may decline and undesirable plants (e.g., invasive plants) may increase.
14. Litter Cover and Depth	Litter provides a source of soil organic material and raw materials for onsite nutrient cycling (Whitford 1988, 1996), helps moderate the soil microclimate, provides food for microorganisms, and plays a role in enhancing erosion resistance by dissipating the energy of raindrops and obstructing overland flow (Hester et al. 1997; Thurow et al. 1988a, 1988b). Increased litter accumulation may influence biotic integrity by reducing sites for seed germination and may be an indicator of reduced decomposition rates. Litter accumulation may be correlated with indicator 15 (annual production).
15. Annual Production	This is the only indicator that is directly linked to the ecological process of energy flow. Solar energy is converted into chemical energy by photosynthesis. The amount of solar energy captured in primary production (e.g., energy flow) represents the total amount of energy available for utilization by animals. Reduced annual production may be linked with reduced plant vigor, reduced litter, or changes in functional/ structural groups.
16. Invasive Plants	Invasive plants impact an ecosystem's type and abundance of species, their interrelationships, and the processes by which energy and nutrients move through an ecosystem. These impacts can influence both biological organisms and physical properties of a site (Olson 1999) and may range from slight to severe depending on the species involved and their degree of dominance. Invasive species may adversely affect a site by increased water usage (e.g., salt cedar/tamarisk in riparian areas) or modifying disturbance regimes (e.g., shortened fire return intervals in annual grass-invaded sites).
17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants	Plant vigor and reproductive capability are key components in ensuring that, when favorable recent weather conditions are present, recruitment can occur to balance plant mortality (indicator 13). Plant community composition and therefore resiliency are dependent on the availability of plants with the capability to reproduce and for recruitment to occur (Svejcar et al. 2014).

7.5.1 After Completing the Assessment

For more information and applications of the IIRH assessment, see previous sections: 3. Intended Applications of Version 5; and 6. Applications of the IIRH Protocol and Relationship to Other Rangeland Assessment, Inventory, and Monitoring Protocols and Programs.

Managers may use the final ratings of attributes of rangeland health to identify where to focus monitoring efforts or where management opportunities may exist. Areas with a "moderate" departure rating are often ideal for implementing monitoring studies or for making management changes since they should be the most responsive to management actions. Prior to implementing management actions, it is important to review other available relevant information to understand the cause of resource problems and monitor trends in vegetation and soils condition. Additional monitoring may be useful regardless of the departure rating, dependent on future changes in uses or management of an area.

8. Summary

Qualitative assessments of rangeland health provide land managers valuable information to help make informed land management decisions and to communicate findings with the public. The IIRH protocol, in association with quantitative inventory and monitoring information (see Section 5.8.2), can be used to provide early warnings of resource problems. The IIRH protocol does not determine the cause of rangeland health problems; it simply identifies where a problem exists. This protocol is not intended nor designed to replace quantitative monitoring or serve as a trend study.

More research and documentation are needed in many ecosystems to quantify indicators and identify thresholds for rangeland health. Once this information is available, the assessment of rangeland health may become more quantitative and less reliant on qualitative assessment of the indicators. With further research, experience, and application of the IIRH protocol, additional refinements will be made to the protocol and the associated technical reference. As the concept of rangeland health continues to evolve and mature and as our understanding of ecological dynamics (described in state-and-transition model diagrams) grows, the application of this protocol will also continue to evolve.

9. Glossary

abundance: the total number of individuals of a species in an area, population, or community (SRM 1999).

accelerated erosion: erosion in excess of natural rates, usually as a result of anthropogenic activities (SSSA 1997).

annual plant: a plant that completes its life cycle and dies in 1 year or less (SRM 1999).

annual production: the net quantity of aboveground vascular plant material produced within a growing season. Synonym: net aboveground primary production.

apparent trend: an assessment of the perceived direction of successional change occurring over time in a plant community and soils in relation to a community phase in the reference state or a desired plant community (NRCS 2006).

assessment of rangeland health: provides information on the functional status of ecological processes in a location at a moment in time relative to the reference state for an ecological site or other functionally similar unit.

at risk: rangelands that have a reversible loss in productive capability and increased vulnerability to irreversible degradation based upon an evaluation of current conditions of the soil and ecological processes (NRC 1994). An "at risk" designation may point out the need for additional information to better quantify the functional status of an attribute.

attribute of rangeland health: a complex variable that represents the status of a suite of interrelated ecological properties (e.g., species composition) and processes (e.g., water cycle, energy flow, and nutrient cycle) that are essential to ecosystem function. The three attributes that collectively define rangeland health include soil/site stability, hydrologic function, and biotic integrity.

bare ground (bare soil): exposed mineral soil not covered by vegetation (live or dead and basal and canopy cover), gravel/rock, visible biological soil crusts, or litter.

bare ground patch: an area where bare ground is concentrated. Bare ground patches may include some ground cover (e.g., plants, litter, rock, and visible biological soil crusts) within their perimeter, but there is proportionally much more bare soil than ground surface cover.

basal area (plants): the cross-sectional area of the stem or stems of a plant or of all plants in a stand. Herbaceous and small woody plants are measured at or near ground level; larger woody plants are measured at breast or another designated height (SRM 1999). Synonym: basal cover.

basal cover (plants): the percent of soil surface covered by plant bases (SRM 1999). Synonym: basal area.

biological soil crust: microorganisms (e.g., algae, cyanobacteria) and nonvascular plants (e.g., mosses, lichens) that grow on or just below the soil surface. Synonym: microbiotic crust and cryptogamic crust.

biomass (plants): the total amount of living plants above and below ground in an area at a given time (SRM 1999). As used in this technical reference, biomass refers only to parts of standing living plants (standing biomass) above ground, and not the roots.

biotic integrity: the capacity of the biotic community to support ecological processes within the natural range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants (vascular and nonvascular), animals, insects, and microorganisms occurring both above and below ground; one of the three attributes of rangeland health.

blowout: a hollow or depression of the land surface, which is generally saucer or trough-shaped, formed by wind erosion, especially in an area of shifting sand, loose soil, or where vegetation is disturbed or destroyed (SSSA 1997). In this technical reference, blowouts are included with wind-scoured areas.

bunchgrass: a grass having the characteristic growth habit of forming a bunch; lacking stolons or rhizomes (SRM 1999).

canopy cover: the percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings within the canopy are included (NRCS 1997b). Synonym: crown cover.

chemical soil crust: a soil surface layer, ranging in thickness from a few millimeters to a few centimeters, that is formed when chemical compounds become concentrated on the soil surface. They can reduce infiltration and increase overland water flow similar to physical crusts. They are usually identified by a white color on the soil surface.

climate: the average or prevailing weather conditions of a place over a period of years (SRM 1999).

climax plant community (climax): the final or stable biotic community in a successional series; it is self-perpetuating and in equilibrium with the physical habitat (SRM 1999). This concept is based on a linear view of succession and is not consistent with state-and-transition models in current ecological site descriptions.

community pathway: community pathways describe the causes of shifts between community phases. Community pathways can include the concepts of episodic plant community changes, as well as succession and seral stages. Community pathways can represent both linear and nonlinear plant community changes. A community pathway can be reversible in part by changes in natural disturbances, weather variation, or changes in management (Caudle et al. 2013).

community phase(s): a unique assemblage of plants and associated dynamic soil property levels that can occur within a state (Caudle et al. 2013).

compaction layer: a near-surface layer of dense soil caused by impact on or disturbance of the soil surface. When soil is compacted, soil grains are rearranged to decrease the void space and bring them into closer contact with one another, thereby increasing the bulk density (SSSA 1997).

composition: the proportions of various plant species in relation to the total on a given area; it may be expressed in terms of cover, density, weight, etc. (SRM 1999). Synonym: species composition.

cool-season plant: a plant that generally makes the major portion of its growth during the late fall, winter, and early spring. Cool-season grasses generally exhibit the C3 photosynthetic pathway (SRM 1999).

core methods: sampling protocols that generate indicators that represent the minimum information necessary to describe three key ecosystem attributes: soil and site stability, watershed function, and biotic integrity. Specific methods were identified in conjunction with the Bureau of Land Management Assessment, Inventory, and Monitoring Strategy and the Natural Resources Conservation Service's National Resources Inventory (Toevs et al. 2011b; Herrick et al. 2016.)

decadent: the natural aging process in plants characterized by dying plants or plant parts that eventually results in mortality. This technical reference version replaces the term decadent with "dying plants or plant parts."

decomposition: the biochemical breakdown of organic matter into its original compounds and nutrients.

depositional area: location where windblown soil accumulates; the deposited soil may originate from either on- or offsite. Soil deposition due to water movement is assessed with other soil/site stability indicators.

describing indicators of rangeland health: protocol to describe the soil profile and 17 indicators of rangeland health to assist in the preparation of a reference sheet to conduct future assessments of rangeland health. There is no predefined reference for this protocol (Appendix 7).

descriptors: the narratives of the five departure categories (extreme to total, moderate to extreme, moderate, slight to moderate, and none to slight) that describe indicator characteristics in the evaluation matrix (Appendix 2).

desired plant community: of the several plant communities that may occupy a site, the one that has been identified through a management plan to best meet the plan's objectives for the site. It must protect the site, at a minimum (SRM 1999).

diagnostic soil horizon: a soil horizon with quantitatively defined features used to differentiate taxa (Soil Science Division Staff 2017). The unique characteristics of diagnostic horizons are used to identify the soil map unit component when determining the ecological site. See also soil horizon.

dominant: species or functional/structural groups with the greatest size per unit area in the plant community; elimination or reduction of these species or groups from the community would have a major impact on the relative dominance of the remaining groups.

ecological processes: includes the water cycle (the capture, storage, and redistribution of precipitation), energy flow (conversion of sunlight to plant and then animal matter), and nutrient cycle (the cycle of nutrients, such as nitrogen and phosphorus, through the physical and biotic components of the environment). Ecological processes functioning within a natural range of variability support specific plant and animal communities.

ecological reference area: a landscape unit in which ecological processes are functioning within a natural range of variability and the plant communities have adequate resistance to and resiliency after most natural disturbances. These areas do not need to be pristine or historically unused lands (e.g., relict areas).

ecological site: "a conceptual division of the landscape that is defined as a distinctive kind of land based on recurring soil, landform, geological, and climate characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its ability to respond similarly to management actions and natural disturbances" (Caudle et al. 2013).

ecological site description: the documentation of the characteristics of an ecological site. The documentation includes the data used to define the distinctive properties and characteristics of the ecological site; the biotic and abiotic characteristics that differentiate the site (i.e., climate, physiographic characteristics, soil characteristics, plant communities); and the ecological dynamics of the site that describe how changes in disturbance processes and management can affect the site. An ecological site description also provides interpretations about the land uses and ecosystem services that a particular ecological site can support and management alternatives for achieving land management (Caudle et al. 2013).

ecological site group: ecological sites grouped by their similar responses to disturbances (e.g., disturbance response groups) (Stringham et al. 2016) or based on physiographic, geological, and landform breaks associated with important shifts in climate and vegetation (Bestelmeyer et al. 2016).

ecosystem: organisms together with their abiotic environment, forming an interacting system, inhabiting an identifiable space (SRM 1999).

Ecosystem Dynamics Interpretive Tool (EDIT): an information system framework designed to help construct, catalog, and share conceptual models of ecosystem change and ecological site descriptions.

energy flow: conversion of sunlight to plant and then animal matter; one of the ecological processes. Annual production is an indicator of energy flow because it assesses the conversion of sunlight to plant biomass, which is then available for consumption by animals.

ephemeral systems (in rangelands and woodlands): areas that receive more water than typical upland ecological sites, but only retain surface water for short periods of time (generally less than 1 month at a time in most years).

episodic: occurring, appearing, or changing at usually irregular intervals.

erosion: detachment and movement of soil or rock fragments by water, wind, ice, gravity; the land surface worn away by running water, wind, ice, or other geological agents, including such processes as gravitational creep (SRM 1999).

evaluation area: the area (generally 1/2 to 1 acre in size) where the IIRH protocol is applied.

evaluation matrix: a matrix used to determine indicator departure from the reference sheet ("none to slight" category). A generic evaluation matrix is provided in this technical reference (Appendix 2), but development and use of ecological site-specific evaluation matrices are strongly recommended.

evaluation sheet: a form used to rate and describe (with comments) the degree of departure for the 17 indicators and 3 attributes of rangeland health. This sheet also documents evaluation area location and characteristics (soils, ecological site, recent weather, and management influences).

evaluator(s): the person or persons conducting an assessment of rangeland health in an evaluation area.

exotic plant: a plant growing on or occurring in an ecosystem beyond its natural range of existence or natural zone of potential dispersal.

expected functional/structural group: refers to a functional/structural group that occurs in at least one of the reference state community phases functioning under the natural disturbance regime.

foliar cover: proportion of the soil surface covered by a vertical projection of a plant or plants. This is effectively the area that is protected from raindrops and the area in shade when the sun is directly overhead.

forb: any broad-leafed, herbaceous plant other than those in the Poaceae, Cyperaceae, and Juncaceae families (SRM 1999).

function: refers to the ecophysiological role that plants and biological soil crusts play on a site. This may include the plant's life cycle (e.g., annual, monocarpic perennial, or perennial), phenology, photosynthetic pathway, nitrogen fixer associations, sprouting ability, and water infiltration.

functionally present: pertains to the number of plants within a functional/structural group that is necessary to consider the functional/structural group as functioning in an evaluation area. Generally, if only a few individuals in a functional/structural group are present in an evaluation area, that functional/structural group is no longer considered functionally present. The rationale for this determination is that the ecological role of that functional/structural group has been diminished to the degree that it is essentially providing little to no ecological function or reproductive capability. This concept is applied when rating the indicators functional/structural groups and vigor with an emphasis on reproductive capability of perennial plants.

functional/structural group: a suite or group of plant species that, because of similar shoot or root structure, photosynthetic pathways, nitrogen fixing ability, life cycle, etc., are grouped together on an ecological site basis. Plant species (including nonvascular plants such as visible biological soil crusts) that are grouped together on the basis of similar growth forms or ecophysiological roles.

functioning: (1) refers to the rangeland health attributes in which the majority (see definition of "preponderance of evidence") of the associated indicators are rated as having little or no deviation from that described in the reference sheet (Appendix 1a and 1b) for the ecological site; (2) refers to the presence and integrity of ecological processes (energy flow, water cycle, and nutrient cycle) being within the range of expectations for the ecological site.

geomorphology: the scientific study of the evolution of the earth's surface; the science of landforms (SSSA 1997).

grass: members of the plant family Poaceae (SRM 1999).

ground cover: percentage of material, other than bare ground, covering the land surface. It may include live and standing dead vegetation, litter, biological soil crust, cobble, gravel (> 5 mm in diameter), stones, and bedrock. Ground cover plus bare ground totals 100 percent. Synonym: cover.

growing season: that portion of the year when temperature and moisture permit plant growth (NRCS 2006).

gully: a well-defined channel cut into the soil by ephemeral water. Gullies normally follow natural drainage channels and are at least 1 ft wide and 2 ft deep (Selby 1993).

headcut: abrupt elevation drop in the channel of a gully that accelerates erosion as it undercuts the gully floor and migrates upstream.

healthy rangeland: land of which the integrity of the soil, vegetation, water, and air, as well as the ecological processes of the rangeland ecosystem, are balanced and sustained. Integrity is defined as maintenance of the structure and functional attributes characteristic of a locale, including natural range of variability (SRM 1999). Synonym: rangeland health.

hydric: characterized by, relating to, or requiring an abundance of moisture (Dickard et al. 2015).

hydrologic function: the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity when a reduction does occur; one of the three attributes of rangeland health.

indicators: components of an ecosystem whose characteristics (e.g., presence or absence, quantity, distribution) are used as an index of an attribute (soil/site stability, hydrologic function, and biotic integrity) that is not feasible or too expensive to measure.

infiltration: the entry of water into the soil (SSSA 1997). As used in this technical reference, infiltration encompasses both the entry of water into the soil and the movement of water into the soil profile.

intermittent system: a stream system that flows only at certain times when it receives water from springs or gradual and long, continued snowmelt (Dickard et al. 2015).

interrill erosion: the removal of a fairly uniform layer of soil on a multitude of relatively small areas by splash due to raindrop impact and by sheetflow (SSSA 1997).

invasive plants: (for purposes of the IIRH protocol) are plant species that are typically not found on the ecological site or should only be in the trace or minor categories under the natural disturbance regime and have the potential to become a dominant or codominant species on the site if their establishment and growth are not actively controlled by natural disturbances or management interventions. Species that become dominant for only 1 to several years (e.g., short-term response to drought or wildfire) are ruderal plants and not invasive plants.

inventory (rangeland inventory): (1) the systematic acquisition and analysis of resource information needed for planning and management of rangeland; (2) the information acquired through rangeland inventory (SRM 1999).

key area: area with a pasture or management unit, often nonrandomly selected to monitor specific management objectives in land use or grazing plans. Extrapolation of assessments of rangeland health conducted on key areas to larger management units is not recommended.

land resource units: the basic units from which major land resource areas are determined. They are also the basic units for state land resource maps. They are typically coextensive with state general soil map units, but some general soil map units are subdivided into land resource units because of significant geographic differences in climate, water resources, or land use.

landscape: large, connected geographical regions that have similar environmental characteristics and that may consist of part or all of one or more watersheds.

land treatments: a wide range of vegetation and soil manipulations, such as use of mechanical equipment, herbicides, prescribed fire, or seeding.

life form: characteristic form or appearance of a plant species at maturity (e.g., tree, shrub, herb) (SRM 1999). For the purposes of determining functional/structural groups for the IIRH protocol, life form also refers to the life cycle of the plant (annual or perennial).

litter: the uppermost layer of organic debris on the soil surface—essentially the freshly fallen or slightly decomposed vegetal material (SRM 1999). In this technical reference, it includes dead plant material, including leaves, stems, and branches, that is detached from the plant.

litter movement: change in the location of litter due to wind or water.

macropore: large soil pores responsible for preferential water flow and rapid, far-reaching transport (SSSA 1997).

major land resource area: a geographic area, usually several thousand acres in extent, that is characterized by a particular pattern of soils, climate, water resources, land uses, and type of farming.

mass movement: dislodgement and downslope transport of soil and rock material as a unit under direct gravitational stress. The process includes slow displacements, such as creep, and rapid movements, such as landslides, rockslides and slips, earthflows, debris flows, and avalanches. Agents of fluid transport (water, ice, air) may play an important, if subordinate, role in the process (SSSA 1997).

micropore: a class of soil pores that are sufficiently small so that water within these pores is considered immobile, but available for plant extraction, and soluble transport is by diffusion only (SSSA 1997).

minor: species or functional/structural groups within a plant community with less size per unit area than subdominant plants and generally greater than 1% and less than 10% of the community composition; elimination of these species or groups from the community would have a minor impact on the composition of the remaining groups.

modal concept (as it applies to ecological site descriptions): an ecological site description reflects the modal (most common) physical characteristics of an ecological site. The physical aspects of a site described in an ecological site description (exposure, slope, landform, soil surface texture, etc.) usually do not include the entire range of values but, rather, the modal values of these variables. However, the reference sheet associated with each ecological site description includes all expected ranges (modal and extreme) of the 17 indicators.

monitoring: the orderly collection, analysis, and interpretation of resource data to evaluate progress toward meeting management objectives. The process must be conducted over time in order to determine whether or not management objectives are being met (SRM 1999).

native invasive: a native plant that is found onsite where it was not a part of the original plant community, or a native plant that because of management or other changes is now increasing beyond its original composition on the site. See also: invasive plants.

natural disturbance regime: the kind, frequency, and intensity of natural disturbance events that would have occurred on an ecological site prior to European influence (ca. 1600) in North America (Winthers et al. 2005). Natural disturbances include, but are not limited to, native insect outbreaks, wildfires, native wildlife activities (herbivory, burrowing, etc.), indigenous human activities, and weather cycles and extremes (including droughts and unusual wet periods, temperatures, and snow and wind events).

natural range of variability: the deviation of characteristics of biotic communities and their environment that can be expected given natural variability in climate and natural disturbance regimes. The natural range of variability does not include influences of nonnative species and also does not encompass soil degradation, such as accelerated erosion, organic matter loss, changes in nutrient availability, or soil structure degradation, beyond what would be expected to occur under the natural disturbance regime.

nitrogen fixation: the biological reduction of molecular nitrogen to chemical forms that can be used by organisms in the synthesis of organic molecules.

noxious weed: any plant designated by a federal, state, or county government to be injurious to public health, agriculture, recreation, wildlife, or any public or private property (Sheley et al. 1999).

nutrient cycle: the cycle of nutrients, such as nitrogen and phosphorus, through the physical and biotic components of the environment; one of the ecological processes.

organic matter: living plant tissue and decomposed or partially decomposed material from living organisms.

overland flow: movement of water over the land's surface. Overland flow occurs when rainfall or snowmelt intensity exceeds soil infiltration capacity and water accumulates on the soil and starts moving downslope toward a drainage network. Sometimes referred to as sheetflow. The path that the overland flow takes constitutes the water flow patterns.

pedestal (erosional): plants or rocks that appear elevated as a result of soil loss by wind or water erosion (does not include nonerosional processes such as frost heaving).

pedon: a three-dimensional body of soil with lateral dimensions large enough to permit the study of horizon shapes and relations (SSSA 1997). See polypedon.

perennial plant: a plant that has a lifespan of 3 or more years (NRCS 1997b).

physical crust: thin surface layers induced by the impact of raindrops on bare soil causing the soil surface to seal and absorb less water.

plant mortality: as used in this technical reference, this term refers to the prevalence of dead plants in an evaluation area.

polypedon: a group of contiguous similar pedons. The limits of a polypedon are reached at a place where there is no soil or where the pedons have characteristics that differ significantly (SSSA 1997). See pedon.

preponderance of evidence: the rating of an attribute of rangeland health by observing where the distribution of indicators for each attribute fall under the five departure categories while also taking into account local knowledge and other information.

qualitative data: observational data derived from visual observations and recorded descriptively but not measured (e.g., descriptive or nonnumerical data).

qualitative rangeland health assessment (qualitative assessment of rangeland health): the determination of the functional status of an attribute(s) through nonnumerical observations of indicators. Qualitative assessments have an element of subjectivity.

quantitative data: data derived from measurements, such as counts, dimensions, weights, etc., and recorded numerically; may include ratios or other values. Qualitative numerical estimates, such as ocular cover and production estimates, are often referred to as semiquantitative.

