Interpreting Indicators of Rangeland Health

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Technical Reference 1734-6

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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 changes learned through 13 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 difference is Version 5 clarifies that the indicator narratives described in the reference sheet (Appendix 1) should describe the **natural range of variability**[1] within the reference state (this was implied in Version 4). A better understanding of reference states for ecological sites and their variability in space and time now enables us to include this information for each indicator.

The **natural range of variability** includes the range of variability associated with the natural disturbance regime. The **natural disturbance regime** is the frequency and intensity of natural disturbance events that would have occurred on an ecological site prior to European influence upon that ecological site (ca. 1600) (Winthers et al. 2005). Disturbance events include natural weather and climate variability and native animals that alter ecosystem structure and function. Natural disturbances include, but are not limited to, insect outbreaks, wildfire, native wildlife (herbivory, burrowing, etc.), indigenous human activity, 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 the presence of nonnative plant or animal species, accelerated erosion, soil organic matter loss, changes in nutrient availability, or soil structure degradation outside of the range associated with natural disturbance regimes.

Another significant modification is Version 5 improves guidance on describing the **natural range of variability** for each indicator in the reference sheet through the development of a reference sheet checklist (Appendix 1). This improves the consistency of indicator descriptions in reference sheets for ecological sites and for IIRH assessments. This checklist assists in developing or revising reference sheets through a process that includes the natural range of variability for each indicator. As a result, evaluators will have adequate information to make consistent evaluations.

It is strongly recommended in Version 5 to update reference sheets to include a functional/structural groups (indicator 12) table. This table is derived from the functional/structural groups sheet found in Appendix 2 and defines the **relative dominance** of functional/structural groups within each community phase in the reference state. The table also lists species expected to occur at any one time in the dominant and subdominant functional/structural groups in each of these community phases. This version also reflects revisions to the evaluation matrix (Appendix 3) descriptors that are used to rate the functional/structural

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

groups (indicator 12). This change makes it easier to evaluate this indicator consistently. Consistent with Version 4, it is strongly recommend that users create ecological site-specific evaluation matrices.

Finally, it is recommended to support rangeland health assessments with quantitative measurements, when possible. Quantitative measurements may become the baseline for monitoring should it be necessary. Those working in the United States are particularly encouraged to consider applying the standardized core methods as described in the “Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems,” second edition (Herrick et al. 2018). The use of these quantitative methods allows data to be combined and compared across ownership and jurisdictional boundaries. Information on method selection by the Bureau of Land Management (BLM) is provided in Toevs et al. (2011a) and Herrick et al. (2015). Examples of two applications of IIRH and the standardized core methods to national assessment and monitoring is provided in Herrick et al. (2010),the “RCA Appraisal: Soil and Water Resources Conservation Act” (USDA 2011; NRCS 2015) and the BLM’s Rangeland Resource Assessment (Karl et al. 2016).

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. In 1994 the National Research Council presented the concept of **rangeland health** as an alternative to **range condition** (NRC 1994). Although the word “health” in the term rangeland health was initially controversial when used in association with natural systems (Wicklum and Davies 1995; Lackey 1998; Rapport et al. 1998; Smith 1999), this technical reference follows the National Academy of Sciences suggestion (NRC 1994) and reflects the increasing use of the term for 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 (Adams et al. 1995). A federal interagency ad hoc committee was established to integrate the 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."

This committee defined integrity to mean *"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. The IIRH protocol does this using observable indicators. This protocol relies on a combination of qualitative and quantitative measures to assess the functional status of rangelands.

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 were used independently. However in other cases, they were blended with quantitative measurements.

Early procedures that included indicator ratings (e.g., a scorecard approach) included the Interagency Range Survey of 1937, Deming Two-Phase and Parker Three-Step Methods that determined, among other things, 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 (USDI 1973). Interagency Technical Reference 1737-15 (Ver. 2), *Riparian area management: Proper functioning condition assessment for lotic areas* (USDI 2015), included a qualitative checklist to assess the proper functioning condition of riparian areas.

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 (Adams et al. 1995). Development of a landscape ecology approach to assessing rangeland function in Australia 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 technical 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 1997). 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 into version 2. Extensive peer review of several iterations of version 2 was used to generate version 3 (Pellant et al. 2000), which was the first published version that was widely applied. 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 from a large number of users and peer reviewers of Versions 3 and 4, including feedback from more than 2,000 participants in multiple-day workshops led by the authors and contributors. These changes should improve the consistency of the application and interpretations made using this protocol. Anticipate future revisions 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, using ecological site descriptions, site-specific state-and-transition models, and ecological reference areas (when available) to develop and modify reference sheets (Appendix 1) for rangeland health assessments. The anticipated primary use of this protocol is on **rangelands**, which are defined as “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. This protocol may also be applied in oak and pinyon-juniper woodlands, low-elevation dry forests, and ephemeral stream systems.

Qualitative assessments of rangeland health provide an effective communication tool for use with the public and land managers. In addition, when the IIRH protocol is used in association with quantitative monitoring and inventory information, it may provide early warnings of resource problems on rangelands.

The protocol described in this technical reference is designed to:

- Be used only by people who are knowledgeable and experienced with the protocol and the ecological system being evaluated (including formal training and/or working closely with others who have training and experience).
- Provide a preliminary evaluation of the <u>current status</u> of soil/site stability, hydrologic function, and biotic integrity at the ecological site level. This evaluation requires all 17 indicators to be rated and considered in the attribute ratings as part of the assessment.
- Be used to communicate fundamental ecological concepts to a wide variety of audiences.
- Improve communication by focusing discussion on critical ecosystem properties and processes.
- Assist in 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 method for triaging landscapes for potential types of restoration (Pyke 2011; Pyke et al. 2015).

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 (but repeated evaluations can be used to help interpret quantitative monitoring data collected at the same times).
- Independently generate national or regional assessments of rangeland health without an appropriate sampling framework.

This protocol requires a good understanding of ecological processes, vegetation, and soils for each location. Based on lessons learned during IIRH trainings, the quality and consistency of evaluations are improved when two or more individuals with collective knowledge of soils, vegetation, and disturbance relationships (e.g., rangeland ecologist, soil scientist, hydrologist, etc.) work together to apply this protocol and obtain consensus ratings. The input of multiple individuals is particularly critical in the development of reference sheets 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.

4. Attributes of Rangeland Health

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 **nutrient cycle** (the cycle of nutrients through the physical and biotic components of the environment).

Ecological processes functioning within a **natural range of variability** support specific plant and animal communities. Direct measures of site integrity and the functional status of ecological processes are difficult or expensive to measure due to the complexity of the processes and their interrelationships. Therefore, observable biological and physical components can be used as indicators of site integrity and the functional status of ecological processes. The IIRH protocol uses 17 indicators (Table 1) for the assessment of functional status of ecological processes.

The product of this qualitative assessment is not a single rating of rangeland health, but it is an assessment of three components called attributes, based on a synthesis of subsets of the 17 indicators (Table 1). An **attribute of rangeland health** as used in the IIRH protocol is a complex variable that represents the status of a suite of related ecological properties (e.g., species composition) and processes (e.g., water cycle, energy flow, and nutrient cycle) that are essential to ecosystem function.

Definitions of these 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/or 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 5) based on a **preponderance of evidence** approach using the applicable indicators. This assessment provides an initial rating for the three attributes which may be used with applicable quantitative monitoring and inventory data to complete a rangeland evaluation. The IIRH protocol described in this technical reference produces three ratings, one for each attribute of rangeland health (Table 1).

Table 1. The three attributes of rangeland health and their associated indicators.

	Attributes of Rangeland Health		
	Soil/Site Stability	**Hydrologic Function**	**Biotic Integrity**
Indicators Used to Rate Attributes	• Rills (indicator 1) • Water flow patterns (2) • Pedestals and/or terracettes (3) • Bare ground (4) • Gullies (5) • Wind-scoured and/or depositional areas (6) • Litter movement (7) • Soil surface resistance to erosion (8) • Soil surface loss and degradation (9) • Compaction layer (11)	• Rills (indicator 1) • Water flow patterns (2) • Pedestals and/or terracettes (3) • Bare ground (4) • Gullies (5) • Soil surface resistance to erosion (8) • Soil surface loss and degradation (9) • Effects of plant community composition and distribution on infiltration and runoff (10) • Compaction layer (11) • Litter cover and depth (14)	• Soil surface resistance to erosion (indicator 8) • Soil surface loss and degradation (9) • Compaction layer (11) • Functional/structural groups (12) • Dead or dying plants or plant parts (13) • Litter cover and depth (14) • Annual production (15) • Invasive plants (16) • Vigor with an emphasis on reproductive capability of perennial plants (17)

The 17 indicators are rated individually to determine the attribute ratings. Five departure categories (Table 2) reflect the collective degree of departure of the appropriate indicators in Table 1 based on the reference sheet (Appendix 1). Degree of departure for each attribute is then rated (Table 2) based on the **preponderance of evidence** of the appropriate indicators (Table1).

Table 2. The 5 departure categories of the evaluation matrix (Appendix 3) 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.

5.1 Landscape Context

Landscapes are large, connected geographical regions that have similar environmental characteristics and that may include part or all of one or more watersheds. Several systems are used to classify landscapes into similar stratified units for comparison. 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 respond similarly to management actions and natural disturbance. Together, soils, climate, and topography determine this potential.

Components of the landscape that can be evaluated using the IIRH protocol include the following:

Rangeland components include grasslands, savannas, shrublands, desert, tundra, and alpine communities. This protocol may also be applied in oak and pinyon-juniper woodlands, low-elevation dry forests, and ephemeral stream systems.

Woodlands are areas with a low density of trees forming open plant communities that support an understory of shrubs and herbaceous plants, including grasses. It is appropriate to apply the IIRH protocol in lower elevation open and drier forest systems (e.g., oak, pinyon-juniper, and similar types of low-density woodlands) when appropriate reference information is available.

Ephemeral stream systems in rangelands and woodlands are drainage systems that receive more runoff than typical upland ecological sites, but the soil-water dynamics are generally similar to other upland sites receiving run-on water. Ephemeral stream systems implicitly include, though do not focus on, the channels or drainageways. Ephemeral stream systems can be evaluated using IIRH protocol when appropriate reference information is available.