range condition: the present status of vegetation of a range site in relation to the climax (natural potential) plant community for that site. It is an expression of the relative degree to which the kinds, proportions, and amounts of plants in a plant community resemble that of the climax plant community for the site (SRM 1999).

rangeland: land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes, and wet meadows (SRM 1999). This technical reference also includes oak and pinyon-juniper woodlands, low-elevation dry forests, and ephemeral stream systems in this definition.

rangeland health: the degree to which the integrity of the soil, vegetation, water, and air, as well as the ecological processes of the rangeland ecosystem, are balanced and sustained. Integrity is defined as maintenance of the structure and functional attributes characteristic of a locale, including natural range of variability (SRM 1999). Synonym: healthy rangeland.

recruitment: the successful entry of new individuals into the breeding population.

reference sheet: a form that is a component of an ecological site description that describes the status of each indicator within the natural disturbance regime for the reference state. It is the primary reference for all assessments of rangeland health and is required to conduct an assessment.

reference sheet checklist: tool to improve consistency in describing the natural disturbance regime within the natural range of variability for each indicator when developing or revising reference sheets.

reference state: the state (see definition of "state") where the functional capacities represented by soil/site stability, hydrologic function, and biotic integrity are functioning at a sustainable/resilient level under the natural disturbance regime. This state usually includes more than one community phase, but is not limited to, what is often referred to as the potential natural plant community.

reference state community phase(s): as used in this technical reference, these are the community phases in a reference state that are functioning under the natural disturbance regime.

relative dominance (composition): the percent of cover or production represented by a species or life form expressed relative to the total cover or production. It can also be based on biomass.

relict (area): a remnant or fragment of the climax plant community that remains from a former period when it was more widely distributed (SRM 1999). Synonym: pristine.

resilience (as it applies to ecological sites): the capacity of the plants, animals, and abiotic environment within an ecological site to regain their fundamental structure, function, and processes when altered by disturbances, such as fire or land use changes (Holling 1973; Peterson et al. 1998; Allen et al. 2005). The capacity of ecological processes to recover following a disturbance. Resilience can be defined in terms of the rate of recovery, the extent of recovery during a particular period of time, or both.

resistance: the capacity of the plants, animals, and abiotic environment to retain their fundamental structure, processes, and functions (or remain largely unchanged) despite stresses and disturbances, such as potential invasions of introduced species (sometimes referred to as novel species) (Folke et al. 2004; D'Antonio and Thomsen 2004), increased carbon dioxide, and climate change.

rhizomatous plant: a plant that develops clonal shoots by producing rhizomes. Rhizomes are horizontal underground stems that usually produce roots and shoots from nodes (SRM 1999).

rill: a small, intermittent watercourse with steep sides, usually only several centimeters deep (SSSA 1997). Rills generally are linear erosion features running parallel to a slope.

runoff (opposite of run-on): the portion of precipitation or irrigation on an area that does not infiltrate but, instead, is discharged by the area (SSSA 1997).

saltation: a particular type of momentum-dependent transport involving the rolling, bouncing, or jumping action of soil particles 0.1 to 0.5 mm in diameter by wind, usually at a height of < 15 cm above the soil surface, for relatively short distances; the rolling, bouncing, or jumping action of mineral grains, gravel, stones, or soil aggregates affected by the energy of flowing water; the bouncing or jumping movement of material downslope in response to gravity (SSSA 1997).

sheetflow: see overland flow.

shrub: a plant that has persistent, woody stems and a relatively low growth habit and that generally produces several basal shoots instead of a single bole. It differs from a tree by its low stature (generally less than 5 meters, or 16 feet) and nonarborescent form (SRM 1999).

similarity index (rangeland): an index of the current plant community composition in relation to a single plant community phase in the reference state or to a desired plant community for the ecological site.

slump: a mass movement process characterized by a landslide involving a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface (concave upward) and about an axis parallel to the slope from which it descends, and by backward tilting of the mass with respect to that slope so that the slump surface often exhibits a reversed slope facing uphill. Also, the landform or mass of material slipped down during, or produced by, a slump (SSSA 1997).

soil aggregates: a group of primary soil particles that cohere to each other more strongly than to other surrounding particles (SSSA 1997). See also soil ped.

soil complex: a kind of map unit used in soil surveys comprised of delineations, each of which shows the size, shape, and location of a landscape unit composed of two or more kinds of component soils, or component soils and a miscellaneous area, plus allowable inclusions in either case. The individual bodies of component soils and miscellaneous areas are too small to be delineated at the scale of 1:24,000. Several to numerous bodies of each kind of component soil or the miscellaneous area are apt to occur in each delineation (SSSA 1997).

soil crusts: biotic and abiotic components found on the surface of soils, including biological, physical, vesicular, and chemical crusts (see respective definitions in this glossary).

soil horizon: a layer, approximately parallel to the surface of the soil, that is distinguishable from adjacent layers by a distinctive set of properties produced by the soil-forming processes (Soil Science Division Staff 2017).

soil inclusions: one or more polypedons or parts of polypedons within a delineation of a map unit, not identified by the map unit name (i.e., is not one of the named component soils or named miscellaneous area components). Such soils or areas are either too small to be delineated separately without creating excessive map or legend detail, occur too erratically to be considered a component, or are not identified by practical mapping methods (SSSA 1997).

soil map unit: a collection of areas defined and named the same in terms of their soil components, miscellaneous areas, or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map (Soil Science Division Staff 2017).

soil map unit component: within the context of a map unit, a component is an entity that can be delineated at some scale. It is commonly a soil but may be a miscellaneous area. Components consisting of soil are named for a soil series or a higher taxonomic class. Those that are miscellaneous areas are given an appropriate name, such as "Rock outcrop" or "Urban land" (Soil Science Division Staff 2017).

soil ped: a unit of soil structure, such as a block, column, granule, plate, or prism, formed by natural processes (in contrast with a clod, which is formed artificially) (SSSA 1997). See also soil aggregates.

soil series: represents a three-dimensional soil body having a unique combination of properties that distinguish it from neighboring series. For U.S. soil maps, the soil series has served as the fundamental mapping concept (Soil Science Division Staff 2017).

soil/site stability: the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water and to recover this capacity when a reduction does occur; one of the three attributes of rangeland health.

soil structure: the combination or arrangement of primary soil particles into secondary units or peds. The secondary units are characterized on the basis of size, shape, and grade (degree of distinctiveness) (SSSA 1997).

soil surface loss and degradation: the reduction in soil surface depth, organic matter, porosity, and structure as a result of wind or water erosion. Soil deposition over the surface horizon can also degrade the soil surface.

soil surface resistance to erosion: the ability of a surface soil to resist erosion by water. Resistance increases in part with increasing soil organic matter or the presence of biological soil crusts.

soil survey: the systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of field examination (SSSA 1997).

soil texture: the relative proportions of the various soil separates (sand, silt, and clay) in a soil (SSSA 1997).

species composition: the proportions of various plant species in relation to the total on a given area. It may be expressed in terms of cover, density, weight, etc. (SRM 1999). Synonym: composition.

standing dead vegetation: the total amount of dead plant material, in aboveground parts, per unit of space, at a given time (NRCS 1997b). This component includes all standing dead vegetation produced in the previous (not the current) growing season that is not detached from the plant and is still standing.

state: includes one or more vegetation community phases (including associated dynamic soil properties) that occur in dynamic equilibrium on a particular ecological site and that are functionally similar with respect to the three attributes of rangeland health (soil/site stability, hydrologic function, and biotic integrity).

status: state or condition. For the purposes of IIRH, status refers to the state or condition of ecological processes (e.g., water cycle, energy flow, and nutrient cycle) at the point in time that an assessment is completed, expressed as departure ratings for the three attributes of rangeland health.

structure (vegetation): refers to plant growth forms (e.g., trees, vines, shrubs, grasses, forbs, and nonvascular plants, such as visible biological soil crusts) within the community. Structure may be subdivided to group species with similar growth forms based on height, growth patterns (bunch, sod-forming, or spreading through long rhizomes or stolons), root structure (fibrous or tap), rooting depth, or sprouting ability.

subdominant: species or functional/structural groups within a plant community with less size per unit area than dominant plants and generally greater than 10% of the community composition; elimination of these species or groups from the community would have a relatively major impact on composition of the remaining groups.

succulent: plant with fleshy structures as an adaptation for storing water. Succulents commonly found on rangelands include cacti, *Euphorbia* spp., and *Sedum* spp., which may comprise a separate functional/structural group because most succulent species photosynthesize through the crassulacean acid metabolism (CAM) pathway, an adaptation for minimizing water loss through transpiration.

terracettes: "benches" of soil deposition (may include incorporated litter or gravel) that form behind or between obstacles (persistent litter, rocks, or plant bases) caused by water (not wind) movement. Does not include horizontal paths caused by livestock or wildlife trailing on steeper slopes.

threshold: a transition boundary that an ecosystem crosses resulting in a new stable state that is not easily reversed without significant inputs of resources.

tiller: a plant shoot that arises from the root or base of a plant.

trace: species or functional/structural groups that represent rare contributions to the measurable plant community composition (e.g., less than 1% of the composition); elimination of these species or groups from the community would have little impact on the composition of the remaining groups.

transition: a shift between two states. Transitions are generally not easily reversible by simply altering the intensity or direction of factors that produced the change. Instead, they require new inputs such as revegetation or shrub removal. Practices such as these, enabling a return to a preexisting state (NRCS 2006), are often expensive and difficult to apply.

tree: a woody, usually single-stemmed, perennial plant that has a definite crown shape and reaches a mature height of at least 4 meters. The distinction between woody plants, known as trees, and those called shrubs is gradual. Some plants, such as oaks (*Quercus* spp.), may grow as either trees or shrubs (SRM 1999).

trend: the direction of change in ecological status or resource value rating observed over time (SRM 1999).

unhealthy rangelands: rangelands on which degradation has resulted in the loss of ecological processes that function properly and the capacity to produce commodities and values that cannot be reversed without external inputs (NRC 1994).

vascular plants: plants with vessels that conduct sap throughout the plant.

vesicular crust: a type of physical soil crust that contains numerous small air pockets or spaces similar to a sponge causing a reduction in infiltration.

viable seed: wildland plant seed that is capable of germination given appropriate environmental conditions.

vigor: the robustness of a plant in comparison to other individuals of the same species. Vigor is reflected primarily by the size of the plant and its parts in relation to the plant's age and the local environment in which it is growing (SRM 1999).

warm-season plant: a plant that makes most or all of its growth during the spring, summer, and fall and is usually dormant in winter; a plant that exhibits the C4 photosynthetic pathway (SRM 1999).

water cycle: the capture, storage, and redistribution of precipitation; one of the ecological processes. Synonym: hydrologic cycle.

water flow patterns: paths that water takes as it moves across the soil surface during periods when surface water from rain or snowmelt exceeds soil infiltration capacity. Sometimes referred to as sheetflow or overland flow.

weather: the current state of the atmosphere with regard to wind, temperature, cloudiness, moisture, pressure, etc. In this technical reference, the term recent weather is used and is defined as weather conditions over the past 2 years.

wind-scoured area: an area, generally in plant interspaces, where the finer soil particles have blown away, sometimes leaving residual gravel, rock, or exposed roots on the soil surface. Includes "blowouts" which are defined as a hollow or depression of the land surface that is generally saucer or trough-shaped and formed by wind erosion.

woodlands: areas with a low density of trees forming open plant communities that support an understory of shrubs and herbaceous plants, including grasses.

10. Appendices

Appendix 1a. Developing Reference Sheets

Reference sheets are the basis for conducting consistent IIRH assessments and must be developed for each ecological site or equivalent unit (see Section 5.2). Reference sheet development and revision requires knowledge of the natural range of spatial and temporal variability and disturbance responses associated with the relevant ecological site. Therefore, reference sheet development and revision should involve multiple experts familiar with the site potential and ecological dynamics of the applicable ecological site.

This appendix includes brief instructions for developing a reference sheet, as well as a reference sheet checklist, a completed example of the reference sheet, and a blank reference sheet. Instructions for completing the functional/structural groups table in the reference sheet are provided in Appendix 1b.

Before developing or revising a reference sheet, refer to the EDIT (Ecosystem Dynamics Interpretive Tool) website (*https://edit.jornada.nmsu.edu/*) and check with the NRCS state rangeland management specialist to determine if a final or draft reference sheet is available. It may be possible to obtain contributor privileges in EDIT to contribute suggestions or data to improve ecological site descriptions, including reference sheets. The local contact for ecological site description questions or suggestions is usually the NRCS state rangeland management specialist.

- If revisions to an existing reference sheet are necessary, work with the NRCS state rangeland management specialist. Revise the reference sheet following the same protocol as for reference sheet development.
- If an available reference sheet does not include a completed functional/structural groups table, check with the NRCS state rangeland management specialist to determine if one is being developed. This table must be completed according to the instructions in Appendix 1b prior to the assessment. The completed table should then be submitted to the NRCS state rangeland management specialist for incorporation into the reference sheet for the ecological site.
- If a draft reference sheet is available, it may be used to conduct an assessment. Provide comments or suggest modifications to the NRCS state rangeland management specialist, or become a contributor to EDIT. Use the reference sheet checklist/evaluation matrix as a guide to organize input.
- If issues are identified with an existing reference sheet during the field season, make notes of these issues, and send the information and any recommended changes to the NRCS state rangeland management specialist.
- If no reference sheet exists, coordinate with the NRCS state rangeland management specialist using the following steps to develop one and upload it to EDIT.

- If "describing indicators of rangeland health" (DIRH) (Appendix 7) data and information are available, they can be used to assist with development of a reference sheet.

Steps required to develop or revise a reference sheet:

Step 1. Assemble (virtually or in person) a diverse group of experts with extensive knowledge of the ecological site.
Include those who have long-term knowledge of the variability and dynamics of the ecological site across its spatial extent, in addition to rangeland professionals who understand general soil/climate/vegetation relationships.

Step 2. As a group, assemble all available sources of information.
Information should include relevant scientific literature, data from ecological reference areas, and data used to support ecological site descriptions. Inventory and monitoring data, including BLM Assessment, Inventory, and Monitoring (AIM) and NRCS National Resources Inventory (NRI) plots, which are identified by ecological site, are valuable resources for determining variability in plant community composition and may provide other indicator information, such as bare ground and litter amount. Local managers or landowners can be valuable sources of weather information and other local conditions.

Step 3. Define and categorize the functional/structural groups for the ecological site (or equivalent unit).
Review the current reference sheet (if available) to determine the adequacy and accuracy of the existing information. Instructions for completing or revising the functional/structural groups indicator table are in Appendix 1b. Ensure that the crosswalk of species assigned to functional/structural groups is maintained with the reference sheet or metadata (see step 6).

Step 4. Visit one or more ecological reference areas (optional).
Visiting one or more ecological reference areas within an ecological site can be useful for developing or revising a reference sheet (see Section 7.3 Step 3. Collect Supplemental Information). Ecological reference areas may be identified from existing inventory and monitoring sites. For example, AIM and NRI plots are identified by ecological site. Therefore, it may be possible to categorize sites by disturbance and management history to identify potential ecological reference areas. Data and observations from plots that are identified as ecological reference areas can help develop reference sheet descriptions.

Visits to ecological reference areas can be used to field check and refine indicator descriptors developed in the office. Where possible, visit a number of ecological reference areas that represent the community phases found in the reference state (see Figure 4 in Section 5.5 States, Transitions, and Disturbances).

Step 5. Describe the characteristics of each indicator in the reference state.
Using the reference sheet checklist included in this appendix as a guide, describe the status and natural range of variability, including the natural disturbance regime, of each indicator. Refer to the reference sheet checklist for the characteristics that should be described for each indicator. This description becomes the "none to slight" departure category in the evaluation matrix for a particular ecological site. The indicator descriptors should be quantitative, whenever possible, and must include expected ranges based on natural disturbance regimes. Natural disturbances may include, but are not limited to, native insect outbreaks, wildfires, native wildlife activities (herbivory, burrowing, etc.), indigenous human activities, and weather cycles and extremes (including droughts and unusual wet periods, temperatures, and snow and wind events). Ecological site descriptions and soil surveys may provide quantitative values for some indicators. Data availability will change over time and vary across sites/regions.

Ecological sites include a range of soils with similar, but not identical, characteristics. In many cases, the effects of within-site variability in soil texture, soil depth, aspect, slope, etc., on the indicator must be described. For example, concave areas are more likely to receive run-on water, have finer textured soils, and higher annual production potential. For additional information, see Section 5.1 Landscape Context and Section 5.4 Natural Range of Variability.

Step 6. Document the reference sheet development process and data sources. Because reference sheets are revised over time as additional data become available and understanding of ecological processes evolves, it is important to document the process and data used for each version of the reference sheet. This information is also helpful in determining if data being used for an IIRH assessment are comparable to data used in developing the reference sheet.

Cite data or other information used to support the descriptors (e.g., ecological site description). Specify whether plant community composition estimates are based on annual production or foliar cover (check the appropriate box at top of reference sheet). Care must be taken when using various sources for cover values since methods and definitions may differ. For example, older versions of ecological site descriptions may not differentiate between canopy cover and foliar cover or may include small rocks and biological soil crusts in measurements of bare ground. The crosswalk of species assigned to functional/structural groups should be included with this information as well.

If datasets such as AIM and NRI are used, document the dates and locations of the data, as well as the analyses that were conducted to quantify any indicator values for the reference sheet.

REFERENCE SHEET CHECKLIST

This checklist is designed to be used when developing new reference sheets or updating existing ones. The characteristics listed under each indicator should be incorporated into the reference sheet and should include any differences that would occur in the community phases or due to differences resulting from the natural disturbance regimes of the reference state. Additional descriptors or measurements may be used to describe each indicator, based on data availability and ecological site characteristics. Many of the listed characteristics may be described qualitatively based on expert opinion, experience, and observations, particularly those that are difficult to consistently measure in the field. Refer to the Measurements description of each indicator (Sections 7.4.1 through 7.4.17) for additional information about quantifying indicator characteristics.

1. **Rills**
   - ☐ Number of rills per unit area
   - ☐ Length, width, and depth of rills
   - ☐ Association of slope and bare areas with rill occurrence
   - ☐ Disturbance/weather effects on rill formation

2. **Water Flow Patterns**
   - ☐ Number of water flow patterns per unit area
   - ☐ Length and width of water flow patterns
   - ☐ Slope effect on water flow patterns
   - ☐ Disturbance/weather effects on water flow patterns
   - ☐ Extent of erosional/depositional areas associated with water flow patterns
   - ☐ Connectivity of water flow patterns

3. **Pedestals and/or Terracettes**
   - ☐ Number of pedestals and terracettes per unit area
   - ☐ Degree of plant root exposure on pedestals
   - ☐ Slope effect on pedestals and terracettes
   - ☐ Disturbance/weather effects on pedestals and terracettes
   - ☐ Association with landscape position, water flow patterns, or bare soil patches

4. **Bare Ground**
   - ☐ Percent bare ground cover range
   - ☐ Size of bare ground patches
   - ☐ Connectivity of bare ground patches
   - ☐ Maximum bare ground patch size and amount resulting from natural disturbances
   - ☐ Changes in percent bare ground following natural disturbances and weather variability (e.g., droughts, wet periods)

5. **Gullies**
   - ☐ Depth and width of gullies
   - ☐ Slope effect on gullies
   - ☐ Disturbance/weather effects on gully activity
   - ☐ Landscape position
   - ☐ Potential for headcuts
   - ☐ Amount of vegetation on banks and bottoms

6. **Wind-Scoured and/or Depositional Areas**
   - ☐ Proportion of site with wind-scoured and/or depositional areas
   - ☐ Connectivity of wind-scoured areas
   - ☐ Effects of landscape position
   - ☐ Effects of soil surface texture
   - ☐ Effects of natural disturbances and weather
   - ☐ Location of wind-scoured and depositional areas relative to plant canopy

7. **Litter Movement**
   - ☐ Proportion of litter moved
   - ☐ Size of litter moved
   - ☐ Distance of litter movement
   - ☐ Effects of natural disturbances and weather on litter movement
   - ☐ Size and locations of litter accumulations
   - ☐ Association of litter movement with landscape position, microtopography, water flow patterns, or bare areas

8. **Soil Surface Resistance to Erosion**
   - ☐ Expected soil stability ratings
   - ☐ Differences in expected soil stability ratings between perennial plant canopy and interspaces
   - ☐ Differences in expected soil stability ratings based on soil surface texture
   - ☐ Disturbance effects on soil stability

9. **Soil Surface Loss and Degradation (for the characteristics listed below, provide ranges to include all soils correlated to the ecological site)**
   - ☐ Thickness (depth) of surface (A) horizon (and O horizon, if expected)
   - ☐ Soil color of A and B horizons
   - ☐ Soil structure, including number, length, and size diversity of soil pores
   - ☐ Potential for soil deposition following wildfire

10. **Effects of Plant Community Composition and Distribution on Infiltration**
   - ☐ Relative dominance and the effects of changes in functional/structural groups on infiltration
   - ☐ Interaction of slope and vegetation on infiltration
   - ☐ Expected community changes from natural disturbances and weather variability
   - ☐ Spatial distribution of functional/structural groups on site

11. **Compaction Layer**
   - ☐ Extent and distribution of compaction layer
   - ☐ Thickness and density of compaction layer
   - ☐ Soil features that may be mistaken for compaction

12. **Functional/Structural Groups**
   - ☐ Completed functional/structural groups table describing:
     - Expected functional/structural groups
     - Expected number of species in dominant and subdominant groups (including expected number of visible biological soil crust life forms)
     - Expected relative dominance of functional/structural groups for each plant community phase within the natural range of variability/natural disturbance regime
   - ☐ Expected shifts in relative dominance resulting from natural disturbances/weather
   - ☐ Spatial variation in expected number of species in each functional/structural group across the range of the ecological site (if known)
   - ☐ Expected percent cover of visible biological soil crusts

13. Dead or Dying Plants or Plant Parts

- ☐ Proportion of dead or dying plants/plant parts within each functional/structural group (perennials)
- ☐ Size of die-out patches (e.g., from insect damage/disease within natural disturbance regime)
- ☐ Weather and disturbance effect on plant parts and plant mortality

14. Litter Cover and Depth

- ☐ Percent of litter cover range
- ☐ Average litter depth
- ☐ Effect of disturbance, weather, and natural herbivory on litter accumulation

15. Annual Production

- ☐ Expected total annual production ranges (low, representative, and high)
- ☐ Effect of natural disturbances and weather on production