5.2 Ephemeral stream systems – definition and IIRH application

Ephemeral stream systems in rangelands and woodlands are areas that receive more runoff than typical upland ecological sites, but the soil-water dynamics are generally similar to other upland sites receiving run-on water. They implicitly include, though do not focus on, the drainageways. Ephemeral drainage systems can be evaluated using IIRH protocol when appropriate reference information is available.

Several widely-applied assessment methods are available to evaluate riparian systems. The most widely applied riparian assessment in the United States is the "Proper Functioning Condition" (PFC) assessment (Dickard et al., 2015). Development of PFC was started in 1988. Like IIRH, the PFC assessment method is based on the assumption that systems need to be physically functional before they can produce long-term aquatic or riparian values – as such, the condition of PFC is a prerequisite for achieving desired conditions. A separate PFC protocol is also available for lentic, or non-flowing, systems (Prichard et al., 2003).

Assessment of ephemeral systems is explicitly outside the purview of the PFC assessment method, because the vegetation attributes and soil properties have no riparian characteristics and are truly "upland" in character. The PFC assessment method is specific to channel, stream-bank, and floodplain attributes and processes of perennial and intermittent streams. These streams have the flow duration and/or shallow water table to maintain adequate soil moisture to support riparian vegetation during all or much of the growing season. This reference uses Meinzer's (1923) definition of the difference between intermittent (at least 30 continuous days of flow) and ephemeral (fewer than 30 days). Perennial streams flow continuously during the growing season. Some latitude should be used in applying these terms as natural variation in flow duration is likely for many systems that are near this arbitrary definition. Therefore, it is recommended to use the presence of a riparian plant community in addition to available stream flow periodicity data when determining if intermittent or ephemeral.

It is important to determine if the area being assessed is ephemeral or intermittent based on potential as the necessary attributes and processes needed for physical function differ. Nadeau's (2011) Stream Flow Duration Assessment Method for Oregon provides a protocol to distinguish ephemeral systems from intermittent or perennial streams in one site visit.

Ephemeral systems can be evaluated using IIRH. Ephemeral ecological sites are described for most areas (e.g. 'draw' sites) and are not covered in PFC. They implicitly include, though do not focus on the drainageways. Ephemeral site receive more runoff than typical upland ecological sites, but the soil water dynamics are generally similar to other upland sites receiving run-on water.

Intermittent systems are those that flow continuously for at least 30 days during some part of the year. PFC is used to evaluate the channel, streambank, and floodplain function, and IIRH can be used for the terrace (i.e., abandoned floodplain) areas.

Table 3. Summary of where to apply the IIRH instead of a riparian assessment protocol such as Proper Functioning Condition (PFC).

Duration of Flow	Channel plus channel edge	Riparian zone	Above riparian zone (e.g., terrace)
Ephemeral (less than 30 days of continuous flow per year and no riparian area)	IIRH	IIRH	IIRH
Seasonal/intermittent (at least 30 days of continuous flow per year)	PFC	PFC	IIRH
Perennial (flows continuously during the growing season)	PFC	PFC	IIRH


Figure 1. Examples of Ephemeral Stream Systems

5.4 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, page 12). The fundamental assumption for the ecological site concept is that soils, climate, geomorphology, and plant species can be grouped with sufficient precision to inform and increase the probability of success of site-specific decisions and predictions. Because natural systems seldom include distinct boundaries in either space or time, ecological sites include a certain amount of variability and uncertainty. Important aspects and principles relative to ecological sites are:

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 existing (current) vegetation. 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) conditions of an ecological site (Figure 2). Expert knowledge and the data used to describe an ecological site are derived from both spatially and temporally variable sources. The physical aspects of a site described in an ecological site description (exposure, slope, landform, soil surface texture, etc.) do not include the entire range of values but, rather, the modal values of these variables.