16. Invasive Plants

- ☐ List of invasive species with the potential to become a dominant or codominant species on the site if their establishment and growth is not actively controlled by management interventions (consult the state noxious weeds list for potential invasive species on each ecological site)
- ☐ Effect of disturbance and weather on susceptibility to plant invasion
- ☐ Composition of native invasive plants (if any) expected to occur under the natural disturbance regime within the natural range of variability

17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants

- ☐ Proportion of reproductive plants by perennial plant functional/structural group
- ☐ Effect of recent weather and disturbance(s) on vigor and reproductive capability of perennial plants
- ☐ Appropriate metrics for expected perennial plants for the ecological site (see Measurements description under Section 7.4.17)

EXAMPLE OF COMPLETED REFERENCE SHEET

INTERPRETING INDICATORS OF RANGELAND HEALTH, Version 5, REFERENCE SHEET

Ecological site name: Loamy 12-16" p.z. Ecological site code: R010XY019ID

Author(s)/participant(s): J. Thompson

Contact for lead author: stateRMS@nrcs.gov (555) 555-1234

Date: 3/12/2011 MLRA: 10 LRU: XY

Composition based on (check one): ☐ Cover ☒ Annual Production

Metadata storage location: Contact lead author or NRCS Idaho state conservationist's office

Indicators. For each indicator, describe the potential for the site using the reference sheet checklist. Where possible, (1) use quantitative measurements; (2) include expected range of values for above- and below-average years and natural disturbance regimes for each community phase within the reference state, when appropriate; and (3) cite data sources used. Continue descriptions on separate sheet.
1. Rills: Rills are not expected on this site, except 1-2 years after wildfire or multiyear droughts. Following these events, shallow rills < 1 m in length may develop on slopes > 10%.
2. Water flow patterns: Water flow patterns rarely occur on this site on slopes < 5%. On slopes > 5%, narrow (< 12"), short (1-5' long), and disconnected water flow patterns may occur following high precipitation storms, affecting < 20% of the site. Water flow patterns occurring on > 5% slopes may nearly double in length, width, and connectivity for 1-3 years following wildfire or after multiyear droughts.
3. Pedestals and/or terracettes: Neither pedestals nor terracettes are expected to occur on slopes < 10%, except for 1-2 years following wildfires or multiyear droughts. Occasional pedestals may occur around bunchgrasses in shrub interspaces on slopes > 10% in association with water flow patterns.
4. Bare ground: Bare ground ranges from 15-20%. Bare ground patches should be small (< 12" diameter) and not connected. Bare ground may increase to as much as 30% 1-3 years after wildfire, and bare soil patches may be up to 24" in diameter. Animal activity (burrows and ant mounds) may occasionally result in isolated bare patches up to 5' in diameter.
5. Gullies: Gullies do not occur on this site.
6. Wind-scoured and/or depositional areas: Wind-scoured areas do not occur on this site. Occasionally, thin, isolated soil deposits may be observed under shrubs, affecting < 5% of the site.
7. Litter movement: On slopes < 5%, fine litter is expected to move less than 6", and coarse litter does not move. On slopes > 5%, as much as half of the fine litter falling in the interspaces may move up to 12", but coarse litter generally does not move. Litter accumulations, if any, are small and usually occur at the bases of perennial bunchgrasses in the shrub interspaces on slopes > 5%. Litter dams are not expected.
8. Soil surface resistance to erosion: Stability class ratings from the soil stability test should be > 4.5 overall, with ratings of 4 or greater in the interspaces and 5 or greater under perennial plant canopy. Finer textured soils within this ecological site are expected to have overall ratings of > 5. Soil stability may temporarily decline up to 1 category following wildfire, due to decreases in biotic soil crusts and organic matter.
9. Soil surface loss and degradation: The surface horizon (A) should be 6-10" (roots growing throughout) with a moderate, very fine granular structure and a diversity of soil pores throughout. The subsurface (B) horizon is friable; structure is medium subangular blocky. The surface (A) horizon color is 7.5YR 3/2 (moist), and the subsurface (B) horizon color is 10YR 4/3 (moist).
10. Effects of plant community composition and distribution on infiltration: Deep-rooted perennial bunchgrasses are dominant, nonsprouting shrubs are subdominant, and perennial forbs are a minor component. Following wildfire (1-5 years), deep-rooted perennial grasses dominate, with a subdominant component of perennial forbs. For the first year following wildfire or a multiyear drought, infiltration will be slightly reduced due to lack of ground cover. After 1 year following the preceding disturbances, deep-rooted perennial bunchgrasses and shrubs are again distributed evenly to provide sufficient ground cover to catch snow and increase infiltration. These processes are particularly important on slopes > 10%, where runoff has the potential to increase in the absence of well-distributed perennial grasses.

11. Compaction layer: No compaction layers occur naturally on this site. No natural soil features that may be confused with a compaction layer occur on this site.

12. Functional/structural groups: The site is dominated by perennial grasses and nonsprouting shrubs, depending on the time since fire. Nonsprouting shrubs may become dominant 15-30 years post-fire. Following wildfire, nonsprouting shrubs are greatly reduced, and perennial forbs become a subdominant component. Expected diversity of perennial forbs is higher at the upper end of the precipitation range for this site (> 5 species). The expected fire return interval across which the three phases develop is 15-30 years.

Dominance Category[1]	**Relative Dominance of F/S Groups for Community Phases in the Reference State** *Minimum expected number of species for dominant and subdominant groups is included in parentheses.*		
	Dominance based on[1]: Annual Production X or Foliar Cover __		
	Phase 1.1 (5-15 years post-fire)	**Phase 1.2** (1-5 years post-fire)	**Phase 1.3** (15-30+ years post-fire)
Dominant	Cool-season, deep-rooted perennial bunchgrasses (4)	Cool-season, deep-rooted perennial bunchgrasses (4)	Nonsprouting shrubs (2)
Subdominant	None	Perennial forbs (3)	Cool-season, deep-rooted perennial bunchgrasses (4)
Minor	Nonsprouting shrubs; sprouting shrubs; cool-season, shallow-rooted perennial bunchgrasses	Sprouting shrubs; cool-season, shallow-rooted perennial bunchgrasses	Perennial forbs; cool-season, shallow-rooted perennial bunchgrasses; biological soil crusts[1]
Trace	Perennial forbs; biological soil crusts[1]	Nonsprouting shrubs; biological soil crusts[1]	Sprouting shrubs; evergreen trees[2]

[1] Biological soil crust dominance is determined based on cover, rather than production. If biological soil crusts are an expected dominant or subdominant group, the number of expected life forms (e.g., lichen, moss) is listed, rather than number of individual species.

[2] May not occur on the site.

13. Dead or dying plants or plant parts: A few (< 10%) dead centers naturally occur in bunchgrasses and will increase to 15% following a multiyear drought. Nonsprouting shrubs may have up to 10% dead branches as plants age, usually occurring in community phase 1.1. Sagebrush may have a large increase in dead branches with moderate mortality in patches up to 3 acres as a result of Aroga moth infestation.

14. Litter cover and depth: Total litter cover is expected to be 20-30% and at a depth of 0.25-0.5 inches under shrubs and < 0.1 inches under grass canopy. Litter may be reduced to 10-20% in cover and near zero depth for 1-2 years following wildfire or multiyear drought.

15. Annual production: Annual production is 1,100 pounds per acre in a year with normal precipitation and temperatures. Low and high production years should yield 850 and 1,400 pounds per acre, respectively. Annual production may be reduced by 40-60% the first year following a wildfire or following a multiyear drought. Annual production may increase for 3-6 years following wildfire due to perennial bunchgrass response.

16. Invasive plants: Western juniper, cheatgrass, medusahead, spotted knapweed, and rush skeletonweed. Western juniper may occur in trace amounts in community 1.3 but has the potential to increase to a subdominant or dominant in the absence of wildfire and act as an invasive on this site. Other than western juniper, the listed invasives are not expected to occur in the reference state. The site has increased susceptibility to invasion by rush skeletonweed, spotted knapweed, and exotic annual grasses following wildfire.

17. Vigor with an emphasis on reproductive capability of perennial plants: Plants in all functional/structural groups should be capable of reproducing annually under normal weather conditions. Vigorous mature cool-season, deep-rooted perennial grasses typically have a basal diameter of > 10 cm. Vigor and reproductive capability may be somewhat reduced during drought or for 1 year following a wildfire. At least 50% of plants should still have reproductive capability during droughts that last 1-2 years.

INTERPRETING INDICATORS OF RANGELAND HEALTH, Version 5, REFERENCE SHEET

Ecological site name: ________________________________ Ecological site code: ____________________

Author(s)/participant(s): ____

Contact for lead author: ____

Date: ________________________ MLRA:________________________ LRU: ________________________

Composition based on (check one): ☐ Cover ☐ Annual Production

Metadata storage location: ____

Indicators. For each indicator, describe the potential for the site using the reference sheet checklist. Where possible, (1) use quantitative measurements; (2) include expected range of values for above- and below-average years and natural disturbance regimes for each community phase within the reference state, when appropriate; and (3) cite data sources used. Continue descriptions on separate sheet.
1. Rills:
2. Water flow patterns:
3. Pedestals and/or terracettes:
4. Bare ground:
5. Gullies:
6. Wind-scoured and/or depositional areas:
7. Litter movement:
8. Soil surface resistance to erosion:
9. Soil surface loss and degradation:
10. Effects of plant community composition and distribution on infiltration:
11. Compaction layer:

12. Functional/structural groups:			
Dominance Category[1]	**Relative Dominance of F/S Groups for Community Phases in the Reference State** *Minimum expected number of species for dominant and subdominant groups is included in parentheses.*		
	Dominance based on[1]: Annual Production __ or Foliar Cover __		
	Phase 1. __	**Phase 1. __**	**Phase 1. __**
Dominant			
Subdominant			
Minor			
Trace			

[1] Biological soil crust dominance is determined based on cover, rather than production. If biological soil crusts are an expected dominant or subdominant group, the number of expected life forms (e.g., lichen, moss) is listed, rather than number of individual species.

13. Dead or dying plants or plant parts:

14. Litter cover and depth:

15. Annual production:

16. Invasive plants:

17. Vigor with an emphasis on reproductive capability of perennial plants:

Appendix 1b. Completing the Functional/ Structural Groups Table in the Reference Sheet

Completing the functional/structural (F/S) groups table in the reference sheet is part of the process of developing or updating reference sheets. The F/S groups table is new to Version 5 of IIRH. This appendix provides detailed instructions for completing the F/S groups table.

The F/S groups table lists the expected F/S groups, by relative dominance category for each community phase that occurs within the natural disturbance regime within the natural range of variability for an ecological site. The table also indicates the minimum number of species expected within the dominant and subdominant F/S groups for each community phase that occurs within the natural disturbance regime of the reference state. This information is used to identify shifts in the expected relative dominance of F/S groups, loss of expected F/S groups, and reductions in number of species expected in dominant and subdominant F/S groups when rating indicator 12. The table may be completed using existing ecological site descriptions (ESDs) and reference sheets if they contain the necessary information. Scientific literature, relevant datasets, and local knowledge of disturbance regimes and vegetation recovery may also be used to complete this table. Appendix 1a provides an example of a completed F/S groups table.

Step 1. List the community phases that occur within the natural disturbance regime within the natural range of variability for the ecological site.

Assign each identified community phase to a column in the F/S groups table. A brief description of the disturbance (e.g., time since fire) associated with each phase may also be listed. Add or delete columns as needed based on the number of community phases expected for the ecological site.

Some ESDs only contain a single community phase within the reference state. This may be because the ESD does not reflect the natural range of variability in the vegetation community, or it may be an accurate reflection of a vegetation community that is characterized by one distinct community phase within the reference state. In both cases, only one phase is described in the F/S groups table. If additional community phases in the reference state are identified for an ecological site and incorporated into the ESD, the reference sheet should be updated to include the additional phase(s).

Step 2. Identify F/S groups and associated species expected for the site.

Refer to the state-and-transition model, narrative, and plant composition data from the ESD to determine the appropriate F/S groups for the site. All species included in the composition data in the ESD should be assigned to a F/S group. Documentation of these assignments can be attached to the reference sheet or incorporated into the ESD composition data table(s).

F/S groups should be sensitive to the described vegetation community dynamics both within the reference state (community phases and pathways) and transitions to alternate states. Therefore, the F/S groups used for the reference sheet are not standardized and it will usually be necessary to subdivide any groupings provided in the ESD composition data. For example, a grassland ESD may group all warm-season grasses together in the species composition data. However, if community phases are differentiated by shifts between short-, mid-, and tall-statured warm-season grasses, this should be taken into consideration when defining the F/S groups.

If a reference sheet is available for the ecological site, the narrative for indicator 12 may provide a preliminary list of F/S groups for the ecological site.

If the ESD and existing reference sheet do not provide initial F/S groups, first group the plant species by lifeform (e.g., trees, vines, shrubs, grasses, forbs, and lichen/moss) and life cycle (annual or perennial). Further subdivision may be useful using height groups, vegetative spread (e.g., bunchgrass versus rhizome/stolons), or root structure (e.g., tap versus fibrous). Next, consider further subdivision of groups based on important physiological functions within the plant community. Physiological functions might include photosynthetic pathways (C3, C4, and CAM), nitrogen fixation, sprouting ability, etc.

Once the F/S groups are identified, determine the appropriate F/S group for each species listed in the composition information for the ESD. The final species groupings should be attached as supporting documentation or incorporated into the composition data section in the ESD.

When biological soil crusts are an expected part of the reference community phases, their dominance is determined by cover, and the life forms categories (moss and lichen, algae, and cyanobacteria) are used, rather than listing individual species. In many cases, these life forms will collectively form a single F/S group, but in some ecological sites, it may be appropriate to separate them into two or more F/S groups (e.g., moss and lichen F/S groups). Note that mosses and lichens are most frequently recorded by cover data because they are easily observed, whereas algae and cyanobacteria can be difficult to detect because of their size (measurements require methods other than standard cover techniques).

Step 3. Describe the expected relative dominance of F/S groups for each community phase.
Dominance should be based on the same metrics reported in the ESD (foliar cover or annual production), and metrics used should be documented in the F/S groups table.

The level of detail of vegetation composition data varies across ESDs. Some ESDs provide species composition data for more than one community phase within the reference state for the ecological site. This information can be used to determine the F/S groups that are expected to be dominant, subdominant, minor, or trace components within each reference state community phase.

However, many ESDs and range site descriptions (the predecessor to ESDs) only have data for one plant community phase (e.g., the "historic climax plant community"). When composition data are only available for the historic climax plant community, but the state-and-transition model describes multiple plant community phases, infer the expected relative dominance from the ESD narrative and state-and-transition model, and transfer the expected composition data to the remaining reference community phases.

For each community phase, record the expected dominant, subdominant, minor, and trace F/S group(s) in the respective fields in the table using the following guidelines:

- Calculate the relative abundance of each F/S group by dividing the cover or annual production of each group by the total cover or annual production in the same community phase, and then multiply by 100 to calculate the percent composition.
- Next, organize the groups by percent composition and assign each one to the appropriate relative dominance category. More than one F/S group may be assigned to each relative dominance category in a community phase.
- Differences of approximately 10% composition may be used to separate dominant from subdominant groups and subdominant from minor or trace groups.

- The minor or trace groups are likely to be separated by less than 10% composition.
- Each trace group generally is less than 1% composition.

These F/S groups that may, but are not always expected to occur across the range of a given ecological site are not included when calculating the number of expected groups for subindicator 12c in the F/S groups worksheet. List these groups, and provide a footnote to the table indicating that they are not always expected to be present across the ecological site.

Step 4. Determine the minimum number of species for dominant and subdominant groups in each phase.
List the minimum number of species expected for each F/S group that is included as an expected dominant or subdominant group in each community phase. Typically, within an F/S group, all species with expected production of ≥ 1 pound per acre will be counted. However, expert knowledge should also be used to generate these numbers.

If additional information is available about the species expected to occur across the spatial range of variability for the ecological site (e.g., higher numbers of forb species are expected in upper elevations of the ecological site), describe it in the narrative section of the reference sheet for indicator 12. Any footnotes about how these numbers were derived should be included at the bottom of the table.

Appendix 2. Generic Evaluation Matrix and Instructions for Developing an Ecological Site-Specific Matrix

	Departure from Reference Sheet				
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
1. Rills	Numerous and frequent throughout. Nearly all are wide, deep, and long. Occur in exposed and vegetated areas.	Moderate in number at frequent intervals. Many are wide, deep, and long. Occur in exposed areas and in some adjacent vegetated areas.	Moderate in number at infrequent intervals. Moderate width, depth, and length. Occur mostly in exposed areas.	Scarce and scattered. Minimal width, depth, and length. Occur in exposed areas.	Reference sheet narrative inserted here.
2. Water Flow Patterns	Extensive. Long and wide. Erosional and/or depositional areas widespread. Usually connected.	Widespread. Longer and wider than expected. Erosional and/or depositional areas common. Occasionally connected.	Common. Lengths and/or widths slightly to moderately higher than expected. Minor erosional and/or depositional areas. Infrequently connected.	Scarce. Length and width nearly match expected. Some minor erosional and/or depositional areas. Rarely connected.	Reference sheet narrative inserted here.
3. Pedestals and/or Terracettes	Pedestals extensive; roots frequently exposed. Terracettes widespread.	Pedestals widespread; roots commonly exposed. Terracettes common.	Pedestals common; roots occasionally exposed. Terracettes uncommon.	Pedestals uncommon; roots rarely exposed. Terracettes scarce.	Reference sheet narrative inserted here.
4. Bare Ground	Substantially higher than expected. Bare ground patches are large and frequently connected.	Much higher than expected. Bare ground patches are large and occasionally connected.	Moderately higher than expected. Bare ground patches are moderate in size and sporadically connected.	Slightly higher than expected. Bare ground patches are small and rarely connected.	Reference sheet narrative inserted here.

Departure from Reference Sheet					
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
5. Gullies	Sporadic or no vegetation on banks and/or bottom. Numerous nickpoints. Significant active bank and bottom erosion, including downcutting. Substantial depth and/or width. Active headcut(s) may be present.	Intermittent vegetation on banks and/or bottom. Nickpoints common. Moderate active bank and bottom erosion, including downcutting. Significant depth and/or width. Active headcut(s) may be present.	Occasional vegetation on banks and/or bottom. Occasional nickpoints and/or slight downcutting. Moderate depth and/or width. Active headcuts absent.	Vegetation on most banks and/or bottom. Few nickpoints and/or minimal downcutting. Minimal gully depth and/or width. Headcuts absent.	Reference sheet narrative inserted here.
6. Wind-Scoured and/or Depositional Areas	Extensive. Wind scours usually connected. Large soil depositions around obstructions.	Common. Wind scours frequently connected. Moderate soil depositions around obstructions.	Occasionally present. Wind scours infrequently connected. Minor soil depositions around obstructions.	Infrequent and few. Wind scours rarely connected. Trace amounts of soil deposition around obstructions.	Reference sheet narrative inserted here.
7. Litter Movement (Wind or Water)	Extreme movement of all size classes (including large). Significant accumulations around obstructions or in depressions.	Moderate to extreme movement of small to moderate size classes. Moderate accumulations around obstructions or in depressions.	Moderate movement of mostly small size classes. Small accumulations around obstructions or in depressions.	Slight movement of small size classes. Minimal or no accumulations around obstructions or in depressions.	Reference sheet narrative inserted here.
8. Soil Surface Resistance to Erosion	Extremely reduced throughout.	Significantly reduced in most interspaces or plant canopies and moderately reduced throughout.	Significantly reduced in at least half of plant interspaces or plant canopies or moderately reduced throughout.	Some reduction in plant interspaces or plant canopies or slightly reduced throughout.	Reference sheet narrative inserted here.

Departure from Reference Sheet					
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
9. Soil Surface Loss and Degradation	Soil surface horizon very thin to absent throughout. Soil surface structure similar to or more degraded than subsurface. No distinguishable difference between surface and subsurface organic matter content.	Severe soil loss or degradation throughout. Minor differences in soil organic matter content and structure between surface and subsurface layers.	Moderate soil loss or degradation in plant interspaces with some degradation beneath plant canopies. Soil organic matter content is markedly reduced.	Slight soil loss or degradation, especially in plant interspaces. Minor change in soil organic matter content.	Reference sheet narrative inserted here.
10. Effects of Plant Community Composition and Distribution on Infiltration	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in a severe reduction in infiltration.	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in greatly decreased infiltration.	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in a moderate reduction in infiltration.	Changes in plant community (functional/ structural groups) composition and/ or distribution are expected to result in a slight reduction in infiltration.	Reference sheet narrative inserted here.
11. Compaction Layer	Extensive and/ or strongly developed (thickness and density); may severely restrict root penetration.	Widespread and/ or moderately to strongly developed (thickness and density); may greatly restrict root penetration.	Moderately widespread and/ or moderately developed (thickness and density); may moderately restrict root penetration.	Not widespread and/or weakly developed (thickness and density); may weakly restrict root penetration.	Reference sheet narrative inserted here.

[1] For the appropriate reference community phase.

Departure from Reference Sheet					
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
12. Functional/ Structural (F/S) Groups	Indicator rating is based on the greatest departure of the four subindicators.				
12a. Relative dominance	All expected dominant F/S groups are now minor, trace, or missing.	Dominant F/S group(s) has become minor or trace, or a minor or trace group is now dominant.	Dominant F/S group(s) has become subdominant.	Subdominant F/S group(s) has become minor or trace, or minor or trace F/S group(s) has become subdominant.	Resembles expected relative dominance.[1]
12b. F/S groups not expected	F/S group(s) not expected is now dominant.	F/S group(s) not expected is now subdominant.	F/S group(s) not expected is now minor.	F/S group(s) not expected is now trace.	None.
12c. Number of expected F/S groups[2]	Severely reduced (missing ≥ 76% of expected F/S groups).	Greatly reduced (missing 51-75% of expected F/S groups).	Moderately reduced (missing 26-50% of expected F/S groups).	Slightly reduced (missing ≤ 25% of expected F/S groups).	All expected F/S groups are present.[1]
12d. Total combined number of species expected in dominant and subdominant F/S groups	Severely reduced (missing ≥ 76%).	Greatly reduced (missing 51-75%).	Moderately reduced (missing 26-50%).	Slightly reduced (missing 10-25%).	Missing less than 10% of expected number of species in dominant and subdominant F/S groups.[1]
13. Dead or Dying Plants or Plant Parts (dominant, subdominant, and minor functional/ structural groups)	Extensive mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Widespread mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Moderate mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Occasional mortality and/ or dying plants/ plant parts in species within expected functional/ structural group(s).	Reference sheet narrative inserted here.
14. Litter Cover and Depth	Largely absent with minimal depth or extensive with much greater depth relative to site potential and recent weather.	Greatly reduced or greatly increased cover and/or depth relative to site potential and recent weather.	Moderately more or less cover and/ or depth relative to site potential and recent weather.	Slightly more or less cover and/or depth relative to site potential and recent weather.	Reference sheet narrative inserted here.