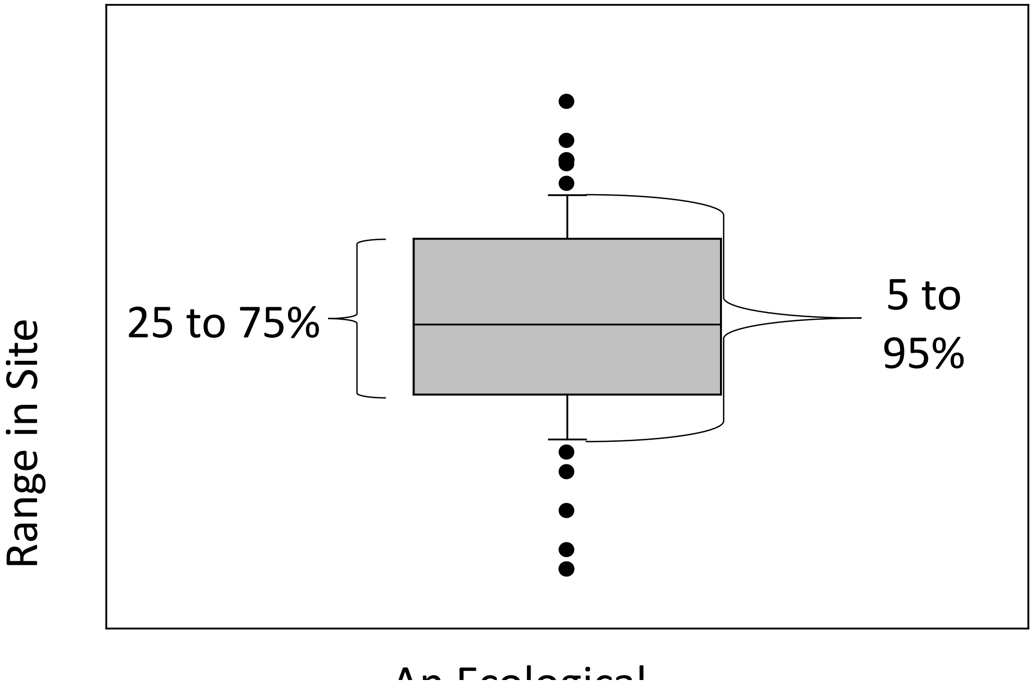


Figure 2. The modal concept of an ecological site may be visualized using a box and whisker diagram. Locations, represented by the vertical line and dots, will range in their individual site characteristics. Most sites will be represented by the central variation (5 to 95 percent). An ecological site description represents these central set of site characteristics (e.g., precipitation), but some locations may fall outside of this central group (outliers, dots). These outliers are still part of the ecological site, but some of their characteristics may fall outside of the central range of values.

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., insect outbreaks, wildfires, native herbivore influence, weather cycles and extremes, including droughts and unusually wet periods, snow and wind events, etc.). However, because states are ultimately defined based on thresholds, it is possible for community phases to exist within the reference state that are not part of the natural range of variability In other words, the reference sheet includes natural range of variability that may be outside the range of the modal concept for the ecological site (Figure 2).

Similarly, transitions between community phases within the natural disturbance regime in the reference state result in plant communities with intermediate compositions between community phases. These transitional plant communities initiated by natural disturbances are documented in the functional/structural groups sheet (Appendix 2) in order to better assess evaluation areas with similar disturbance regimes. For example, in sagebrush steppe ecosystems, plant community composition progresses from grass-dominated after wildfires (phase 1.2) to shrub/grass-dominated (phase 1.1) over time (Figure 3). Relative dominance of shrubs and grasses varies during the transition between these two phases.

5.2 Natural Range of Variability

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 1). The process to include natural range of variability is described in Step 2 (Section 7.2). The following describes two components of the natural range of variability, spatial and temporal variability.

5.2.1 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, topographic position, events within the natural disturbance regime, and plant communities associated with the natural range of variability (see Section 2. Introduction, Section 5.1 Landscape Context, and Section 5.3 States, Transitions, and Disturbances). For example, south-facing slopes are subject to higher evaporation rates and generally have shallower soils than north-facing slopes. Both higher evaporation rates and shallower soil depth 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.

Sites that are located lower on the landscape (downslope) may receive run-on water during intense storms or snowmelt. The effect of receiving increased runoff can be positive for plant growth downslope in run-on areas. Increased runoff can be negative if it results in accelerated erosion and deposition. While sources of spatial variability are expected to be similar within an ecological site, the quality of evaluations can be improved by recognizing and documenting both the expected variation and how these sources of variation may influence individual indicators of rangeland health.

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. However, most 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.

5.2.2 Temporal Variability

Plant communities and soils also vary naturally through time. Seasonal, annual, and multiple-year variation in climate 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 obvious later in the season. Plant growth and development patterns are determined by moisture availability and temperature, 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 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 in conducting an IIRH assessment.

During a short-term drought (1–2 years), annual plant production is expected to decline from what has been defined as the long-term average. This change may also result in less seed production, reduced canopy cover and litter, and increased bare ground. Exceptionally long, dry periods (e.g. greater than 5 years in the Great Basin) may cause parts or all of some perennial plants to die. As the plant community responds to extreme dry conditions, the amount of bare ground increases and the site may become more susceptible to erosion and other degradation. 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).

5.3 States, Transitions, and Disturbances

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 3). 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).