[1] For the appropriate reference community phase.

[2] Must be functionally present

Departure from Reference Sheet					
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
15. Annual Production	20% or less of potential production based on recent weather.	21-40% of potential production based on recent weather.	41-60% of potential production based on recent weather.	61-80% of potential production based on recent weather.	Reference sheet narrative inserted here (annual production > 80% of potential).
16. Invasive Plants	Dominant throughout.	Common throughout.	Scattered throughout.	Uncommon.	Nonnative invasive plants not present. If native invasive species are present, composition matches that expected for the ecological site.
17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants (dominant, subdominant, and minor functional/structural groups)	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/structural group(s) are extremely reduced, or functional/structural group(s) is no longer functionally present.	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/structural group(s) are greatly reduced.	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/structural group(s) are moderately reduced.	Vigor and capability to produce seed or vegetative tillers in species within the expected functional/structural group(s) are slightly reduced.	Reference sheet narrative inserted here.

Instructions for developing an ecological site-specific evaluation matrix

The generic evaluation matrix can be used to conduct an IIRH assessment. Obtaining or developing an ecological site-specific matrix for each ecological site can more accurately describe the possible range of variation for each indicator compared to the generic evaluation matrix. Similar to developing reference sheets, an ecological site-specific evaluation matrix is best developed by a team of experts with local expertise to incorporate spatial and disturbance variation information. See Table 4 in Section 7.2.2 for an example of an ecological site-specific evaluation matrix for the bare ground indicator. Note that the generic evaluation matrix descriptors for indicators 12 (functional/structural groups) and 15 (annual production) should not be modified.

1. For each indicator, copy text from the reference sheet into the "none to slight" box.

2. Write a descriptor for "extreme to total" departure for each indicator. Extreme is defined as a departure from the narrative found in the "none to slight" box that characterizes an extremely degraded condition for that indicator. Departure descriptors should be based on many of the same elements found in the reference sheet checklist (Appendix 1a). "Extreme to total" departure would describe the worst possible situation for the indicator. The range included in this departure category varies among ecological sites and is relative to disturbance events. For example, in a tallgrass prairie site (40 inches annual precipitation), the "extreme to total" departure descriptor for bare ground might be "exceeds 70% bare ground immediately following fire." In a nongravelly Mojave Desert site (less than 6 inches annual precipitation), the "extreme to total" departure descriptor might be "95–100% bare ground."

3. Write or modify descriptors for "slight to moderate," "moderate," and "moderate to extreme." Keep in mind that both the magnitude of change and the shape of the departure curve may be dissimilar for different indicators on the same ecological site or the same indicator on different sites. Most indicator descriptors in the generic evaluation matrix assume an approximately linear relationship among departure categories and a similar proportion of change from the "none to slight" description, which is likely an inaccurate assumption for some of the indicators. Therefore, the change relationship and shape of the departure curve, if known, need to be considered and incorporated into the ecological site-specific evaluation matrix. Research identifying ecological thresholds relating to indicators, such as bare ground, may be used to inform the departure categories.

4. Indicators associated with soil/site stability are likely to require more deliberation due to the inherently higher erosion potential on certain ecological sites. Table 4 in Section 7.2.2 provides an example evaluation matrix with ecological site-specific departure descriptors of bare ground for the Limy ecological site in Major Land Resource Area 42 (south-central New Mexico). A similar approach can be taken when revising other indicators. An ecological site-specific evaluation matrix should be developed for ecological sites where departure categories are not a good match for the descriptors in the generic evaluation matrix (see discussion in Section 7.2.2 Obtain an Evaluation Matrix) (Required)).

Appendix 3. Checklists for the IIRH Protocol

	IIRH Tasks Workflow/Checklist*	√
Before going to the field	Identify evaluator(s).	
	Select evaluation area(s).	
	Assemble soils information and ecological site description(s).	
	Obtain or develop reference sheet(s).	
	Obtain or develop ecological site-specific evaluation matrix.	
	If reference sheet is not available, develop one using Appendix 1a and 1b before continuing.	
	Use the reference sheet checklist (Appendix 1a) to review current reference sheets for completeness.	
	Gather available information about management actions, disturbance history, and recent weather at evaluation areas (fire history, vegetation treatments, precipitation records, etc.).	
	Identify and visit ecological reference areas.	
At the evaluation area	Delineate evaluation area.	
	Determine the ecological site.	
	Complete first page of evaluation sheet (Appendix 4).	
	Evaluator(s) independently observes conditions throughout the evaluation area.	
	Test soil stability and record results on page 2 of the evaluation sheet.	
	Measure or estimate annual production and record on page 2 of the evaluation sheet.	
	Collect additional quantitative data and take photos (list any additional methods):	
	Identify the reference phase that best fits the evaluation area based on disturbance history.	
	List plant species in the evaluation area using the functional/structural groups worksheet.	
	Document the relative dominance of functional/structural groups for the evaluation area on the functional/structural groups worksheet or page 2 of the evaluation sheet.	
	Rate the 17 indicators. Include written observations and rationale for all ratings in the evaluation sheet.	
	Rate the 3 attributes of rangeland health based on the ratings of the 17 indicators; provide written rationale for the ratings.	

* Specific tasks will vary depending on project objectives and protocols.

Checklist of IIRH References, Field Equipment, and Forms*	√
References	
Ecological site description (including reference sheet)	
Soil survey information for the general evaluation area	
Copy of "Interpreting Indicators of Rangeland Health," Version 5	
"Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems," Volume 1, Second Edition (or other appropriate quantitative methods manuals)	
Noxious weed and sensitive species lists	
Appropriate supplemental information (disturbance history, land treatments, weather, management actions)	
Equipment	
Soil stability kit and deionized water	
Transect tape(s), monitoring multitool, and pin flags	
Shovel/sharpshooter spade/soil auger	
Annual production hoops (9.6 sq ft, 0.01 acre, and 0.1 acre), paper bags, rubber bands, gram scale(s), compass, and clippers	
Colored flagging or pins to mark evaluation area perimeter or clip plots	
Camera and photocard	
Clipboard and pencils	
Water for soil texturing, hydrochloric acid, soil color reference, soil sieves, and tape measure	
Forms	
Reference sheet	
Evaluation sheet	
Evaluation matrix	
Functional/structural groups worksheet	
IIRH Field Form for Estimating Annual Production	
Soil stability data sheets	
Line point intercept and gap intercept data sheets	
Describing indicators of rangeland health matrix	

* Specific references, equipment, and forms will vary depending on project objectives and protocols. Blanks are provided for additional items that may be needed for specific projects.

Appendix 4. Evaluation Sheet, Including Functional/Structural Groups Worksheet, and Instructions

Use page 1 of the evaluation sheet to document the ecological site and reference sheet used, characterize the site, and document supplemental information used in the assessment, as needed, based on agency or user documentation requirements, user experience, and application. Use page 2 of the evaluation sheet to rate and record observations of the indicators, rate the attributes, and provide justifications.

Completing Page 1 of the Evaluation Sheet

Figure A4.1 illustrates the generic landscape units that may be used to describe topographic position of the evaluation area. A step-by-step process to determine the ecological site at an evaluation area is described in Appendix 5. Appendix 6 provides additional reference materials for describing and hand-texturing soils.

Soil and topographic features that are important to soil/plant/air/water relationships are included on page 1 of the evaluation sheet; these characteristics assist with understanding and interpreting site potential of the evaluation area relative to the ecological site. Record soil details from the ecological site description (if it includes sufficient information) or the soil survey map unit component and soil series (for surface horizon soil color). Using observations from the evaluation area's soil pit(s), complete the evaluation area portion of the "Ecological Site Determination" section. Compare the "soil and site reference description" and the "evaluation area soil and site characterization" to determine if the evaluation area's soils fit the description for the soils associated with the ecological site.

In the "Evaluation Area Location" section of the evaluation sheet, document the size and location of the evaluation area.

Document supplemental information, to better understand and interpret observed conditions in the evaluation area. Supplemental information includes the following:

- Recent weather, particularly the last 2 years' precipitation (required).
- Known disturbance history, such as fires (required).
- Any known land treatments that have been applied in the area, such as mechanical and herbicide treatments, seedings, or prescribed fire (required).
- Evidence of livestock and wildlife use, recreation, or other land uses/management information that may affect ecological processes.
- Offsite influences that may affect ecological processes within the evaluation area. Offsite influences can include the topographic position of the evaluation area, adjacent roads, trails, watering points, gullies, and others. Consider the topographic position when documenting the potential offsite influences that may impact the evaluation area.

Page 1 of the evaluation sheet is also used to document:

- Whether photos were taken (recommended).
- Types of quantitative data collected to assist with the assessment process.
- The reference community phase used for the evaluation.
- Expected relative dominance of functional/structural groups in the reference community phase, if the functional/structural groups worksheet is not used for the assessment.

Once the ecological site has been determined and a reference sheet has been obtained, record the reference sheet documentation used for the assessment at the top of page 1. An example of a completed page 1 of the evaluation sheet is shown in Figure A4.2.

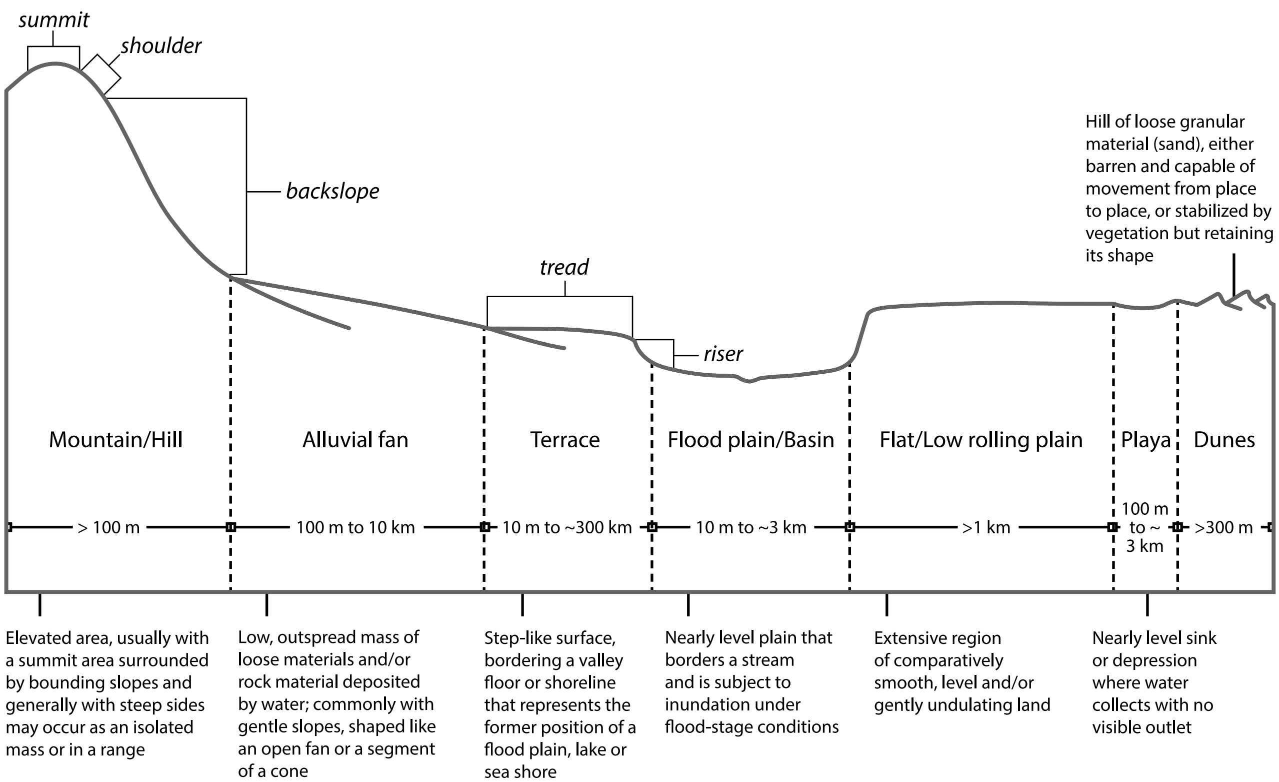


Figure A4.1. Generic landscape units (mountain/hill, alluvial fan, terrace, floodplain/basin, flat/low rolling plain, playa, dunes) to describe topographic position (Herrick et al. 2017).

INTERPRETING INDICATORS OF RANGELAND HEALTH VERSION 5 EVALUATION FORM – PAGE 1

Complete the following information as necessary for project documentation and assessment purposes.

Evaluation area name or ID: Big Sage CM 14		Date: 8/14/2018
Management unit: Cow Creek Allotment	State: ID	Office: Sand Hill FO
Evaluator(s): A. Smith, B. Jones, C. Carter		

Ecological Site/Reference Sheet Used for Evaluation ***(Complete this section last)***

Ecological site name: Loamy 13-16"	Ecological site ID: R025XY011ID
Reference sheet used/authors: Attachment to provisional ESD/J. Thompson	Date: 3/12/2011
Soil component: Vitale	Composition based on (check one): Cover ☐ Annual Production ☒

Ecological Site Determination ***(Describe reference on the left and observations of the evaluation area on the right.)***

Soil Survey: Owyhee County	Soil Map Unit: 193
Soil and site reference description Description Source: Ecological Site Description OR (Soil Survey)	**Evaluation area soil and site characterization**
Parent material: Alluvium / Slope range: 5-40 %	Parent material: Alluvium / Slope: 18 %
Elevation range: 1,700-2,100 ft / (m) / Aspect (if specified):	Elevation: 1,910 ft / (m) / Aspect: northwest
Topographic position: Side slopes	Topographic position: Side slope
Precipitation range: 33-46 in / (cm)	Average annual precipitation: 40 in / (cm)
Seasonal precipitation distribution:	Seasonal precipitation distribution:
Soil depth[1]: Very shallow ☐ Shallow ☒ Moderate ☐ Deep ☐ Very deep ☐	Pit depth: 70 in / (cm)

Type and depth of diagnostic horizons: in / (cm)					**Type and depth of diagnostic horizons:** in / (cm)				
Soil horizon	Depth	Texture	Eff [2]	Other	Soil horizon	Depth	Texture	Eff [2]	Other
A	0-8	Very stony loam			A	0-5	Stony loam	NE	10yr 4/2 moist
B1	8-40	V. gravelly sandy loam			B1	5-35	V. gravelly sandy loam	VS	
B2	40-71	V. cobbly clay loam			B2	35-60	V. cobbly clay loam		estimate 30% clay
B3	71-86	Extremely cobbly loam			B3	60-70	Extremely cobbly loam		

Evaluation Area Location

Criteria used to select evaluation area: Randomized sampling

Location description/directions: Approximately 300 meters north from county road and 150 meters west of Cow Creek drainage in pasture 3 of Cow Creek allotment.

Size of evaluation area: 0.7 acre		UTM Zone: 11 Datum: NAD 83		Position by GPS? (Yes) / No
Township Range	OR	UTM E 692990.65 m	OR	N. Latitude
Section 1/4 Section		N 26770633982.74 m		W. Longitude

Supplemental Information & Reference Community Phase

Recent weather (last 2 years): drought ☐ normal ☒ wet ☐

Natural disturbance type(s) and date(s): Wildfire burned this area 15 years ago (2004).

Land treatment type(s) and date(s): No treatment records were found, but evaluation area is probably part of a shrub control (herbicide) project completed in 1960's, per grazing permittee.

Wildlife, livestock, recreation, or other uses: Grazed by cattle in April and May this year. Some off-road OHV travel occurring adjacent to evaluation area. Jackrabbit and sage-grouse sign observed on evaluation area.

Offsite influences: Evaluation area may receive runoff & weed seeds from adjacent road.

Photos taken? (Yes) / No | Quantitative data collected: Line point intercept, soil stability

F/S groups worksheet completed? (**Yes**) (attach worksheet) **No** (document expected relative dominance on next line)

Reference community phase/description[3]: 1.1

[1] Depth classes: Very shallow < 25 cm; Shallow 25-50 cm; Moderate 50-100 cm; Deep 100-150 cm; Very Deep > 150 cm

[2] Soil effervescence (Eff) codes: NE – non-eff.; VS – very slightly eff.; SL – slightly eff.; ST – strongly eff.; V – violently eff.

[3] If F/S worksheet is not completed, describe expected reference community F/S groups' relative dominance in this field.

Figure A4.2. Example of a completed page 1 of the evaluation sheet.

Completing Page 2 of the Evaluation Sheet

Record indicator ratings and observations and overall attribute ratings and justifications on page 2 of the evaluation sheet. Figure A4.3 provides a completed example of page 2 of the evaluation sheet.

- For each indicator, record the departure rating in the corresponding blank cell. Standardized abbreviations for departure ratings are provided at the top of page 2.
- Write notes supporting each indicator rating in the comments section.

Use of the functional/structural groups worksheet is strongly recommended to support the rating for indicator 12. Detailed instructions for completing this worksheet are provided in this appendix.

Once all 17 indicators have been rated, summarize ratings in the three charts at the bottom of the evaluation sheet, which are used for rating the three attributes. There is one chart, rating box, and rationale space for each attribute. The letters S, H, or B found in the rating column for each indicator identify the attribute(s) to which each indicator is related. For example, bare ground is related to soil/site stability (S) and hydrologic function (H), while annual production is related to biotic integrity (B).

- Populate each attribute's chart by identifying the indicators related to that attribute and writing the indicator number in the appropriate departure category column within the chart. Work from the bottom up to create a histogram of the indicator departure ratings related to the attribute.
- Once the charts have been populated for each of the three attributes, review the indicator departure patterns of each attribute. Use a preponderance of evidence approach to assign a departure rating for each attribute (see Section 7.5).
- To the right of each chart, provide a short rationale for the attribute rating.

A blank evaluation sheet is provided at the end of this appendix.

Interpreting Indicators of Rangeland Health Version 5 Evaluation Form (page 2)	
Evaluation area name or ID: Big Sage_CM_14	Date: 8/14/2018

Departure from Expected	Code	Instructions
None to slight	N-S	(1) Assign 17 indicator ratings, record comments and any measurements.
Slight to moderate	S-M	(2) In the attribute rating tables at the bottom of the form, write the indicator number in the appropriate column for each indicator applicable to the attribute.
Moderate	M	(3) Assign overall rating for each attribute based on preponderance of evidence.
Moderate to extreme	M-E	(4) Provide rationale for each attribute rating in writing.
Extreme to total	E-T	

Indicator	Rating	Comments
1. Rills	S H N-S	No rills observed in evaluation area
2. Water flow patterns	S H S-M	Short, disconnected waterflow patterns 3' long and up to 1' wide in plant interspaces on slopes > 5%
3. Pedestals and/or terracettes	S H S-M	Occasional pedestalled bunchgrasses associated with water flow patterns on slopes > 5%
4. Bare ground (observed): 32 %	S H M-E	Bare ground is much higher than expected, with bare patches > 2' that are occassionally connected
5. Gullies	S H N-S	None
6. Wind-scoured and/or depositional areas	S N-S	Minor soil deposits found around perennial plant bases; no wind scours noted – matches what is expected for the site
7. Litter movement (wind or water)	S S-M	Displacement of fine material up to 2' associated with water flow patterns on slopes > 5%. Coarse litter does not appear to be moving
8. Soil surface resistance to erosion Interspace: 3.2 Plant canopy: 3.8	S H B M	Observed values are consistently 1-2 categories lower than expected
9. Soil surface loss and degradation	S H B S-M	A-horizon is thinner (5 cm) and lighter (10yr 4/2) in color than expected
10. Effects of plant community composition and distribution relative to infiltration	H S-M	Deep-rooted perennial grasses are somewhat reduced, resulting in slightly less infiltration, especially on steeper slopes
11. Compaction layer	S H B S-M	Thin, weakly developed compaction layer in interspaces, ~2" thick
12. Functional/structural groups a. Relative dominance: S-M b. F/S groups not expected at the site: M c. Number of F/S groups: N-S d. Spp # in dom & subdom F/S groups: N-S	B M	Annual grasses are not expected for this site, but now a minor component; relative dominance has shifted towards shrubs with a decrease in perennial grasses. Biological crust cover is substantially lower than expected
13. Dead or dying plants or plant parts	B S-M	Approx. 20% of deep-rooted bunchgrasses have slight crown die-out which is not expected given the normal precipitation over the past two years
14. Litter cover and depth Observed cover: 38 % Depth: 0.1 cm (in)	H B N-S	Amount is slightly higher than expected however depth is on the lower end of what is expected for site
15. Annual production: (Pounds) or Kilograms Observed: 775 ÷ Expected 1100 = 70%	B S-M	Production is reduced relative to that expected relative to recent weather (normal year) based on ocular estimate
16. Invasive plants	B M-E	Cheatgrass is common
17. Vigor with an emphasis on reproductive capability of perennial plants	B N-S	Perennial plants at the site are producing seed and have good vigor. Crown diameter is an average of 4-6" on mature bunchgrasses

Soil/Site Stability "S" *(10 indicators)*

Attribute Rating: S-M

Rationale: Bare ground is higher than expected & soil stability has declined impacting site stability

E-T	M-E	M	S-M	N-S
			5	
			9	
			7	6
			3	5
	4	8	2	1

Hydrologic Function "H" *(10 indicators)*

Attribute Rating: S-M

Rationale: Bare ground is higher than expected and soil stability has declined; Soil compaction & degradation of A horizon may impact hydrologic function

E-T	M-E	M	S-M	N-S
			11	
			10	
			9	5
			3	14
	4	8	2	1

Biotic Integrity "B" *(9 indicators)*

Attribute Rating: M

Rationale: Annual grasses invading site; biotic integrity & site productivity are moderately affected

E-T	M-E	M	S-M	N-S
			15	
			13	
		12	11	17
	16	8	9	14

Figure A4.3. Example of a completed page 2 of the evaluation sheet.

Functional/Structural Groups Worksheet Instructions

The functional/structural groups worksheet is used to document observed species, functional/structural groups, and relative dominance at an evaluation area. The worksheet is also used to compare those observations to the appropriate reference phase from the functional/structural groups table for indicator 12 in the reference sheet in a consistent manner. An example of a completed functional/structural groups worksheet is provided in Figures A4.4 and A4.5. A blank functional/structural groups worksheet is provided at the end of this appendix.

In section 1 of the worksheet, record the ecological site, and identify the most appropriate reference plant community phase for the evaluation area.

In sections 2 and 3, list the observed functional/structural groups and associated species within each respective group that are found in the evaluation area. Remember that species or functional/structural groups in the evaluation area may be different than the groups or species identified for the selected reference phase. If an unexpected species occurs in the evaluation area, follow the process described for step 2 in Appendix 1b, and assign the species to the appropriate functional/structural group based on its characteristics. If the unexpected species does not fit one of the expected groups, it should be listed under a new functional/structural group name.

In section 4, specify whether plant species composition estimates are based on the current growing season's annual production or foliar cover. Next, refer to the functional/structural groups table for indicator 12 in the reference sheet, and copy the relative dominance information for the selected reference plant community phase in the "Expected" column. If adjustments to the selected reference community phase are needed based on time since disturbances in the evaluation area, record adjustments and rationale in the "Comments" field. See step 1 in Section 7.4.12 for additional information on adjustments. One approach to portraying adjustments is to modify the relative dominance in the "Expected" column to reflect changes in relative dominance described in the "Comments" field.

In the "Observed" column, record the relative dominance of the functional/structural groups observed in the evaluation area. More than one functional/structural group may be assigned to each relative dominance category. Refer to step 3 in Appendix 1b for instructions for calculating relative abundance from quantitative data.

To complete section 5 of the functional/structural groups worksheet, refer to step 4 in Section 7.4.12. Rate the four subindicators by circling the best fit for each on the evaluation matrix included in the worksheet. Finally, in section 6, record the overall departure for indicator 12.

Keep this worksheet with the evaluation sheet to support the ratings and observations made at each evaluation area.

INTERPRETING INDICATORS OF RANGELAND HEALTH *VERSION 5*
Functional/Structural Groups Worksheet

Evaluation Area ID: Big CM 14 **Date:** 8/14/2018 **Evaluator(s):** A. Smith, B. Jones and C. Carter

Instructions (Numbers correspond to fields in the worksheet; see Appendix 4 for detailed instructions.):

1. Record the ecological site for the evaluation area. Considering the disturbance and land treatment history at the evaluation area, select the appropriate reference community phase from the F/S groups table in the reference sheet.
2. Observe and list the F/S groups present in the evaluation area.
3. Record the species within each F/S group present in the evaluation area. At the bottom of this section, record the number of expected F/S groups and number of species in expected dominant and subdominant groups observed in the evaluation area.
4. Copy the relative dominance for the selected reference phase from the reference sheet to the **Expected** column. In the **Observed** column, document the relative dominance of F/S groups at the evaluation area. Use the **Comments** field to make notes, including any adjustments to relative dominance and rationale.
5. For each subindicator, circle the departure category description that best fits the observed changes in F/S groups in the evaluation area.
6. Rate the overall departure for the F/S groups indicator by choosing the greatest departure category of the four subindicators.

1) Ecological site: R025XY011ID	**Reference phase for evaluation area: 1.** 1
2) F/S Groups in Evaluation Area	**3) Species List**
Deep-rooted, cool-season perennial bunchgrasses	Idaho fescue, bluebunch wheatgrass, prairie Junegrass, squirreltail
Shallow-rooted, cool-season perennial bunchgrasses	Sandberg bluegrass, bulbous bluegrass
Perennial forbs	Common yarrow, Indian paintbrush, Hood's phlox, lupine
Non-sprouting shrubs	Mountain big sagebrush
Evergreen trees	Western Juniper
Annual grasses	Cheatgrass, ventenata
Biological soil crusts[1]	5% cover of mosses and lichens. Cyanobacteria present but not recorded in cover measurements.
Number of expected F/S groups present[2] in evaluation area:	6
Number of species in expected dominant and subdominant groups present in evaluation groups:	4

[1] Biological soil crust dominance is determined based on cover, rather than production. If biological soil crusts are an expected dominant or subdominant group, the number of expected life forms (e.g., lichen, moss) is listed, rather than number of individual species.

[2] When an F/S group that is expected to be dominant, subdominant, or minor is reduced in the evaluation area to a few remnant individuals, the group is considered to not be "functionally present" and is not included in the number of F/S groups present (12c).

Figure A4.4. Example of a completed functional/structural groups worksheet (sections 1-3).

INTERPRETING INDICATORS OF RANGELAND HEALTH VERSION 5
Functional/Structural Groups Worksheet

Evaluation Area ID: Big CM 14 **Date:** 8/14/2018 **Evaluator(s):** A. Smith, B. Jones and C. Carter

4)	**Expected** relative dominance of F/S groups for Phase 1. 1 Based on: Production X Foliar Cover ____	**Observed** relative dominance of F/S groups in the evaluation area
Dominant	Cool-season, deep-rooted perennial bunchgrassess	Non-sprouting shrubs
Subdominant	None	Cool-season, deep-rooted perennial bunchgrasses, cool-season, shallow-rooted perennial grasses
Minor	Non-sprouting shrubs, sprouting shrubs, cool-season, shallow-rooted perennial bunchgrasses, perennial forbs	Annual grasses, perennial forbs
Trace	Biological soil crusts	Biological soil crusts, evergreen trees

Comments: Non-sprouting shrubs are expected to increase from minor to subdominant given fire occured 15 years ago (2003) which is near the timeframe for moving from phase 1.1 to 1.2.

5) Indicator and subindicators rating (circle the appropriate departure category for each subindicator below).

Subindicator	E-T	M-E	M	S-M	N-S
12a. Relative dominance	All expected dominant F/S groups are now minor, trace, or missing.	Dominant F/S group(s) has become minor or trace, or a minor or trace group is now dominant.	Dominant F/Sgroup(s) has become subdominant.	Subdominant F/Sgroup has become minor or trace, or a minor or trace F/S group has become subdominant.	Resembles expected relative dominance for appropriate reference phase.
12b. F/S groups not expected at the site	F/S group(s) not expected is now dominant.	F/S group(s) not expected is now subdominant.	F/S group(s) not expected is now minor.	F/S group(s) not expected is now trace.	None.
12c. Number of expected F/S groups	Severly reduced (missing ≥ 76% of expected F/S groups).	Greatly reduced (missing 51-75% of expected F/S groups).	Moderately reduced (missing 26-50% of expected F/S groups).	Slightly reduced (missing ≤ 25% of expected F/S groups).	All expected F/S groups for appropriate phase are present.
12d. Total combined number of species expected in dominant and subdominant F/S groups	Severely reduced (missing ≥ 76%).	Greatly reduced (missing 51-75%).	Moderately reduced (missing 26-50%).	Slightly reduced (missing 10-25%).	Missing less than 10% of expected # of species in dominant and subdominant F/S groups for appropriate reference phase.
6) Overall departure category for F/S groups indicator:					M

Data Entry Date: 9/21/2018 **By:** A. Smith **Error Check Date:** 9/30/2018 **By:** B. Jones

Figure A4.5. Example of a completed functional/structural groups worksheet (sections 4-6).

INTERPRETING INDICATORS OF RANGELAND HEALTH VERSION 5 EVALUATION FORM – PAGE 1

Complete the following information as necessary for project documentation and assessment purposes.

Evaluation area name or ID:		Date:
Management unit:	State:	Office:
Evaluator(s):		

Ecological Site/Reference Sheet Used for Evaluation *(Complete this section last)*

Ecological site name:	Ecological site ID:	
Reference sheet used/authors:		Date:
Soil component:	Composition based on (check one): Cover ☐ Annual Production ☐	

Ecological Site Determination *(Describe reference on the left and observations of the evaluation area on the right.)*

Soil Survey:		Soil Map Unit:	
Soil and site reference description Description Source: Ecological Site Description OR Soil Survey		**Evaluation area soil and site characterization**	
Parent material:	Slope range: %	Parent material:	Slope: %
Elevation range: ft / m	Aspect (if specified):	Elevation: ft / m	Aspect:
Topographic position:		Topographic position:	
Precipitation range: in / cm		Average annual precipitation: in / cm	
Seasonal precipitation distribution:		Seasonal precipitation distribution:	
Soil depth[1]: Very shallow ☐ Shallow ☐ Moderate ☐ Deep ☐ Very deep ☐		Pit depth: in / cm	

Type and depth of diagnostic horizons: in / cm | **Type and depth of diagnostic horizons:** in / cm

Soil horizon	Depth	Texture	Eff [2]	Other	Soil horizon	Depth	Texture	Eff [2]	Other

Evaluation Area Location

Criteria used to select evaluation area:				
Location description/directions				
Size of evaluation area:		UTM Zone: Datum:		Position by GPS? Yes / No
Township Range	OR	m	OR	N. Latitude
Section 1/4 Section		m		W. Longitude

Supplemental Information & Reference Community Phase

Recent weather (last 2 years): drought ☐ normal ☐ wet ☐

Natural disturbance type(s) and date(s):

Land treatment type(s) and date(s):

Wildlife, livestock, recreation, or other uses:

Offsite influences:

Photos taken? Yes / No	Quantitative data collected:

F/S groups worksheet completed? **Yes** (attach worksheet) **No** (document expected relative dominance on next line)

Reference community phase/description[3]

[1] Depth classes: Very shallow < 25 cm; Shallow 25-50 cm; Moderate 50-100 cm; Deep 100-150 cm; Very Deep > 150 cm

[2] Soil effervescence (Eff) codes: NE – non-eff.; VS – very slightly eff.; SL – slightly eff.; ST – strongly eff.; V – violently eff.

[3] If F/S worksheet is not completed, describe expected reference community F/S groups' relative dominance in this field.

Interpreting Indicators of Rangeland Health Version 5 Evaluation Form (page 2)	
Evaluation area name or ID:	Date:

Departure from Expected	Code	Instructions
None to slight	N-S	(1) Assign 17 indicator ratings, record comments and any measurements.
Slight to moderate	S-M	(2) In the attribute rating tables at the bottom of the form, write the indicator number in the appropriate column for each indicator applicable to the attribute.
Moderate	M	(3) Assign overall rating for each attribute based on preponderance of evidence.
Moderate to extreme	M-E	(4) Provide rationale for each attribute rating in writing.
Extreme to total	E-T	

Indicator	Rating			Comments
1. Rills	S	H		
2. Water flow patterns	S	H		
3. Pedestals and/or terracettes	S	H		
4. Bare ground (observed): _____ %	S	H		
5. Gullies	S	H		
6. Wind-scoured and/or depositional areas	S			
7. Litter movement (wind or water)	S			
8. Soil surface resistance to erosion Interspace: _____ Plant canopy: _____	S	H	B	
9. Soil surface loss and degradation	S	H	B	
10. Effects of plant community composition and distribution relative to infiltration		H		
11. Compaction layer	S	H	B	
12. Functional/structural groups			B	
a. Relative dominance: ____				
b. F/S groups not expected at the site: ____				
c. Number of F/S groups: ____				
d. Spp # in dom & subdom F/S groups: ____				
13. Dead or dying plants or plant parts			B	
14. Litter cover and depth Observed cover: ____ % Depth: ____ cm / in		H	B	
15. Annual production: Pounds or Kilograms Observed: ____ ÷ Expected ____ = ____			B	
16. Invasive plants			B	
17. Vigor with an emphasis on reproductive capability of perennial plants			B	

Soil/Site Stability "S" *(10 indicators)*						**Hydrologic Function "H"** *(10 indicators)*						**Biotic Integrity "B"** *(9 indicators)*					
Attribute Rating: ____					Rationale:	Attribute Rating: ____					Rationale:	Attribute Rating: ____					Rationale:
E-T	M-E	M	S-M	N-S		E-T	M-E	M	S-M	N-S		E-T	M-E	M	S-M	N-S	

INTERPRETING INDICATORS OF RANGELAND HEALTH *VERSION 5*

Functional/Structural Groups Worksheet

Evaluation Area ID: ___________________ **Date:** ____________ **Evaluator(s):** ___________________________________

Instructions (Numbers correspond to fields in the worksheet; see Appendix 4 for detailed instructions.):

1. Record the ecological site for the evaluation area. Considering the disturbance and land treatment history at the evaluation area, select the appropriate reference community phase from the F/S groups table in the reference sheet.
2. Observe and list the F/S groups present in the evaluation area.
3. Record the species within each F/S group present in the evaluation area. At the bottom of this section, record the number of expected F/S groups and number of species in expected dominant and subdominant groups observed in the evaluation area.
4. Copy the relative dominance for the selected reference phase from the reference sheet to the **Expected** column. In the **Observed** column, document the relative dominance of F/S groups at the evaluation area. Use the **Comments** field to make notes, including any adjustments to relative dominance and rationale.
5. For each subindicator, circle the departure category description that best fits the observed changes in F/S groups in the evaluation area.
6. Rate the overall departure for the F/S groups indicator by choosing the greatest departure category of the four subindicators.

1) Ecological site:	**Reference phase for evaluation area: 1.**
2) F/S Groups in Evaluation Area	**3) Species List**
Biological soil crusts[1]	
Number of expected F/S groups present[2] in evaluation area:	
Number of species in expected dominant and subdominant groups present in evaluation groups:	

[1] Biological soil crust dominance is determined based on cover, rather than production. If biological soil crusts are an expected dominant or subdominant group, the number of expected life forms (e.g., lichen, moss) is listed, rather than number of individual species.

[2] When an F/S group that is expected to be dominant, subdominant, or minor is reduced in the evaluation area to a few remnant individuals, the group is considered to not be "functionally present" and is not included in the number of F/S groups present (12c).

INTERPRETING INDICATORS OF RANGELAND HEALTH VERSION 5
Functional/Structural Groups Worksheet

Evaluation Area ID: ______________ **Date:** _________________ **Evaluator(s):** ____________________________________

4)	**Expected** relative dominance of F/S groups for Phase 1. _____ Based on: Production _____ Foliar Cover _____	**Observed** relative dominance of F/S groups in the evaluation area
Dominant		
Subdominant		
Minor		
Trace		
Comments:		

5) Indicator and subindicators rating (circle the appropriate departure category for each subindicator below).

Subindicator	E-T	M-E	M	S-M	N-S
12a. Relative dominance	All expected dominant F/S groups are now minor, trace, or missing.	Dominant F/S group(s) has become minor or trace, or a minor or trace group is now dominant.	Dominant F/ Sgroup(s) has become subdominant.	Subdominant F/ Sgroup has become minor or trace, or a minor or trace F/S group has become subdominant.	Resembles expected relative dominance for appropriate reference phase.
12b. F/S groups not expected at the site	F/S group(s) not expected is now dominant.	F/S group(s) not expected is now subdominant.	F/S group(s) not expected is now minor.	F/S group(s) not expected is now trace.	None.
12c. Number of expected F/S groups	Severely reduced (missing ≥ 76% of expected F/S groups).	Greatly reduced (missing 51-75% of expected F/S groups).	Moderately reduced (missing 26-50% of expected F/S groups).	Slightly reduced (missing ≤ 25% of expected F/S groups).	All expected F/S groups for appropriate phase are present.
12d. Total combined number of species expected in dominant and subdominant F/S groups	Severely reduced (missing ≥ 76%).	Greatly reduced (missing 51-75%).	Moderately reduced (missing 26-50%).	Slightly reduced (missing 10-25%).	Missing less than 10% of expected # of species in dominant and subdominant F/S groups for appropriate reference phase.
				6) Overall departure category for F/S groups indicator:	

Data Entry Date: ______________ **By:** _________________ **Error Check Date:** _______________ **By:** ____________________

Appendix 5. Guide to Determining the Ecological Site at an Evaluation Area

The ecological site must be determined at each evaluation area to ensure that the correct reference sheet is used to conduct the IIRH assessment. Ecological sites are delineated based on effective precipitation, soil characteristics (e.g., texture, depth, chemistry, and restrictive layers), and physiographic characteristics (e.g., elevation, slope, and aspect). Soil surveys provide the foundation for describing and mapping ecological sites (Figure A5.1), whereas soil maps only help identify the potential dominant soils (and therefore ecological sites) that might be found in the evaluation area.

First, a list of the ecological sites likely to occur at an evaluation area should be compiled according to the instructions that follow. However, this step alone does not determine the ecological site at a specific evaluation area. Many soil map units are comprised of more than one soil map unit component, and each component may be correlated to a different ecological site. In addition to the soil components listed in a soil map unit description, soil inclusions (soils representing less than 15% of the soil map unit area) are found in most soil map units and may be correlated to different ecological sites.

After reviewing the soils data and listing the possible ecological sites in an evaluation area, the ecological site determination is made in the field by observing the evaluation area's soils and physiographic characteristics and comparing these characteristics to the descriptions provided in the ecological site description or soil survey. An example ecological site determination is shown in Figure A4.2 in Appendix 4.

Elmore County Area, Idaho, Parts of Elmore and Owyhee Counties

47 – Davey-Mazuma complex, 12 to 40 percent slopes

Map Unit Setting

National map unit symbol: 2r0l
Elevation: 2,300 to 3,100 feet
Mean annual precipitation: 7 to 8 inches
Mean annual air temperature: 50 to 53 degrees
Frost-free period: 140 days
Farmland classification: Not prime farmland

Map Unit Composition

Davey and similar soils: 50 percent
Mazuma and similar soils: 30 percent

Estimates are based on observations, descriptions, and transects of the map unit.

Description of Davey Setting

Landform: Terraces
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Mixed alluvium

Typical profile

A – 0 to 15 inches: loamy fine sand
Bw – 15 to 22 inches: fine sandy loam
Bk – 22 to 60 inches: loamy sand

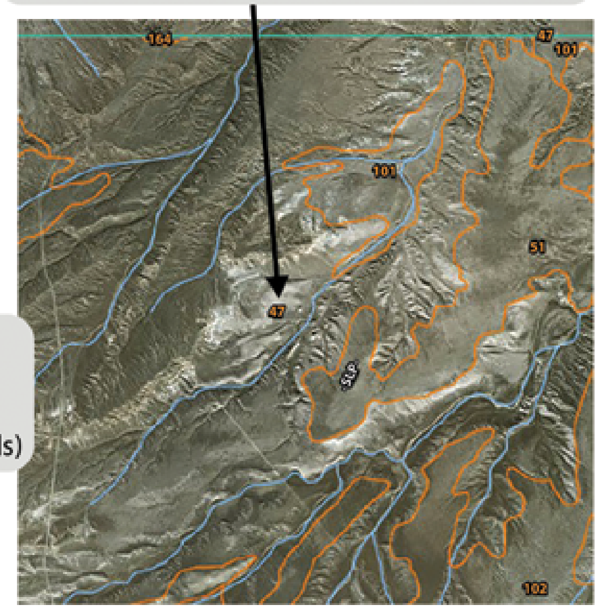
Properties and qualities

Slope: 12 to 40 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): High (2.00 to 6.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 20 percent
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum in profile: 5.0
Available water storage in profile: Low (about 5.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6s
Hydrological Soil Group: A
Ecological site: SANDY LOAM 8-12 ARTRW8/ACHY-HECOC8 (R011XY014ID)
Hydric soil rating: No

a) MAP UNIT = 47, Davy-Mazuma complex



b) Components:
50% Davey
30% Mazuma
(20% other soils)

c) Most likely component:
Davey loamy fine sand
12-40%

d) ECOLOGICAL SITE DETERMINATION:
Sandy Loam 8-12 ARTRW8/ACHY – HECOC8 (R011XY014ID)

Figure A5.1. Example of using a soil survey to identify the ecological site of an evaluation area. (a) Use the soil survey map to determine the location of an evaluation area. This evaluation area is in Map Unit 47 of the Elmore Area County Soil Survey. (b) Refer to the map unit composition to determine the soil component(s) in the evaluation area. In this soil survey, the majority of the soil composition is Davey (50%) and Mazuma (30%). (c) Compare physiographic features of the evaluation area with those of the soil component's setting and slope. In this example, the slope of the evaluation area matches the slope of the Davey soil component (12-40%). The soil component is then identified by digging a soil pit and comparing to the description of the Davey soil component. (d) After determining the soil component in the evaluation area, document the information in the ecological site determination section on page 1 of the evaluation sheet.

Steps for identifying soils and ecological sites when a soil survey and ecological site correlations are available:

Step 1. Develop a list of potential ecological sites and soil map unit components.
It is recommended to use the unique ecological site ID, rather than the ecological site name; this prevents accidentally using an ecological site description with the same name from a different land resource unit/major land resource area. Ecological sites are grouped into land resource units (LRUs), which are then grouped into major land resource areas (MLRAs) within each state. Refer to U.S. Department of Agriculture Handbook 296 for further information. Each ecological site description has a unique code that identifies the MLRA, LRU, ecological site number, and state. For example, ecological site description code R011XY014ID is interpreted as shown in Figure A5.2.

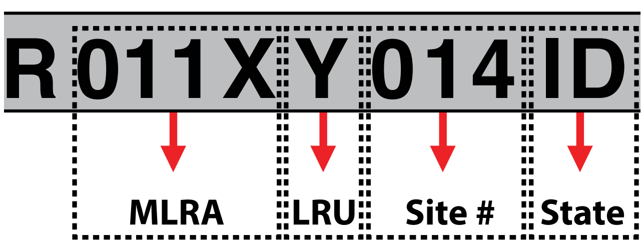


Figure A5.2. Components of an ecological site description code. "R" at the beginning of the code denotes a rangeland ecological site.

Step 1a. Ecological site mapping in EDIT (Ecosystem Dynamics Interpretive Tool).
Visit the EDIT website (*edit.jornada.nmsu.edu*) and navigate to the ecological site descriptions catalog. Using the MLRA mapping feature, zoom in to the area of interest. The soil map unit polygons will appear as you zoom in. Click on the appropriate soil map unit. A list of ecological sites associated with the dominant soil components within that soil map unit will be provided if the ecological site correlations are available in the database. The correlated soils and ecological site description status can be found by clicking on each listed ecological site.

Step 1b. Obtain ecological site correlations from soil survey data. When ecological site mapping correlations are not available in EDIT, or when additional soils information is required, consult electronic or hard copies of soils surveys. Most soil map unit component descriptions include ecological site correlations.

The availability of soil surveys in paper or electronic format varies across the Western United States. Soil surveys are now published electronically as they are revised and updated, so hard copies of soil surveys may no longer contain the most up-to-date information. Third-order soil surveys, which are most commonly available for rangelands, are somewhat coarse and usually represent complexes of multiple soils. They may also include soil inclusions, which may or may not be listed in the soil survey.