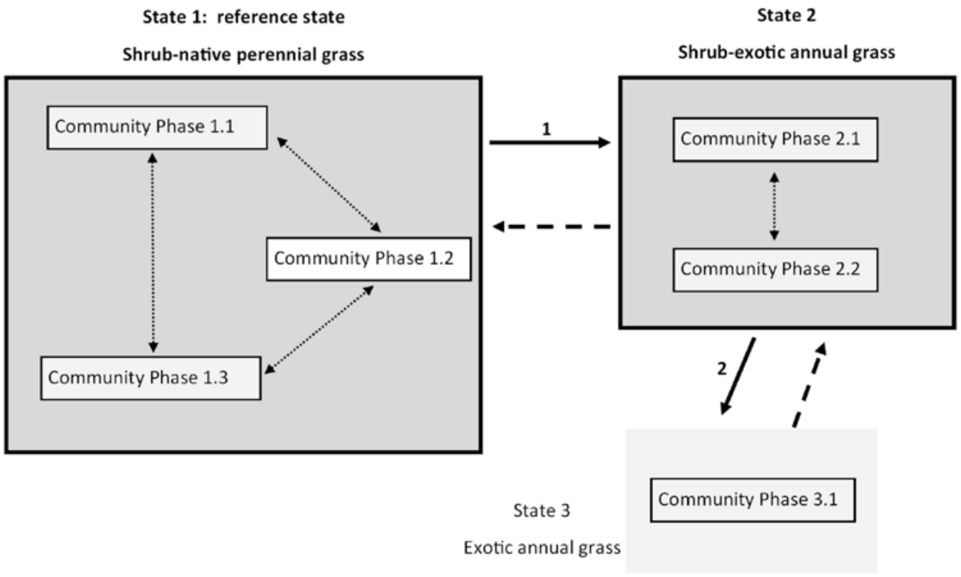
States are distinguished from each other by large differences in dominance among plant functional groups, dynamic soil properties, ecosystem processes, and consequently in vegetation structure, biodiversity, and management requirements that persist over large periods of time. They also differ by their responses to disturbance. However, a state may include a number of different plant communities (e.g., **community phases**), which are often connected by **community pathways** (Bestelmeyer et al. 2003; Stringham et al. 2003; Caudle et al. 2013) (Figure 3). Community pathways (Caudle et al. 2013) describe causes of shifts in dominance 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 is reversible and attributable to succession, natural disturbances, short-term climatic variation, and practices such as grazing 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 3). This state usually includes more than one community phase. While this technical reference uses the community phases occurring *within the natural disturbance regime* of the reference state as the reference for rangeland health assessments, it is recognized that managers may choose to manage for communities in another state (e.g., a seeded forage state). If sustainability is an objective and the site maintains its productive potential, the desired plant community is nearly always found in the reference state (Borman and Pyke 1994), as it is the state that maintains the most future management options.

Shifts between states are referred to as **transitions** (Figure 3). Unlike community pathways, transitions are generally not easily reversible by simply altering the intensity or direction of factors that produced the change. Therefore, a state transition is often referred to as “crossing a **threshold**.” Transition or threshold reversal, if possible, requires new inputs such as revegetation or plant species/functional group removal. Practices such as these, enabling a return to a preexisting state (NRCS 2006), are often expensive and difficult to apply. 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). For example, as shrubs replace warm season grasses in U.S. Southwest rangelands, runoff and erosion increase in shrub interspaces, further reducing soil and water resource availability for the remaining grasses (Schlesinger et al. 1990).

Kachergis et al. (2011) evaluated the utility of the 17 indicators to help 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 of functional indicators, suggesting that the 17 indicators can be used to approximate ecosystem functions associated with different states. In addition to a reference state that functions as expected for the claypan ecological site, four botanically and functionally distinct potential states, consistent with the theoretical concept of alternate states, were suggested by the indicators.

Generic state and transition diagram. Dashed lines between communities within an ecological state are community pathways, solid lines between ecological states are transitions, and dotted lnes 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 may ormay not have different soil or ecosystem health values, but they are functionally equivalent.



Community	Indicators
1.1	Shrubs and native perennial grasses codominant
1.2	Native perennial grasses dominant; shrubs subdominant
1.3	Shrubs dominant; perennial grasses subdominant
2.1	Shrubs dominant; exotic grasses subdominant
2.2	Exotic grasses dominant; shrubs subdominant
3.1	Exotic annual grasses dominant
Transition	**Mechanisms**
1	Wildfire; introduction of exotic, invasive annual grasses
2	Repeated wildfires outside of natural fire regime interval

Figure 3. Conceptual example of a state-and-transition diagram for an ecological site.

5.5 Resistance and Resilience

There is an increasing interest among managers and scientists to better understand 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). Staying within the natural range of variability, including the natural disturbance regime for an ecological site, depends on the resilience of the ecosystem. Ecological **resilience**, as it applies to ecological sites, is 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 like fire or land-use changes (Holling 1973; Peterson et al. 1998). This interpretation of resilience assumes that an ecosystem can be expressed as two or more alternative stable states and recognizes the occurrence of state transitions based on shifts between sets of feedback mechanisms.

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. When disturbances modify the structure and function of a community phase beyond the limits of ecological resilience, the community will cross a threshold to an alternate state rather than recover to a phase within the reference state.

5.6 Other Landscape Classification Systems

In countries where ecological site concepts are not available, similar soil/climate potential concepts could be developed using the best available information and tools, such as the Land-Potential Knowledge System (LandPKS; see Appendix 11: Information Sources Useful in Completing an IIRH Assessment). 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.

5.7 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 a system 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 too difficult, inconvenient, or 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.

5.7.1 Qualitative Assessment of Indicators

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), although quantitative measures are often required to assist evaluators in making acceptable indicator ratings (see Section 7.3 Step 3. Collect Supplementary Information). 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 used in conjunction with, quantitative assessment methods.