Soil survey information can be accessed in the following ways:

- Web Soil Survey (*https://websoilsurvey.sc.egov.usda.gov*) provides interactive tools for navigating to and delineating an area of interest. An area of interest, such as a management unit, can also be imported to Web Soil Survey as a shapefile. Note that Web Soil Survey has a maximum area of interest resolution of 100,000 acres.
- Spatial and tabular soils data can be downloaded from Web Soil Survey, allowing these data to be used with other spatial datasets with desktop geographic information system applications, such as ArcGIS.
- If published soils data are not available for the area of interest, contact the local NRCS office to see if unpublished information is available.

Step 2. Use soil survey information to identify ecological site correlations.

- ArcGIS users may use the Soil Data Viewer plugin, which enables creation of ecological site shapefiles from the Soil Survey Geographic Database (SSURGO) and use of the ecological site maps with local datasets.
- The Soil Data Development Toolbox is compatible with ArcToolbox and allows users to work with the Gridded Soil Survey Geographic (gSSURGO) Database, which can be accessed

through the NRCS Geospatial Data Gateway (Appendix 10).

- Using Web Soil Survey, import or navigate to and select the area of interest. Soil map units for the area of interest can now be viewed. The ecological site interpretations can be found by going to the "Suitabilities and Limitations for Use" tab and then selecting "Ecological Site ID" under the "Land Classifications" menu.
- Remember: Ecological site maps generated using Soil Data Viewer or Web Soil Survey will represent the site correlated with the dominant soil(s) in each soil map unit, whereas the EDIT interface provides a list of ecological sites associated with the major soil components and their percentages for the map unit. The user must determine which other ecological sites might occur based on the components of each soil map unit. The secondary major soil components and inclusions may represent different ecological sites, which are identified under the map unit component description in the soil survey.

Step 3. Obtain the ecological site description(s). After compiling the list of ecological sites expected to be found in the field, refer to EDIT (*edit.jornada.nmsu.edu*) to obtain ecological site description reports. If the required ecological site description is not available online, contact the state NRCS rangeland management specialist to see if a draft is available for use.

Step 4. Bring copies of the relevant ecological site descriptions to the field. It is a good idea to also bring copies of the soil map unit descriptions and soil series descriptions, as they usually contain more detail and may help with interpretation of soil profile observations.

Step 5. In the evaluation area, compare the physiographic characteristics to the soil description in the ecological site description (i.e., are the ranges in elevation, slope, aspect, etc., within those described for the ecological site?).

Step 6. If the evaluation area matches the basic physiographic characteristics outlined in step 5, document this in the "Soil and site reference description" field of the evaluation sheet (Appendix 4; Figure A4.2). Also, circle the source (ecological site description or soil survey) in the "Soil and site reference description" field, and record the expected conditions in each blank field. The most detailed reference information is usually provided by the soil survey, if available.

Step 7. On the right side of the evaluation sheet in the "Evaluation area soil and site characterization" fields, document observations of the evaluation area's soil and physiographic characteristics. See Figure A4.1 in Appendix 4 to help determine the topographic position of the evaluation area. The evaluation area's characteristics should fit within the source of the information being used to complete the site verification.

- Be aware of the key characteristics that differentiate the potential ecological sites in the area. For instance, the soil map unit may represent a soil complex that alternates between a shallow claypan with a restrictive layer at a given depth and a deeper loamy soil; another example is a soil map unit that contains loamy and sandy soils that result in different ecological sites. Knowing these likely soil differences will make the ecological site identification process easier and more efficient.
- Dig a sufficient number of soil pits in the evaluation area to confirm that it is within a single ecological site. If more than one ecological site occurs within the evaluation area, each site must be assessed separately.
- Digging to a minimum depth of 20-25 inches (51-64 cm) is usually required to distinguish ecological sites in most areas. "Shallow" ecological sites are often distinguished by soils less than 20 inches (51 cm) in depth. It is strongly recommended to dig a deeper hole if possible; greater depths will increase the accuracy of soil and ecological site identification.

- Record observations of soil horizons and their depth, texture, and effervescence and other diagnostic characteristics, such as soil structure, color, grade, and size in the ecological site determination section on page 1 of the evaluation sheet.
- Tips for hand-texturing soils are provided in Appendix 6. Refer to the "Field Book for Describing and Sampling Soils" (Schoeneberger et al. 2012) for additional information about soil properties.
- Mobile apps and other technological tools are increasingly available and can facilitate soil identification when using soil pits. It is also recommended to consult a soil scientist or resource specialist familiar with soil identification in this phase of the evaluation if there is uncertainity about the soils.

Step 8. To complete the ecological site determination, compare the observations on the right side of the evaluation sheet from the evaluation area to those on the left from the soil information source. If the soil characteristics observed in the evaluation area have major differences from those described in the soil information source, determine whether another information source, such as a different ecological site description or soil component description, better matches the evaluation area characteristics. If the evaluation area matches the characteristics described in the soil information source, record the ecological site in the appropriate field at the top of the evaluation sheet. In some instances, none of the soil components listed for the map unit will match the soils found at an evaluation area within that map unit. In this situation, it can be helpful to review soil descriptions from adjacent map units, or even adjacent soil survey areas, to identify the correct soil and correlated ecological site description.

Appendix 6. Resources for Describing and Hand-Texturing Soils

Texture class is one of the first things determined after digging a soil pit and beginning the soil determination process. Texture is related to weathering and parent material. The differences in soil horizons may be due to the differences in texture of their respective parent materials (NRCS 2020).

Texture class can be determined fairly easily in the field by feeling the sand particles and estimating silt and clay content by flexibility and stickiness. There is no field mechanical-analysis procedure that is as accurate as the fingers of an experienced specialist, especially if standard samples are available. One must be familiar with the composition of the local soils. This is because certain characteristics of soils can create incorrect results if not taken into account (NRCS 2020). For example:

- In some environments, clay aggregates form that are so strongly cemented together that they feel like fine sand or silt. In humid climates, iron oxide is the cement. In desert climates, silica is the cement. In arid regions, lime can be the cement. It takes prolonged rubbing to show that they are clays and not silt loams.
- Some soils derived from granite contain grains that resemble mica but are softer. Rubbing breaks down these grains and reveals that they are clay. These grains resist dispersion, and field and laboratory determinations may disagree.
- Many soil conditions and components previously mentioned cause inconsistencies between field texture estimates and standard laboratory data. These include, but are not limited to, the presence of cements, large clay crystals, and mineral grains. If field and laboratory determinations are inconsistent, one or more of these conditions is suspected.

The following figures and table assist with hand-texturing soils and describing soil structure, rock fragment content, and effervescence. Additional resources are listed in Appendix 10.

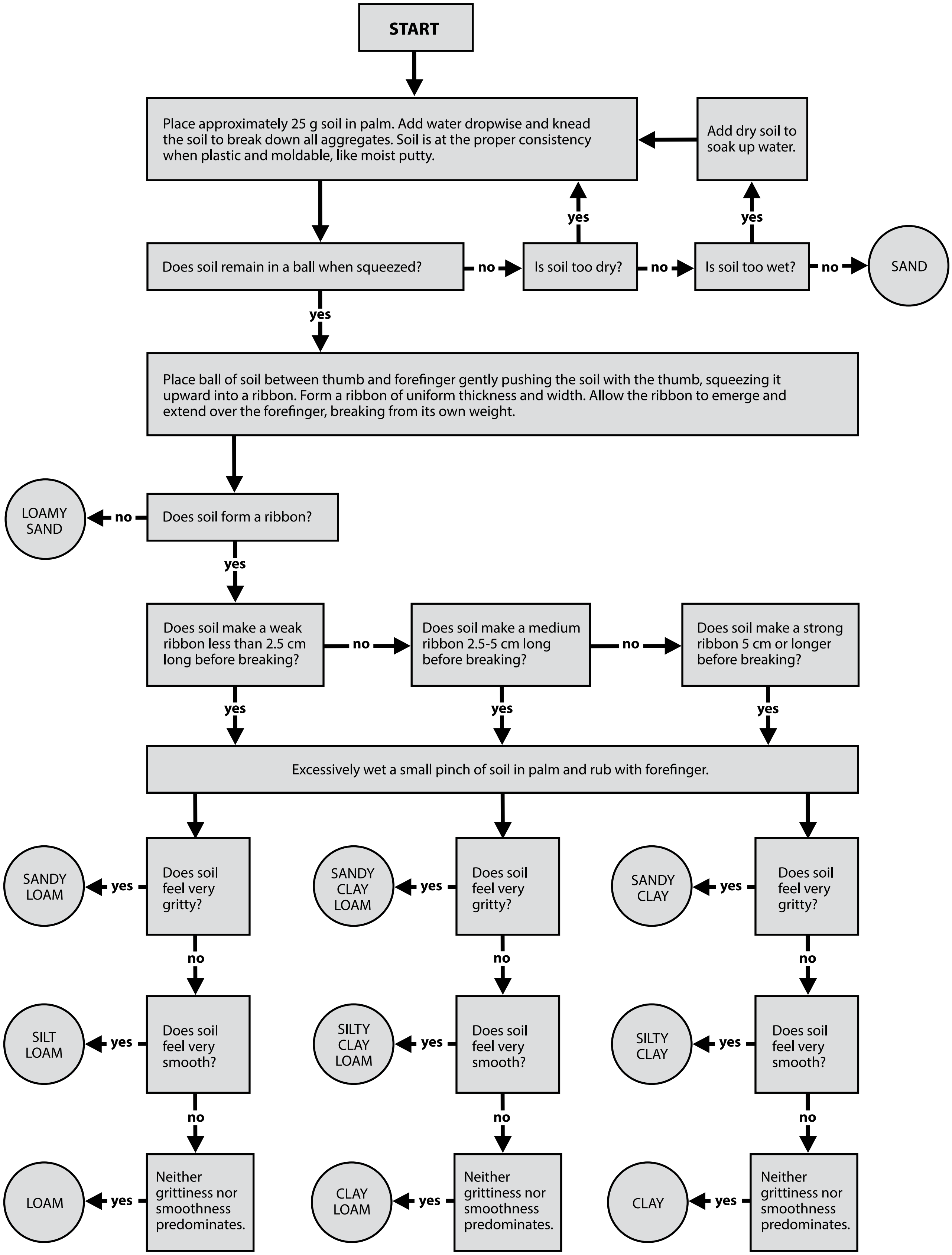
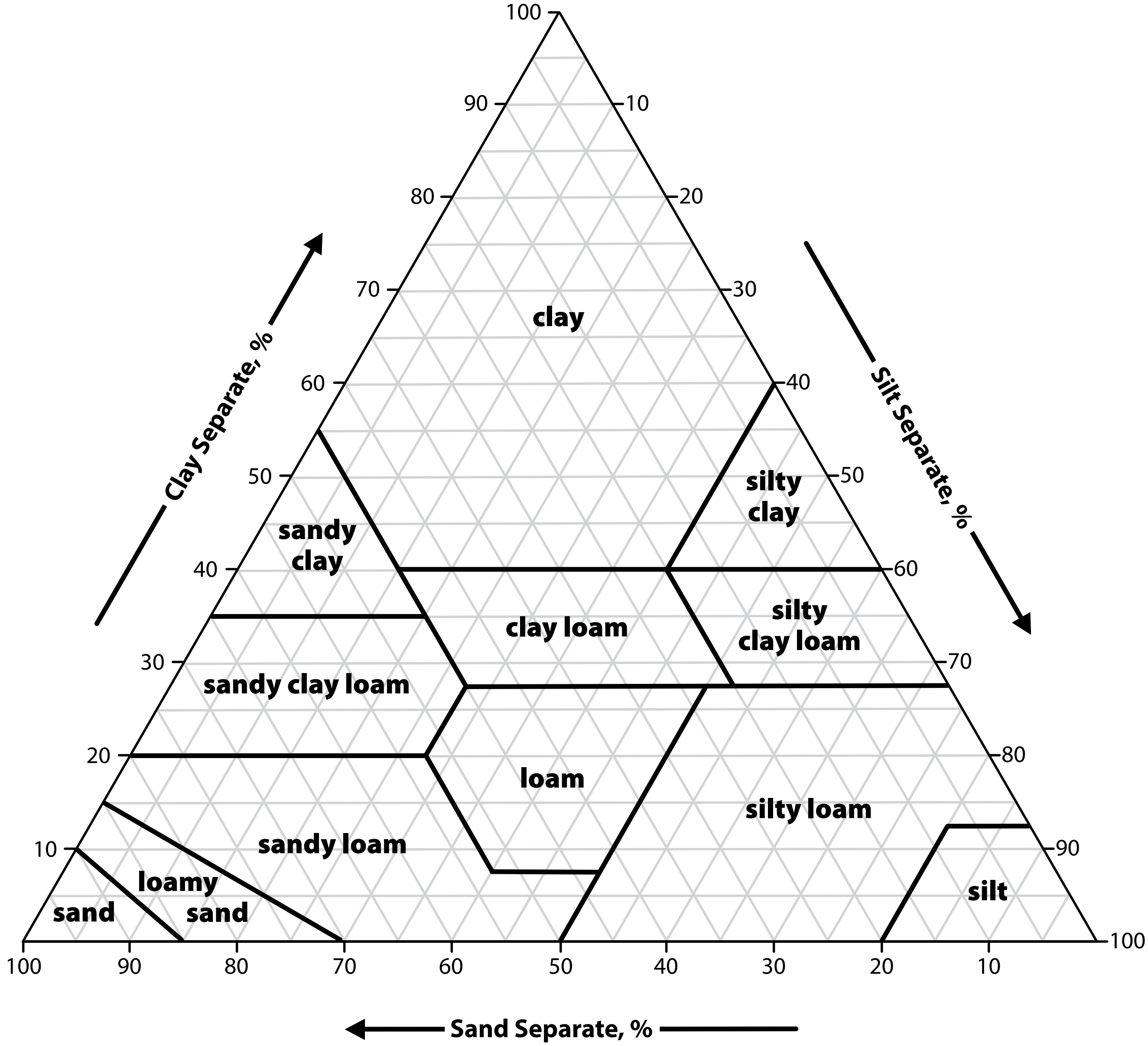


Figure A6.1. A flow diagram for selecting soil texture by feel analysis (Thien 1979). Other texturing methods and keys may be used as well (Salley et al. 2018).



Texture modifiers: Conventions for using "Rock Fragment Texture Modifiers" and for using textural adjectives that convey the "% volume" ranges for **Rock Fragments – Size and Quantity**	
Fragment Content % by Volume	**Rock Fragment Modifier Usage**
< 15	No texture adjective is used (noun only) (e.g., loam)
15 to < 35	Use adjective for appropriate size (e.g., gravelly)
35 to < 60	Use "very" with the appropriate size adjective (e.g., very gravelly)
60 to < 90	Use "extremely" with the appropriate size adjective (e.g., extremely gravelly)
≥ 90	No adjective or modifiers. If ≤ 10% fine earth, use the appropriate noun for the dominant size class (e.g., gravel)

Figure A6.2. Soil textural triangle and table of soil textural modifiers (NRCS 2019).

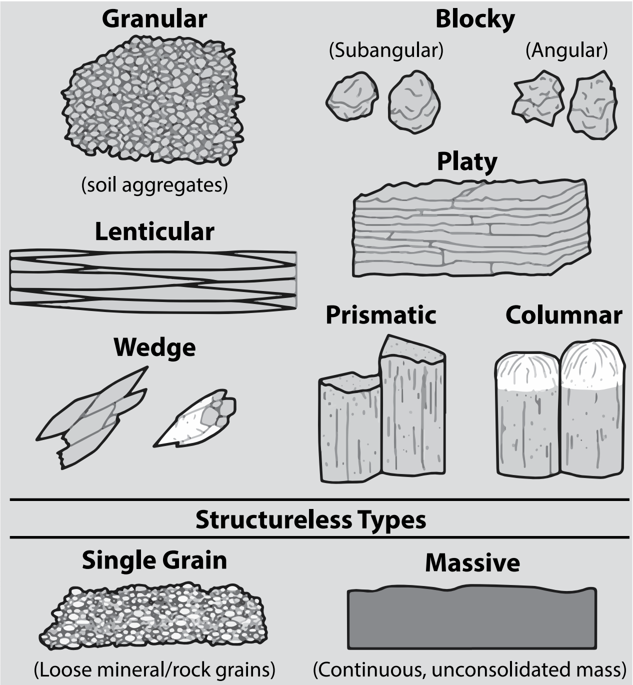
Table A6.1. Summary of common soil descriptors: A. Effervescence classes used to describe the entire soil matrix using 1 M HCl (Soil Science Division Staff 2017); B. Soil structure classes by size and shape; C. Examples of soil structure types; D. Soil structure grades and descriptions; and E. Particle size classes.

A. Effervescence class	Criteria
Noneffervescent	No bubbles form
Very slightly effervescent	Few bubbles form
Slightly effervescent	Numerous bubbles form
Strongly effervescent	Bubbles form low foam
Violently effervescent	Thick foam forms quickly

B. Soil Structure Classes by Size and Shape

Class	Platy and granular (mm)	Prismatic, columnar, and wedge (mm)	Blocky and lenticular
Very fine	< 1	< 10	< 5
Fine	1 to < 2	10 to < 20	5 to < 10
Medium	2 to < 5	20 to < 50	10 to < 20
Coarse	5 to < 10	50 to < 100	20 to 50
Very coarse	≥ 10	100 to < 500	≥ 50
Extremely coarse	N/A	≥ 500	N/A

C. Examples of Soil Structure Types



D. Soil Structure Grades and Descriptions

Weak	The units are barely observable in place. When they are gently disturbed, the disturbed soil material parts into a mixture of whole and broken units, the majority of which exhibit no planes of weakness.
Moderate	The units are well formed and evident in undisturbed soil. When disturbed, the soil material parts into a mixture of mostly whole units, some broken units, and material that is not in units. Peds part from adjoining peds to reveal nearly entire faces that have properties distinct from those of fractured surfaces.
Strong	The units are distinct in undisturbed soil. They separate cleanly when the soil is disturbed. When removed, the soil material separates mainly into whole units. Peds have distinctive surface properties.

E. USDA Particle Size Classes

FINE EARTH			ROCK FRAGMENTS		
Class	Subclass	Size (mm)	Class	Subclass	Size (mm)
Clay	Fine	< 0.0002	Gravel	Fine	2-5[1]
	Coarse	0.0002-0.002			
Silt	Fine	0.002-0.02		Medium	5-20
	Coarse	0.02-0.05			
Sand	Very Fine	0.05-0.1		Coarse	20-76
	Fine	0.1-0.25			
	Medium	0.25-0.5	Cobbles	-	76-250
	Coarse	0.5-1.0	Stones	-	250-600
	Very Coarse	1.0-2.0	Boulders	-	> 600

[1] Note that particles from 2-5 mm are considered gravel (rock) for purposes of soil description and identification. However, only fragments ≥ 5 mm are recorded as rock for purposes of calculating ground cover.

Appendix 7. Describing Indicators of Rangeland Health

An IIRH assessment cannot be completed without a reference sheet, and a reference sheet cannot be generated without an ecological site description or equivalent unit with which it is associated. If an IIRH assessment cannot be completed, a protocol called "describing indicators of rangeland health" (DIRH) may be completed to document information on the soil profile and the current status of IIRH indicators (Herrick et al. 2019). The DIRH protocol is designed to be used in two ways. First, where the IIRH protocol is completed on what are believed to be relatively undegraded lands based on other evidence (e.g., knowledge of historic disturbance regimes), data from similar intact sites can be combined and used to help develop or revise the reference sheet. Second, DIRH data can be collected on land with no known reference, regardless of its level of degradation, and then used at a later date to assist in the completion of an IIRH assessment after a reference sheet has been developed. Table A7.1 provides information to help determine when to use the DIRH protocol instead of the IIRH protocol.

Table A7.1. Determination of when to use the describing indicators of rangeland health (DIRH) protocol instead of the IIRH protocol to collect information.

Soil Survey Status	Ecological Site Description Status	Identify Soil Map Unit Component?	Identify Ecological Site?	Complete IIRH?
A soil survey exists.	Ecological site description exists.[1]	Yes	Yes	Yes[2]
No soil survey exists, but soils are comparable to soils described in another soil survey within the major land resource area.	Ecological sites are described for the major land resource area, including the precipitation zone.	Yes	Yes	Yes
No relevant soil information exists.	Ecological sites are not described for the major land resource area.	No, follow DIRH instructions.	No	No, follow DIRH instructions.

[1] If a soil survey exists, it should include soils/ecological site correlations.

[2] Refer to Appendix 1a to develop a reference sheet if one does not exist.

Instructions for Completing the DIRH Protocol

Step 1. Describe site characteristics that determine land potential, including climate, topography, and relatively static soil properties. Climate information can generally be obtained for a given location using models. For example, the Land-Potential Knowledge System (LandPKS) mobile app provides access to long-term monthly temperature and precipitation averages based on the mobile device's internal GPS and public databases derived from modeled output (Herrick et al. 2016). Ideally, these monthly averages should be supplemented with more detailed information on the size and frequency of extreme weather events. Topographic information should include slope and slope shape (concave, convex, or linear) and ideally landscape position. Sufficient soil information should be collected to identify the soil where a soil survey exists. For most regions, the minimum dataset includes soil depth, texture by depth, and whether or not vertical cracks more than 3 inches wide form when the soil dries. Soil identification can be improved with additional data, especially for subsurface layers, including pH, electrical conductivity, and color. Most of these properties can be recorded using widely available tools, such as the LandPKS and the Database for Inventory, Monitoring, and Assessment (Courtright and Van Zee 2011).

Step 2. Collect quantitative data. Sufficient quantitative data should be collected to characterize plant and soil surface cover, plant community composition and structure, and soil surface aggregate stability. In the United States, use of the core methods (Herrick et al. 2017) facilitates integration and comparison with other datasets. Use of these methods globally also allows for comparison with data collected on similar sites in the United States. For example, soil, climate, and topography combinations in southern Africa are replicated in Texas and the southwestern U.S., while analogs for much of northern Asia can be found in the U.S. northern Great Plains. The "stick" protocol (Riginos et al. 2011) can be used to generate relatively compatible quantitative data using a simpler method than some of the recommended protocols in Herrick et al. 2017. Table A7.2 provides information for measuring and classifying the indicators when using this method.

Table A7.2. DIRH matrix based on indicators included in this technical reference. Unless otherwise noted, the classes are based on observations or measurements completed in a 0.2 ha (50 m diameter or 0.5 acre) circular plot.