5.7.2 Quantitative Assessment of Indicators

Quantitative measurements should be made where it is necessary to document assessments for direct comparisons with other locations, where quantitative data to support qualitative assessments is needed, or where monitoring data are required to determine **trend**. Examples of quantitative data that are needed to support IIRH assessments include, but are not limited to:

- Bare ground (indicator 4)
- Soil surface resistance to erosion (indicator 8) (Appendix 8. Soil Stability Test)
- Litter cover and depth (indicator 14)
- Annual production (indicator 15) (Appendix 9)

At a minimum, quantitative data to support making qualitative assessments is required to train evaluators to rate some of the indicators. When conducting an assessment, collecting appropriate quantitative data is highly recommended.

Many quantitative assessment indicators correlate with the 17 qualitative indicators used in this protocol and can be evaluated with quantitative measurements (Table 4). In some cases, no equivalent quantitative measurement exists for an indicator. This reflects the fact that some ecosystem properties are more accurately reflected by qualitative indicators, while others are more effectively measured quantitatively (Rapport 1995). The specific values associated with each departure class may vary significantly among ecological sites. For example, rill density in the reference state is higher in badlands (e.g., Mancos shale sites in the Colorado Plateau) ecological sites than in ecological sites located on flat terrain in the U.S. Central Great Plains.

The best approach to selecting quantitative indicators to measure in conjunction with the qualitative IIRH protocol is to select the best quantitative indicators for each of the three attributes of rangeland health, rather than selecting an equivalent quantitative indicator for each of the 17 qualitative indicators. The best quantitative indicators are those that, as a group, are most consistently correlated with the ecosystem functions associated with each of the three attributes (Table 4). For example, quantitative indicators for bare ground and soil surface resistance to erosion are both highly correlated with resistance to erosion in most ecological sites and are therefore good indicators of soil/site stability. This same thought process was used in the development of the BLM Assessment, Inventory, and Monitoring Program and the NRCS National Resources Inventory.

Table 4. 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. Because an appropriate quantitative indicator does not exist for each qualitative indicator, it is recommended to focus on selecting the best possible indicators (qualitative and quantitative) for each attribute. For specific indicator comparisons, see Appendix 10.
(1) NRCS 2006; (2) Elzinga et al. 1998 and (3) Herrick et al. 2018.

Attributes of Rangeland Health	Qualitative Assessment Indicators	Key Quantitative Assessment Indicators	Selected Measurements and References
Soil/Site Stability	• Rills • Water flow patterns • Pedestals and/or terracettes • Bare ground • Gullies • Wind-scoured and/or depositional areas • Litter movement • Soil surface resistance to erosion • Soil surface loss and degradation • Compaction layer	Bare ground	**Line point intercept (3)**, point frame (2)
		Proportion of soil surface covered by canopy gaps longer than a defined minimum	**Canopy gap intercept (3)**, continuous line intercept (2)
		Proportion of soil surface covered by basal gaps longer than a defined minimum	Basal gap intercept (3), continuous line intercept (2)
		Soil macroaggregate stability in water	**Soil stability test (3)** (Appendix 8)
Hydrologic Function	• Rills • Water flow patterns • Pedestals and/or terracettes • Bare ground • Gullies • Soil surface resistance to erosion • Soil surface loss and degradation • Effects of plant community composition and distribution on infiltration and runoff • Compaction layer • Litter cover and depth	Bare ground	**Line point intercept (3)**, point frame (2)
		Proportion of soil surface covered by canopy gaps longer than a defined minimum	**Canopy gap intercept (3)**, continuous line intercept (2)
		Proportion of soil surface covered by basal gaps longer than a defined minimum	Basal gap intercept (3), continuous line intercept (2)
		Soil macroaggregate stability in water	**Soil stability test (3)** (Appendix 8)
		Litter cover	**Line point intercept (3)**, point frame (2)
		Plant foliar cover by species or functional/structural groups	**Line point intercept (3)**, point frame (2)
Biotic Integrity	• Soil surface resistance to erosion • Soil surface loss and degradation • Compaction layer • Functional/structural groups	Soil macroaggregate stability in water	**Soil stability test (3)** (Appendix 8)
		Plant foliar cover by functional group	**Line point intercept (3)**, point frame (2)
		Plant basal cover by functional group	**Line point intercept (3)**, point frame (2)
		Litter cover	**Line point intercept (3)**, point frame (2)

Attributes of Rangeland Health	Qualitative Assessment Indicators	Key Quantitative Assessment Indicators	Selected Measurements and References
	• 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	Plant production by functional group	Harvest (1), double sampling (1), Appendix 9
		Invasive plant cover	**Line point intercept (3)**
		Invasive plant density	Belt transect (2), quadrats (2)

5.8 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 processes of a site (in positive or negative ways depending on the ecosystem and the type of crust) and therefore is an important factor in applying the IIRH protocol. Descriptions follow of the three types of soil crusts for consideration in evaluating rangeland health. All three types of crusts may co-occur, with the biological influence often increasing in the absence of disturbance on initially physical or (e.g. in the case of gypsum), chemical crusts.

5.8.1 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. 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 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 descriptions, refer to **ecological reference areas** when developing the reference sheet (Appendix 1).

5.8.2 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 more dense, infiltration rates are reduced and overland water flow increases. Also, water can pond in flat crusted areas increasing evaporation. Physical crusts can be identified by lifting the soil surface with a pen or other sharp 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).