Indicator	Class 5	Class 4	Class 3	Class 2	Class 1
1. Rills. Small, shallow, intermittent watercourses with steep sides. Rills are generally linear.	Numerous (> 10/0.4 ha plot) and long (> 0.6 m).	Moderate in number (> 5) and long (> 0.6 m).	Few (> 5) or long (> 0.6 m).	Very few (< 5) and short (< 0.6 m).	Not present.
Rill connectivity	Very long (> 5 m).	Long (2-5 m).	Short (0.5-2 m).	Very short (0.25-0.5 m).	Extremely short (0.1-0.5 m).
2. Water Flow Patterns. Soil surface patterns caused by runoff. Indicated by litter, soil, and gravel redistribution. Steep cuts may occur on one side (see #1).	Very long (15 m); numerous; unstable with active erosion; almost always connected.	Long (6-15 m); very common and usually connected; erosion and depositional areas very common.	Moderately long (1.5-6 m); common and often connected; erosion and depositional areas common.	Very short (< 1.5 m); rare and occasionally connected; erosion and depositional areas rare.	None.

Table A7.2. continued

Indicator	Class 5	Class 4	Class 3	Class 2	Class 1
3. Pedestals and/or Terracettes. Plants or rocks appear elevated because of soil loss around them. Does not include deposition of soil on top of plant (check level of root-shoot interface).	Widespread throughout area; common exposed roots.	Common inflow paths; occasional exposed roots.	Common inflow paths; roots rarely exposed.	Few inflow paths and interspaces only; no exposed roots.	None.
4. Bare Ground. (a) Percent soil surface not covered by vegetation, rock, plant litter, mosses, lichens, or dark algal crusts.	Record point-intercept data for at least 100 points and canopy gap intercept data for at least 75-100 m (may be divided among up to 4 transects).[1]				
(b) Bare ground patch size. A bare ground patch is an area where bare ground is greater than expected and greater than the overall average of the area of interest. It may include some ground cover (plants, litter, rocks, and visible biological soil crusts) within the patch.	Very large (> 2 m diameter).	Large (1-2 m diameter).	Moderate (0.25-1 m diameter).	Small (0.1-0.25 m diameter).	Very small (< 0.1 m diameter).
(c) Bare ground patch (as defined for 4(b)) connectivity.	Generally connected.	Occasionally connected.	Sporadically connected.	Rarely connected.	Never connected.
5. Gullies. Large, deep, intermittent watercourses with steep sides. Stable gullies have less steep sides with plants and no active erosion at the headcut (top) or top of sides.	Active headcut, whether or not in evaluation area; unstable sides.	Active headcut, whether or not in evaluation area; partially stable sides.	Active headcut, whether or not in evaluation area; stable sides with a few nickpoints.	Inactive; stable throughout.	None.
6. Wind-Scoured and/or Depositional Areas	Widespread throughout area (> 50% of area affected).	Many (25-50% of area affected).	Common (10-25% of area affected).	Few.	None.
7. Litter Movement (Wind or Water). Distance moved by different sizes of plant litter (needles, leaves, bark, branches). Indicated by litter accumulation in low, flat (water) or protected (wind) areas.	Fine litter moved very long distances (> 6 m); large litter moved moderate distances (< 3 m).	Fine litter moved long distances (< 6 m); large litter moved short distances (< 1.5 m).	Fine litter moved moderate distances (< 3 m); large litter moved very short distances (< 0.6 m).	Fine litter moved short distances (< 1.5 m).	Fine litter moved very short distances (< 0.6 m).
8. Soil Surface Resistance to Erosion	Average soil aggregate stability values under plant canopies and in plant interspaces based on the soil stability test.[1]				

Table A7.2. continued

Indicator	Class 5	Class 4	Class 3	Class 2	Class 1
9. Soil Surface Loss and Degradation	Take at least 1 photo of the top 30 cm of soil in a pit under a typical plant or patch of plant and in an interspace and (a) measure depth of the surface (A) horizon (organic matter-rich layer, if any); (b) record its color and the color of the soil at 35 cm or 10 cm below the bottom of the A horizon (whichever is greater); and (c) record the type, size, and strength of soil structure using the photos in Schoeneberger (2012).				
10. Effects of Plant Community Composition and Distribution on Infiltration	Use line point intercept data and canopy gap intercept data from #4.[1]				
11. Compaction Layer. Dense soil layers below the soil surface with horizontal (platy) structure at least 2 in (can be up to 8-10 in) below the soil surface, which affect or reduce root penetration (e.g., grow horizontally).	Extensive; severely restricts water movement and root penetration.	Common; greatly restricts water movement and root penetration.	Moderately widespread; moderately restricts water movement and root penetration.	Rarely present or thin; weakly restricts infiltration and root penetration.	None.
12. Functional/Structural Groups	Use line point intercept data from #4[1] or record plant production by species.				
13. Dead or Dying Plants or Plant Parts. Proportion of aboveground biomass that is dead or dying (may also use line point intercept data from #4 if mortality is included).	> 50%.	25-50%.	10-25%.	2-10%.	< 2%.
14. Litter Cover and Depth	Use line point intercept data from #4[1] Measure litter depth at multiple locations on the transect.				
15. Annual Production	Weigh and estimate annual production for at least 4 locations in the plot, including adjusting for moisture content, growth stage, and utilization.[2]				
16. Invasive Plants	Use line point intercept data from #4.[1]				
17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants. The ability of perennial plants, but not invasive plants, to produce seeds or tillers and to recover following grazing, drought, or other disturbance.	At least 10% of the individuals of < 50% of the species capable of reproduction, including < 50% of the species that are dominant or subdominant.	At least 10% of the individuals of 50% of the species capable of reproduction, including 50% of the species that are dominant or subdominant.	At least 10% of the individuals of 75% of the species capable of reproduction, including 75% of the species that are dominant or subdominant.	At least 10% of the individuals of 90% of the species capable of reproduction, including 90% of the species that are dominant or subdominant.	Nearly all perennial species capable of reproduction, including all that are currently dominant or subdominant.

[1] See "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems" (Herrick et al. 2017).

[2] See "National Range and Pasture Handbook" (NRCS 2006) for protocols to determine species composition by weight.

Appendix 8. Estimating Annual Production

An estimate of annual production is required to rate indicator 15, annual production. Annual production is the net quantity of aboveground vascular plant material produced within a growing season. For IIRH assessments, departure ratings for the annual production indicator are determined based on 20% reductions from expected values provided in the reference sheet (see evaluation matrix in Appendix 2). Methods for estimating annual production are: (1) total harvest, which involves clipping plots and weighing vegetation (NRCS 2006; BLM 2001); (2) weight unit, which involves comparing vegetation in a plot to a sample with a known weight; and (3) double sampling, which involves estimating by weight unit and harvesting to correct estimates (NRCS 2006; BLM 2001). All three methods can be used to estimate annual production in order to rate departure from expected annual production in an evaluation area (in conjunction with the appropriate ecological site description). Evaluators should select the method with which they are most comfortable.

Ideally, annual production data should be collected as close to the end of a growing season as possible. If this is not possible, annual production estimates can be made before or after a growing season as long as the adjustment factors listed in step 5 are used. Estimates after a growing season can be improved by developing weight units for various species when they are fully grown and ungrazed and using them for subsequent annual production estimates.

The total harvest and/or weight unit methods are recommended to estimate annual production for observers with little or no experience or for those with experience that need to "calibrate" their estimates. The goal in using these two methods is to train individuals to estimate total annual production to an accuracy of (+ or - 20%) based on an ocular estimate.

The total harvest method may be more efficient in some herbaceous plant communities (e.g., cheatgrass stands, crested wheatgrass seedings), while the weight unit method is more efficient when estimating production on shrub or tree species. Estimating total annual production for the purposes of IIRH does not require determining production or composition by species.

Detailed guidance and forms to record data are available in the "National Range and Pasture Handbook" (NRCS 2006), "Inventory and Monitoring: Ecological Site Inventory" technical reference (BLM 2001), and "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems Volume II" (Herrick et al. 2009). A blank "IIRH Field Form for Estimating Annual Production," as well as a competed example of the form, are provided at the end of this appendix. Basic steps required to estimate total annual production in an evaluation area using the weight unit or total harvest methods follow. Please refer to the preceding references for more detailed information on these methods, especially if determining species composition by weight is the objective.

Step 1. Prepare to conduct annual production studies.
Before going to the evaluation area, ensure the necessary equipment is packed, such as plot frames of the appropriate size, scales, forms, clippers, paper bags, rubber bands, and ecological site descriptions for the evaluation areas where IIRH will be applied (see Appendix 3). Also, review and gather recent weather information, as well as growing season conditions for the past several years. Visit with appropriate local managers (federal, state, tribal, private landowners, etc.) to learn precipitation amounts and timing, as well as other recent weather variables for the past 2-3 years. Knowledge of seed mixes for past seeding treatments can also be helpful in identifying species in annual production plots.

Step 2. Select plot locations for estimating annual production.
The recommended minimum number of plots for estimating annual production using the weight unit or total harvest methods is five plots. Select plot locations randomly to avoid bias in production estimates. A restricted random approach is recommended. One option is to randomly establish one plot near the center of the evaluation area and randomly establish a plot in each quarter of the evaluation area (Figure A8.1).

To randomly establish the plots in this way, select a random direction (azimuth) between 0 and 360 degrees and a random number less than 10. In the middle of the evaluation area, face the random direction and then take steps equal to the random number less than 10. This will be the starting point for the first production plot (Figure A8.1). Place the frame on the ground with the edge against your toe. Next, select four random bearings within each quarter of the evaluation area (0-90, 91-180, 181-270, and 271-360 degrees) and four random numbers less than 10 to pace along each bearing starting from plot 1. Make sure the random pace numbers remain within the evaluation area. Use these five plot locations to estimate total annual production with the weight unit or total harvest methods.

Additional plots may be required in evaluation areas with patchy vegetation to account for spatial heterogeneity. Annual production of herbaceous species is recorded in 9.6-ft^2 plots (see step 3b). If trees or large shrubs are present in a patchy distribution, a larger plot can be centered on 9.6-ft^2 plots to estimate tree/large shrub production.

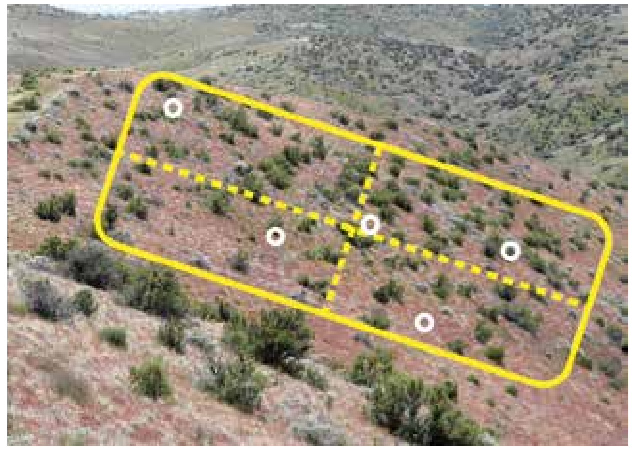


Figure A8.1. Example of five annual production plot locations that were selected randomly in an evaluation area.

Step 3a. Determine which plot sampling approach to use when estimating or clipping annual production.
There are two different approaches (Figures A8.2a and A8.2b), one mainly used by the Bureau of Land Management (BLM) and one mainly used by the Natural Resources Conservation Service (NRCS), for determining which vegetation to include in each plot.

For the BLM approach (Figure A8.2a), all portions of plants inside the perimeter of the plot are included in the annual production calculation. This includes plants that are rooted outside the plot but have foliage inside the perimeter of the plot. See the "Inventory and Monitoring: Ecological Site Inventory" technical reference (BLM 2001) for more information on this approach. Note, in sparse vegetation with shrubs, this approach can reduce variability among plots, especially when there are a minimal number of plots. Also, with taller vegetation or in windy conditions, it can be difficult to determine which plant parts are within the perimeter of the plot.

For the NRCS approach (Figure A8.2b), all plants rooted inside the perimeter of the plot are measured or estimated, even if parts of the plant extend beyond the perimeter of the plot. In the example in Figure A8.2b, although a part of the tall shrub overhangs into the plot, it is rooted outside plot and thus would not be included in the annual production estimate; both the portion of the short shrub inside and outside the plot would be included. See the "National Range and Pasture Handbook" (NRCS 2006) for more information on this approach.

Both approaches are acceptable for estimating production to rate the annual production indicator, so evaluators should use the approach with which they are most comfortable. Once an approach is selected, it should be used consistently. Document the approach used in the "IIRH Field Form for Estimating Annual Production," which is provided at the end of this appendix.

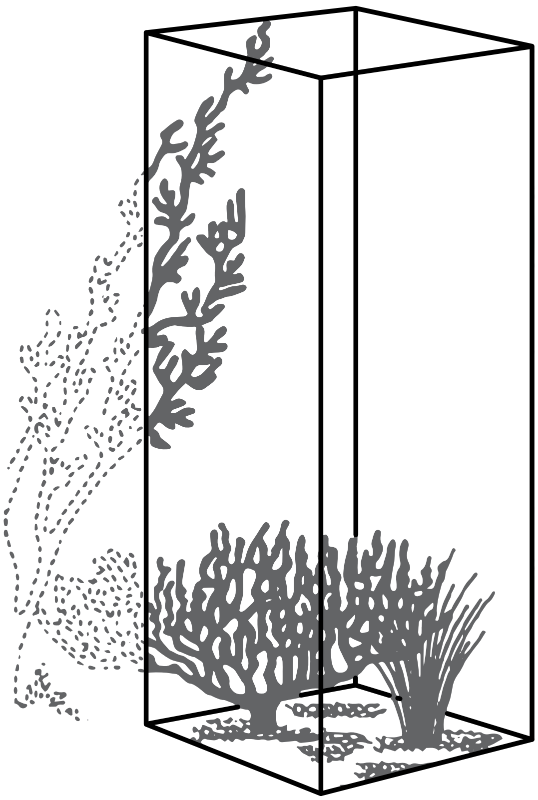


Figure A8.2a. Example of BLM approach for estimating annual production in a plot. This approach includes portions of plants rooted outside the plot that extend inside the plot.

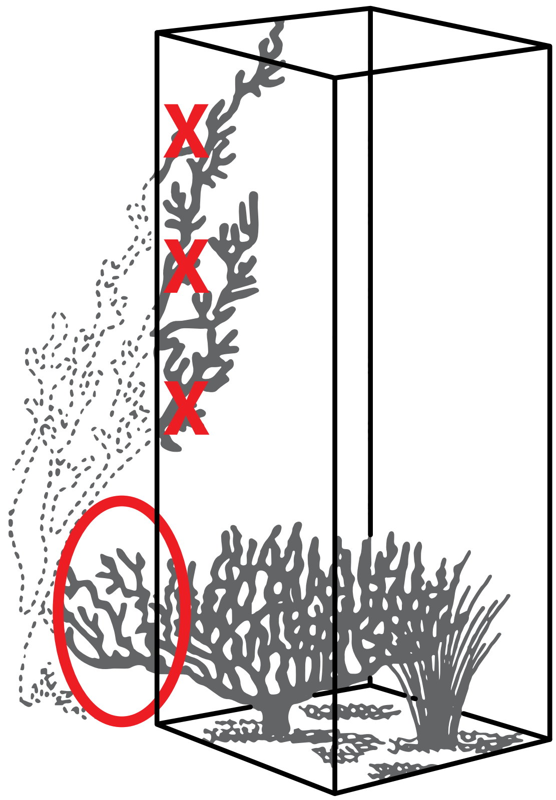


Figure A8.2b. Example of NRCS approach for estimating annual production in a plot. This approach includes portions of plants rooted inside the plot that extend outside the plot (circled). This approach does not include portions of plants rooted outside the plot that overhang inside the plot (red Xs).

Step 3b. Determine plot size (modified from NRCS 2006).
Different plot sizes and shapes are used depending on vegetation distribution and variability (see instructions on the back of the "IIRH Field Form for Estimating Annual Production").

If vegetation is relatively short, then 1.92-ft^2 (59-inch circumference), 2.4-ft^2 (66-inch circumference), 4.8-ft^2 (93.2-inch circumference), and 9.6-ft^2 (131.8-inch circumference) plots are well suited to use in determining production in pounds per acre. A 9.6-ft^2 plot is generally used in areas where vegetation density and production are relatively light (e.g., sagebrush steppe). The smaller plots (especially the 1.92-ft^2 plot) are of sufficient size in areas of homogeneous, relatively dense vegetation, such as that in meadows, plains, and prairie regions. Plots larger than 9.6 ft^2 should be used where vegetation is sparse and heterogeneous.

If vegetation consists of trees or large shrubs, larger plots must be used. If the tree or shrub cover is uniform, a 0.1-acre (66 ft^2) plot is suitable. For statistical analyses, 10 plots of 0.01 acre are preferable to a single 0.1-acre plot.

If vegetation includes a mixture of larger and smaller statured plant types (e.g., trees and grasses), two sizes of plots are generally needed. A series of 10 square or rectangular plots of 0.01 acre and a smaller plot, such as a 9.6-ft^2 plot, nested in a designated corner of each square or rectangular plot is suitable. A 0.01-acre plot is used for trees or large shrubs, and the smaller plot is used for lower growing plants. Convert the weights of the vegetation from both plots to pounds per acre.

Step 4a. Using the weight unit method.
The weight unit method is an efficient means of estimating annual production and lends itself readily to self-training. Estimating annual production by weight units is one method that can be used to train evaluators to estimate annual production in evaluation areas. This method is based on procedures described in the "National Range and Pasture Handbook" (NRCS 2006) but has been modified for the purposes of an IIRH assessment. Once evaluators gain experience estimating annual production using this method, a simple ocular estimate may be used to rate the total annual production in evaluation areas with similar vegetation and growing season conditions in future assessments. It is recommended to periodically calibrate estimates of annual production. This can be accomplished by making an ocular estimate of annual production in a plot based on weight units and then clipping the plot. Use the total harvest method described in step 4b to weigh the clippings and adjust the ocular estimate to the measured values.

Use the following procedure to establish a weight unit for a species:

1. Decide which weight unit (pounds or grams) is appropriate for the species (or group of species with similar characteristics (e.g., annual grasses)).

2. Outside the plot that will be sampled, visually select part of a plant, an entire plant, or a group of plants that will most likely equal this weight. The size and weight of a unit vary according to the kind of plant (see Figure A8.3). For example, a unit of 5 to 15 grams is suitable for small grass or forb species. Weight units for large plants may be several pounds or kilograms.

3. Harvest and weigh the plant material to determine actual wet weight of each weight unit. Remove leaves or leaders from the previous growing season before weighing, since they are not part of this growing season's annual production). Use a rubberband to keep the weight unit together to estimate weight units in all five plots.

4. Repeat this process until the desired weight unit can be estimated with reasonable accuracy on current and future plots.

5. Record the weight units by species or groups of species in the "IIRH Field Form for Estimating Annual Production." The back of this field form describes the step-by-step process to record weight units and make necessary adjustments (see step 5) to estimate total annual production.

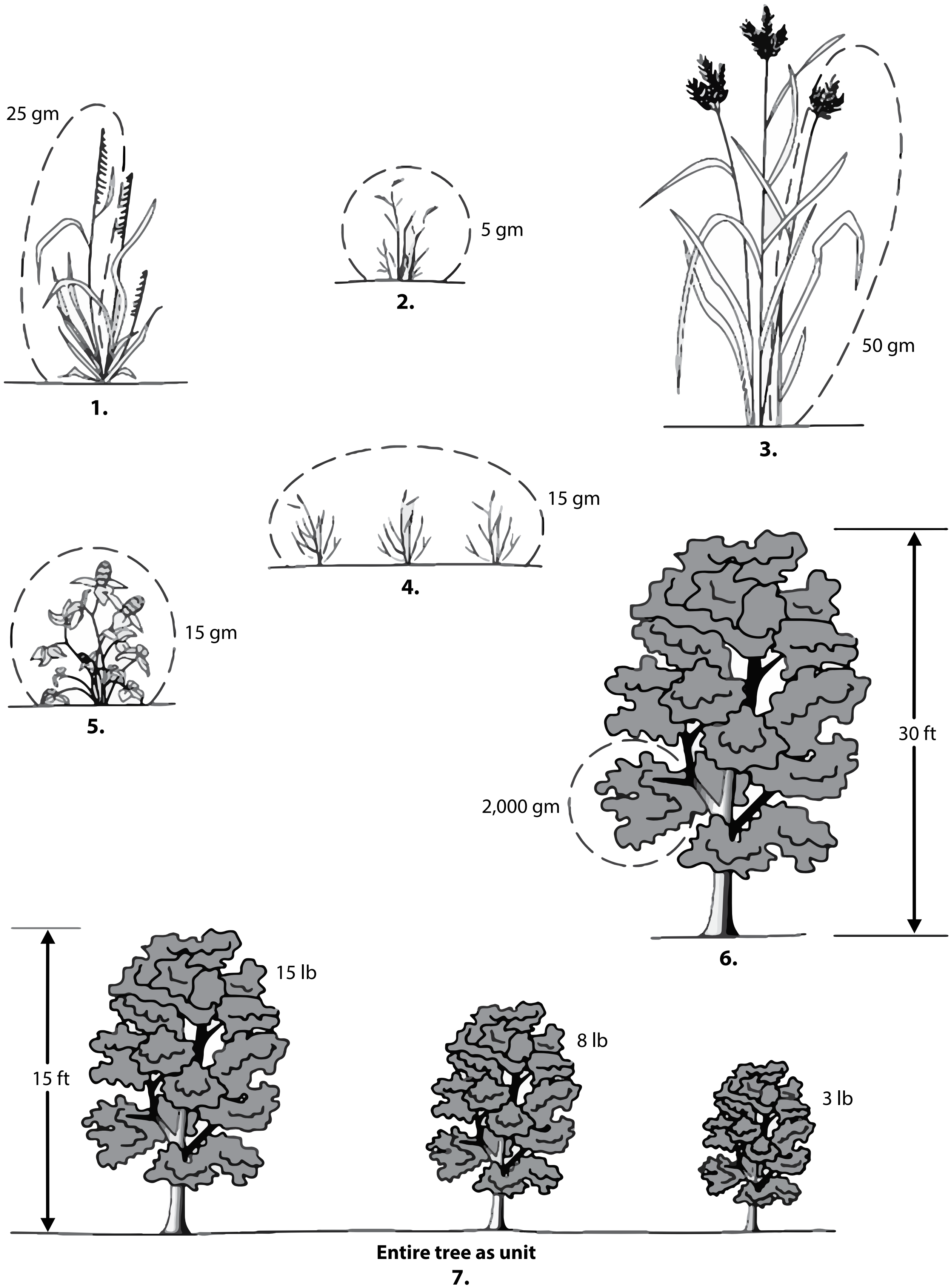


Figure A8.3. Examples of weight units for different plant types (NRCS 2006).