5.8.3 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 they do occur, 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. 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 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 natural range of variability. This often occurs on abandoned farmland where saline irrigation water was used, or where irrigation resulted in the elevation of a saline water table nearer to the soil surface.

5.9 Management Influences on Indicators

The benchmark for the assessment of each of the 17 IIRH indicators 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). The ecological dynamics description in the ecological site description provides general examples of disturbances that contribute to the natural range of variability as determined by the natural disturbance regime. The historical baseline reflects the natural disturbance regime (frequency and intensity) that would have occurred prior to European influence on landscapes (ca. 1600). Human activities outside of the historical range cause varying degrees of departure that are captured in the evaluation sheet (Appendix 5). Anthropogenic disturbances or management activities that can either directly or indirectly result in departures outside of the natural range of variability as determined by the natural disturbance regime include, but are not limited to:

- Fire return intervals that are longer or shorter than what occurred historically.

- Recreational activities that disturb soil or vegetation (off-road vehicle use, recreational trails, etc.).
- Introduction of nonnative plants.
- Livestock use that does not mimic historical herbivory.
- Land treatments (seeding, herbicide application, tree thinning, etc.).
- Roads, energy infrastructure, and urban/suburban development.

These anthropogenic disturbances or management activities may affect one or more of the 17 indicators to varying degrees. Also, it is important to note that pre-European indigenous human influences on ecosystems in the United States included alteration of disturbance regimes and that this is 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.

5.10 Spatial Extrapolation to Regions, Landscapes, and Management Units

Appropriate sample designs incorporating randomized site selection are required to aggregate qualitative assessments into larger landscape units, such as from ecological sites to ecoregions. When randomized site selection is incorporated into the sampling strategy, multiple ecological site-level assessments can be aggregated within similar landscape units to generate a map for each attribute of rangeland health (Figure 4). These maps can help identify areas where management interventions may potentially have the greatest effect on runoff, water quality, and other resource concerns. For example, Miller (2008) assessed 500 locations to prioritize ecological sites for restoration at the Grand Staircase-Escalante National Monument using IIRH Version 3. However, it is extremely important to recognize that these maps generally only portray the dominant ecological site in each map unit.

Another approach is to report the proportion of each reporting unit determined to be in each of the departure classes with a known degree of certainty. The NRCS National Resources Inventory data is an example of this approach, which is possible because of the statistical sampling framework used with the National Resources Inventory (Herrick et al. 2010). The limitation of this approach is that it does not distinguish ecological sites in the report. Another example illustrating this approach is the BLM’s Rangeland Resource Assessment (Karl et al. 2016).

Land managers may select evaluation areas by using local and professional knowledge to identify locations with specific resource or use concerns instead of using using a randomized site selection processes. However, this approach may incorporate bias, either unintentionally or intentionally, and limits the ability aggregate and extrapolate evaluation results. In the past, **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 was presence of a small subset of the plant community (e.g., key species). Key areas may be an appropriate evaluation area in small management units with uniform or well-understood, historically consistent livestock utilization and distribution.

Stratification of samples by dominant ecological sites (or, in larger landscapes, groups of ecological sites, or ecoregions) within the study area ensures that landscape variability is captured in assessments (Figure 4). Likewise, stratification by management unit (e.g., grazing allotment or pasture) ensures that effects of management variability are 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 an allotment; Figure 4B). 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.