Step 4b. Using the total harvest method.
The total harvest method involves clipping and weighing the current production of all vegetation in each plot. Apply adjustments (air dry, utilization, and growth) to the vegetation clipped in the plots. Do not consolidate plant species in the same bag for weighing if there are significant differences in air dry weight, utilization, and amount of growing season completed between species (see step 5). Remove leaves and stems from the previous growing season prior to weighing the vegetation in each plot. This method is efficient in annual grass-dominated rangelands and areas with introduced wheatgrass seedings. Once evaluators gain experience estimating annual production on a particular ecological site using this method, a simple ocular estimate may be used to rate the total annual production and growing season conditions in evaluation areas in the same ecological site for future assessments.

Step 5. Incorporate adjustments and determine total annual production.
Three adjustments are required when using the weight unit and total harvest methods:

1. **Air dry values.** All production data must be expressed in air-dried weight in pounds per acre (lb/acre) or in kilograms per hectare (kg/ha). The field weight must be converted to air-dried weight. This will require drying either the weight units or clipped plot vegetation or using regional or locally developed conversion tables (Table A8.1). If the vegetation is cured and at air-dried weight, no conversion is required.
2. **Utilization.** Portions of plants removed by herbivory are "reconstructed" in order to estimate total annual production. Detailed instructions on different approaches to determine utilization are available in "Utilization Studies and Residual Measurements" (BLM 1999) and the "National Range and Pasture Handbook" (NRCS 2006). Use these same approaches to reconstruct dropped leaves, fruits, seeds, etc., and include with the utilization reconstruction.
3. **Amount of growing season completed.** Use plant community growth curves, which can be found in most ecological site descriptions, to adjust total annual production relative to plant growth stages throughout the growing season (based on the amount of growing season completed).

Applying and recording adjustment factors are the same for both the weight unit and total harvest methods and are described on the back of the "IIRH Field Form for Estimating Annual Production." For the last step, enter the total annual production value using the formula on the back of the field form. Both methods can be used simultaneously in an evaluation area (e.g., herbaceous vegetation is clipped and weighed using the total harvest method and shrub production is estimated using the weight unit method). In summary, total annual production = (field weight from either method x air-dried weight conversion)/(% remaining after utilization x % growing season completed).

Table A8.1. Generic dry weight conversion factors of different plant types (NRCS 2006). Annual production of pinyon pine and juniper can be calculated using tables in "Inventorying, Classifying, and Correlating Juniper and Pinyon Communities in Soils in Western United States" (NRCS 1997a) and the "National Range and Pasture Handbook" (NRCS 2006).

Percentage of Air-Dry Matter in Harvested Plant Material at Various Stages of Growth					
Grasses	**Before heading; initial growth to boot stage (%)**	**Headed out; boot stage to flowering (%)**	**Seed ripe; leaf tips drying (%)**	**Leaves dry; stems partly dry (%)**	**Apparent dormancy (%)**
Cool-season Wheatgrasses Perennial bromes Bluegrasses Prairie Junegrass	35	45	60	85	95
Warm-season Tall grasses Bluestem Indiangrass Switchgrass	30	45	60	85	95
Midgrasses Sideoats grama Tobosa Galleta	40	55	65	90	95
Short grasses Blue grama Buffalograss Short three-awns	45	60	80	90	95
Trees	**New leaf and twig growth until leaves**	**Older and full-size green leaves (%)**	**Green fruit (%)**	**Dry fruit (%)**	
Evergreen coniferous Ponderosa pine Slash pine Longleaf pine Utah juniper Rocky Mountain juniper Spruce	45	55	35	85	
Live oak **Deciduous** Blackjack oak Post oak Hickory	40 40	55 50	40 35	80 85	

Table A8.1. continued

Percentage of Air-Dry Matter in Harvested Plant Material at Various Stages of Growth					
Shrubs	**New leaf and twig growth until leaves are full size (%)**	**Older and full-size green leaves (%)**	**Green fruit (%)**	**Dry fruit (%)**	
Evergreen Big sagebrush Bitterbrush Ephedra Algerita Gallberry	55	65	35	85	
Deciduous Snowberry Rabbitbrush Snakeweed Gambel oak Mesquite	35	50	30	85	
Yucca and yucca-like plants Yucca Sotol Saw palmetto	55	65	35	85	
Forbs	**Initial growth to flowering (%)**	**Flowering to seed maturity (%)**	**Seed ripe; leaf tips dry (%)**	**Leaves dry; stems drying (%)**	**Dry (%)**
Succulent Violet Waterleaf Buttercup Bluebells Onion Lilies	15	35	60	90	100
Leafy Lupine Lespedeza Compassplant Balsamroot Tickclover	20	40	60	90	100
Fibrous leaves or mat Phlox Mat eriogonum Pussytoes	30	50	75	90	100
Succulents	**New growth pads and fruits (%)**	**Older pads (%)**	**Old growth in dry years (%)**		
Pricklypear and barrel cactus	10	10	15+		
Cholla cactus	20	25	30+		

IIRH Field Form for Estimating Annual Production: Weight Unit and Total Harvest Methods

State ________ Office ______________ Ecological site ______________________________ Ecol. site code ________

Observers ____ Date ____________

Evaluation site ID or name: _________________________ Plot approach used: 1) ___ Rooted in plot (NRCS); 2) ___ In plot cylinder (BLM)

Species or Species Group and Method Used: Weight Unit (WU) or Total Harvest (TH) (1)			No. of Weight Units or Clipped Weight (2) Plot Number:												Adjustments (Adj)			
Species Name	W U ☐	T H ☐	1	2	3	4	5	Total # wgt. units or clipped wgt. by spp (3)	Avg. # wgt. units or avg. clipped wgt. (4)	Wgt. unit wgt. (5)	g or lb (6)	Plot size (7)	Plot CF (8)	Field wgt. (lb/ac) (9)	Air dry wgt. adj. (10)	Util. adj. (11)	Growth adj. (12)	Total wgt. in lb/ac (13)
			Total Pounds per Acre of Annual Production in the Evaluation Area															

Instructions for Estimating Annual Production

Column 1 Enter the acceptable plant symbol from the USDA PLANTS Database at https://plants.usda.gov/ or the common name of the plant species. For each species (or group of species), place a check mark in the appropriate column to indicate whether the weight unit or total harvest method was used in the plots.

Column 2 For plots 1 through 5 (P-1 through P-5), enter an estimate of the number of weight units by species or group of species (e.g., annual grasses after they have become dormant) occurring in the appropriate plot(s), or the clipped weight by species occurring in the plots. The weight unit number can be expressed numerically (e.g., 6, 11.5). If weight by species is recorded, the number entered would be the total measured or estimated weight for that species. For example, a number of 52 in P-3 would mean that 52 grams or pounds is the clipped or estimated weight for that species in plot 3.

Column 3 This column represents the summarized total number of weight units or clipped weight by species occurring in plots 1 through 5 as determined by the data collector.

Column 4 Enter the average number of weight units (e.g., column 3 ÷ number of plots estimated).

Column 5 If weight units are entered in the plot data (2) columns, complete this column by entering the weight unit weight by species. If weight by species was entered in the plot data (2) columns, rather than weight units, enter 1 in this column.

Column 6 Enter the weight measure unit (grams or pounds) for the weight unit shown in column 4 or for the summarized species weight listed in column 3.

Column 7 Enter the plot size used.

Column 8 Enter the plot size conversion factor (CF) for grams to pounds per acre:

Plot Size	Weight or Clipped Unit	Conversion Factor: g/plot to lb/ac		Plot Size	Weight or Clipped Unit	Conversion Factor: g/plot to lb/ac
0.96 ft^2	grams	100		9.6 ft^2	grams	10
1.92 ft^2	grams	50		96 ft^2	grams	1
2.4 ft^2	grams	40		0.01 acre	grams	.22
4.8 ft^2	grams	20		0.1 acre	grams	.022

Column 9 Field weight is calculated: Weight Unit Method: Field Weight (9) = Columns (4) x (5) x (8); Total Harvest Method: Field Weight (9) = Columns (4) x (8).

Column 10 Enter the appropriate conversion to air dry weight percent in decimal form (30% is entered as 0.30), from green weight conversion tables (Table A8.1), local conversion tables, or by drying and reweighing weight units.

Column 11 Complete this column only when the current season's growth of plant species has been reduced by grazing (herbivory). Enter the amount in decimal form (e.g., 0.25, 0.40, 0.60), which best reflects the percentage of the "plant remaining" after grazing utilization has occurred. For example, if a plant species averages 30 percent utilization in the production transect, the percentage of plant material remaining would be 70 percent. Thus, the adjustment entered for that particular species would be .70. Utilization may vary through the plots, requiring an estimate of the average use.

Column 12 Enter the cumulative percent of growth, in decimal form, that has occurred up to the time plot data is collected. The values entered can reflect the growth curves for the site (provided in most ecological site descriptions) or based on locally developed growth curve data.

Column 13 This column represents the air-dried reconstructed weight in pounds per acre after considering all conversion, correction, and adjustment factors. Calculate pounds per acre (nearest pound) for each plant species or group of species by multiplying the average number of weight units (4), by the weight of the individual weight unit (5), by the plot size conversion factor (8). This equals field weight (9). Multiply field weight (9) by the air-dried weight adjustment (10). Then divide by the product of utility adjustment (11) and growth adjustment (12). The formula is:

$$\text{Total Annual Production (air dry weight in pounds per acre)} = \frac{\text{Columns (9) x (10)}}{\text{Columns (11) x (12)}}$$

Example of a Completed IIRH Field Form for Estimating Annual Production: Weight Unit and Total Harvest Methods

State ___________ Office _______________________ Ecological site ____ Ecol. site code ___________

Observers ____ Date___________________

Evaluation site ID or name: ____ Plot approach used: 1) ___ Rooted in plot (NRCS); 2) ___ In plot cylinder (BLM)

Species or Species Group and Method Used: Weight Unit (WU) or Total Harvest (TH) (1)			No. of Weight Units or Clipped Weight (2) Plot Number:											Adjustments (Adj)			
Species Name	WU	TH	1	2	3	4	5	Total # wgt. units or clipped wgt. by spp (3)	Avg. # wgt. units or avg. clipped wgt. (4)	Wgt. unit wgt. (5)	g or lb (6)	Plot size (7)	Plot CF (8)	Field wgt. (lb/ac) (9)	Air dry wgt. adj. (10)	Util. adj. (11)	Growth adj. (12)	Total wgt. in lb/ac (13)
Bluebunch Wheatgrass	✔		2	3.5	4	3	Trace	12.5	2.5	20	g	9.6 ft^2	10	500	0.65	0.7	0.9	516
Annual Grasses		✔	56	60	51	45	66	278	55.6	NA	g	9.6 ft^2	10	556	0.95	1	1	528
Wyoming Big Sagebrush	✔		8	20	18	17	15	78	15.6	90	g	0.01 ac	0.22	309	0.65	1	1	201
			Total Pounds per Acre of Annual Production in the Evaluation Area															1,300

Weight Unit Formula:

Field Weight (9) = Columns (4) x (5) x (8); Pounds per Acre = $\frac{\text{Columns (9) x (10)}}{\text{Columns (11) x (12)}}$

Bluebunch Wheatgrass

Field Weight = 2.5 x 20 x 10 = 500 lb/ac; Pounds per Acre = $\frac{500 \times 0.65}{0.7 \times 0.9} = \frac{325}{0.63}$ = 516 lb/ac

Wyoming Big Sagebrush

Field Weight = 15.6 x 90 x 0.22 = 309 lb/ac; Pounds per Acre = $\frac{309 \times 0.65}{1 \times 1}$ = 201 lb/ac

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Total Harvest Formula:

Field Weight (9) = Columns (4) x (8); Pounds per Acre = $\frac{\text{Columns (9) x (10)}}{\text{Columns (11) x (12)}}$

Annual Grasses

Field Weight = 55.6 x 10 = 556 lb/ac; Pounds per Acre = $\frac{556 \times 0.95}{1 \times 1}$ = 528 lb/ac

Appendix 9. Soil Stability Bottle Cap Test

The soil stability test measures the soil's stability (or resistance to erosion). Soil surface resistance to erosion (indicator 8) is a very sensitive indicator of land degradation. Soil surface resistance to erosion is also a valuable indicator because it is less sensitive to short-term changes (e.g., due to drought) than other indicators, such as bare ground. Soil stability is usually greater when there is more organic matter in the soil. Soil stability is also affected by soil texture (Riginos and Herrick 2010). For instructions for completing the full soil stability test, see the "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems," Volume I, Second Edition (Herrick et al. 2017).

The simplest version of the soil stability test is the bottle cap test, which may be used to rate indicator 8 when a full soil stability test cannot be completed.

To perform the bottle cap test, complete the following steps:

1. Dig up a small soil fragment (a chip about 6-8 mm in diameter) and put it in a bottle cap that is filled with water.
2. Watch the soil fragment for 30 seconds.
3. Gently swirl the water for 5 seconds.
4. Assign one of the following stability ratings (Table A9.1):
    - M = Melts in the first 30 seconds (without swirling)
    - D = Disintegrates when swirled (but does not melt) (Figure A9.1)
    - S = Stable (even after swirling) (Figure A9.2)

Repeat the bottle cap test at several locations within each monitoring site. An increase in soil stability over time means that the risk of erosion has decreased at that site.

Table A9.1. Scale to compare bottle cap test ratings to the relative scale of 1-6 for the soil stability test.

Bottle Cap Test Rating	Description	Equivalent Numerical Range
M	Melts in the first 30 seconds (without swirling)	1-2
D	Disintegrates when swirled (but does not melt)	3-4
S	Stable (even after swirling)	5-6

Figure A9.1. Soil sample that disintegrated when swirled.

Figure A9.2. Soil sample that remained stable, even after swirling.

Appendix 10. Information Sources Useful for Completing an IIRH Assessment

Aerial Photos

- EarthExplorer: *https://earthexplorer.usgs.gov*
- Multimedia Gallery: *https://www.usgs.gov/products/multimedia-gallery/images*
- 1-888-ASK-USGS (1-888-275-8747)
- Images newer than 1996 can be obtained from the National Aerial Photography Program or the National High Altitude Photography and are searchable on EarthExplorer.
- U.S. Department of Agriculture Aerial Photography: *https://www.fsa.usda.gov/programs-and-services/aerial-photography*
- Google Earth: *https://www.google.com/earth*
- Digital Orthophoto Quarter Quadrangle (DOQQ): These aerial photographs have been digitized and georectified, which gives them properties of a map. DOQQs are helpful when using GIS technology to stratify landscapes.
- Natural Resources Conservation Service National Geospatial Center of Excellence: *https://www.ncgc.nrcs.usda.gov/products/datasets/index.html*

Topographic Maps

- U.S. Geological Survey topographic maps (7.5-minute quadrangles): *https://store.usgs.gov/maps*

Digital Raster Graphics

- These U.S. Geological Survey topographic maps have been digitized and georectified and are ready for GIS applications: *https://archive.usgs.gov/archive/sites/topomaps.usgs.gov/drg/index.html*

Soil Surveys and Maps

- Visit the local Natural Resources Conservation Service office.
- NRCS National Soil Survey Handbook: *http://soils.usda.gov/technical/handbook*
- Web Soil Survey: *https://soils.usda.gov/survey*
- SoilWeb: *https://casoilresource.lawr.ucdavis.edu/gmap/*
- STATSGO2 (State Soil Geographic Database): Map coverage (1:250,000) is available for most areas.
- SSURGO Database: Map coverage (ranges between 1:12,000 and 1:63,360) is available for most areas.
- NRCS Geospatial Data Gateway: *https://gdg.sc.egov.usda.gov*

- Visit the local U.S. Forest Service office to obtain a Terrestrial Ecosystem Survey for the area of interest. Some offices may have these data available in digital form.

- Soil survey data (SoilWeb) available through mobile apps: *https://casoilresource.lawr.ucdavis.edu/soilweb-apps*

General Maps

- Bureau of Land Management land status maps: *https://www.blm.gov/maps*

Species Lists

- U.S. Forest Service, Bureau of Land Management, and Natural Resources Conservation Service local offices (monitoring records)

- Ecological site descriptions

- North American Native Plant Society local chapter: *http://nanps.org*

- U.S. Department of Agriculture PLANTS Database: *https://plants.usda.gov/java*

Ecological Site Descriptions

- Ecosystem Dynamics Interpretive Tool: *https://edit.jornada.nmsu.edu*

- Local Natural Resources Conservation Service offices.

Geologic Maps

- National Geologic Map Database: *https://ngmdb.usgs.gov*

Invasive Species

- Introduced, Invasive, and Noxious Plants: *https://plants.usda.gov/java/noxiousDriver*

Other Landscape Tools

- The Land-Potential Knowledge System (LandPKS) (*https://www.landpotential.org*) provides web-based tools to assist land managers in collecting site-specific soil and vegetation data and provides access to several global databases on soils, climate, and topography (Herrick et al. 2016).

- The Landscape Toolbox (*https://www.landscapetoolbox.org*) is a coordinated system of tools and methods for implementing land health monitoring and integrating monitoring data into management decisionmaking.

Land Treatment Information

- The Land Treatment Digital Library (LTDL) (*https://ltdl.wr.usgs.gov*) catalogs legacy land treatment information on Bureau of Land Management lands in the Western United States. The LTDL can be used by federal managers and scientists for compiling information for data calls, producing maps, generating reports, and conducting analyses at varying spatial and temporal scales.

Additional Information about Soil-Related Indicators

- Rangeland Soil Quality Information Sheets: *https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/resource*

Rangeland Analysis Platform

- This online tool (*https://rangelands.app*) provides quick snapshots of rangeland vegetation and allows users to compare trends in rangeland resources through time at various scales.

BLM Assessment, Inventory, and Monitoring Data

- Landscape Approach Data Portal: *https://landscape.blm.gov/geoportal/catalog/main/home.page*

Appendix 11. Common and Scientific Plant Names Used in This Technical Reference

Common Plant Names	Scientific Plant Names
Algerita	*Mahonia trifoliolata*
Balsamroot	*Balsamorhiza* spp.
Barrel cactus	*Ferocactus* spp.
Basin wildrye	*Leymus cinereus*
Big sagebrush	*Artemisia tridentata*
Bitterbrush	*Purshia* spp.
Blackjack oak	*Quercus marilandica*
Blue grama	*Bouteloua gracilis*
Bluebells	*Mertensia* spp.
Bluebunch wheatgrass	*Pseudoroegneria spicata*
Bluestem	*Andropogon* spp.
Buffalograss	*Bouteloua dactyloides*
Bulbous bluegrass	*Poa bulbosa*
Burrograss	*Scleropogon brevifolius*
Buttercup	*Kumlienia* spp.
Cheatgrass	*Bromus tectorum*
Cholla cactus	*Cylindropuntia* spp.
Compassplant	*Silphium laciniatum*
Crested wheatgrass	*Agropyron cristatum*
Diffuse knapweed	*Centaurea diffusa*
Ephedra	*Ephedra* spp.
Field (Japanese) brome	*Bromus arvensis*
Fourwing saltbush	*Atriplex canescens*
Gallberry	*Ilex coriacea*
Galleta	*Pleuraphis* spp.
Gambel oak	*Quercus gambelii*
Hickory	*Carya* spp.
Hood's phlox	*Phlox hoodii*
Idaho fescue	*Festuca idahoensis*
Indiangrass	*Sorghastrum nutans*

Common Plant Names	Scientific Plant Names
Indian paintbrush	*Castilleja* spp.
Juniper	*Juniperus* spp.
Kentucky bluegrass	*Poa pratensis*
Knapweed	*Centaurea* spp.
Lespedeza	*Lespedeza* spp.
Lily	*Calochortus* spp.
Little bluestem	*Schizachyrium scoparium*
Longleaf pine	*Pinus palustris*
Low or little sagebrush	*Artemisia arbuscula*
Lupine	*Lupinus* spp.
Maiden blue-eyed Mary	*Collinsia parviflora*
Matted buckwheat	*Eriogonum caespitosum*
Medusahead	*Taeniatherum caput-medusae*
Mesquite	*Prosopis* spp.
Mountain big sagebrush	*Artemisia tridentata* Nutt. ssp. *vaseyana*
Oak	*Quercus* spp.
Onion	*Allium* spp.
Phlox	*Phlox* spp.
Pinyon pine	*Pinus* spp.
Ponderosa pine	*Pinus ponderosa*
Post oak	*Quercus stellata*
Prairie Junegrass	*Koeleria macrantha*
Pricklypear cactus	*Opuntia* spp.
Pussytoes	*Antennaria* spp.
Rabbitbrush	*Chrysothamnus* spp.
Rocky mountain juniper	*Juniperus scopulorum*
Rush skeletonweed	*Chondrilla juncea*
Russian thistle	*Salsola kali*

Common Plant Names	Scientific Plant Names
Sandberg bluegrass	*Poa secunda*
Saw palmetto	*Serenoa repens*
Sideoats grama	*Bouteloua curtipendula*
Sixweeks fescue	*Vulpia octoflora*
Slash pine	*Pinus elliottii*
Snakeweed	*Gutierrezia* spp.
Snowberry	*Symphoricarpos* spp.
Sotol	*Dasylirion* spp.
Spotted knapweed	*Centaurea stoebe*
Spruce	*Picea* spp.
Squirreltail (bottlebrush squirreltail)	*Elymus elymoides*
Switchgrass	*Panicum virgatum*
Tamarisk	*Tamarix* spp.
Thickspike wheatgrass	*Elymus lanceolatus*

Common Plant Names	Scientific Plant Names
Threeawn	*Aristida* spp.
Thurber's needlegrass	*Achnatherum thurberianum*
Tickclover	*Desmodium* spp.
Tobosagrass	*Pleuraphis mutica*
Utah juniper	*Juniperus osteosperma*
Ventenata	*Ventenata dubia*
Violet	*Viola* spp.
Waterleaf	*Hydrophyllum* spp.
Western juniper	*Juniperus occidentalis*
Wyoming big sagebrush	*Artemisia tridentata* Nutt. ssp. *wyomingensis*
Yarrow	*Achillea* spp.
Yellow star-thistle	*Centaurea solstitialis*
Yucca	*Yucca* spp.

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