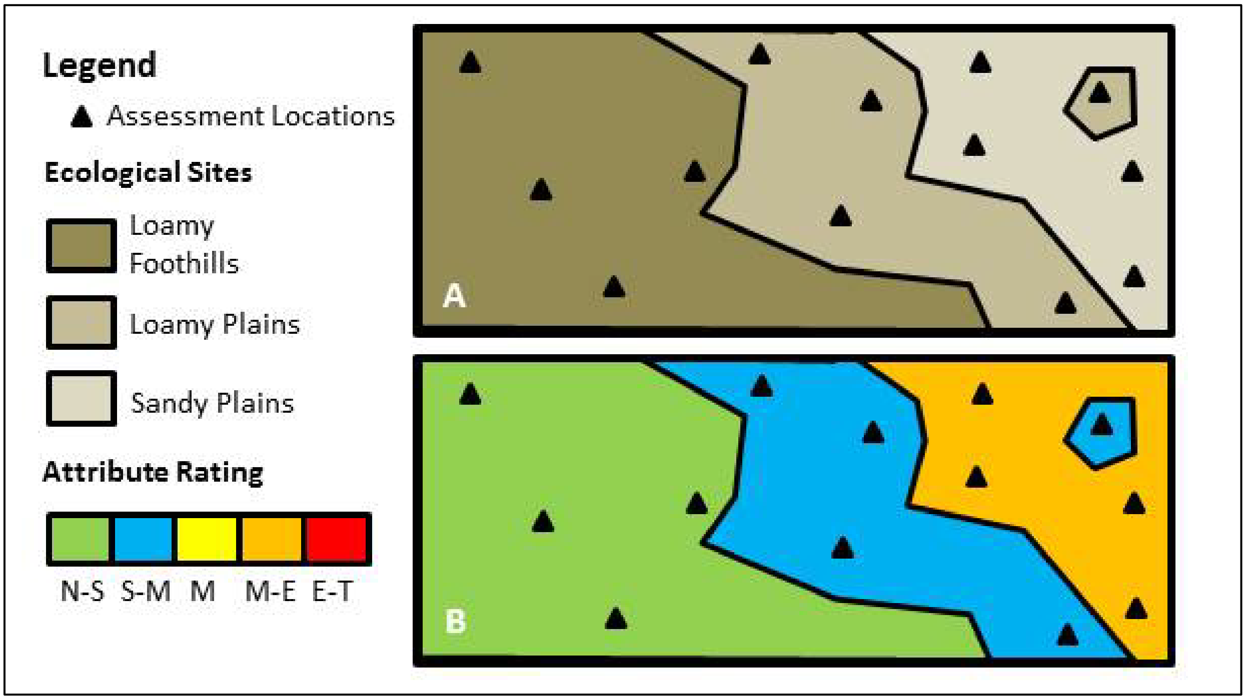


Figure 4. Appropriate sample designs enable results of assessments at particular locations to be extrapolated across the landscape. In this example, assessment locations were randomly chosen within previously mapped ecological sites (A), enabling results of assessments to be mapped by ecological site (B). This example is based on mapping the ecological site associated with the dominant soil map unit component in the soil map unit, which may represent less than 50% of the polygon. In some cases (e.g., where it is more productive or sensitive to degradation), it may be necessary to manage for the ecological site associated with a subdominant component. In this example, assessment locations were randomly chosen within previously mapped ecological sites (A), enabling median attribute ratings resulting from assessments to be mapped by ecological site (B).

5.11 Annual Production, Foliar Cover, and Standing Biomass

Both standing **biomass** and **foliar cover** correlate with **annual production**. However, these relationships vary by species. The relationships between biomass, foliar cover, and annual production also vary 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 biomass and foliar cover for annual production is not appropriate. However, biomass and foliar cover can be used as surrogates for annual production only where the relationships are well-understood and documented.

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 9) include three components: (1) current year's growth present at the time of the evaluation, (2) current year's growth that has been removed by herbivory, and (3) expected growth that will occur by the end of the growing season(s). Expected growth is estimated from ecological site- and plant-specific growth curves. Annual production includes aboveground production of all species, including stem elongation. **Standing biomass** differs from annual production in that it includes all live plant material above ground regardless of the year it was produced.

Foliar cover is the percentage of ground covered by the vertical projection of the aerial portion of plants (Figure 5). This is effectively the area that is protected from raindrops and the area in shade when the sun is directly overhead. This is the definition used in erosion models. Foliar cover reflects changes in the density of the plant canopy associated with leaf and twig detachment, as well as changes in the size and number of individual plants in a defined area. 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. Small openings within the canopy are included. 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 (Godinez-Alvarez et al. 2009). Canopy cover is also very difficult to standardize.

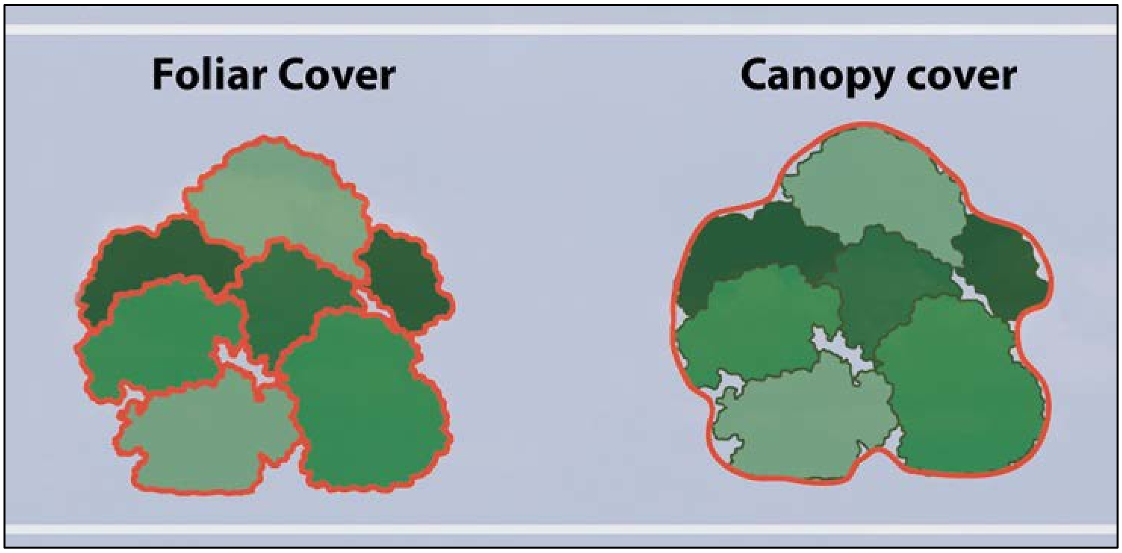


Figure 5. Comparison of foliar to canopy cover.

Foliar cover measurements or estimates may be based on several methods including line point intercept and visual estimates. Visual estimates should always be supported with the collection of quantitative data to improve cover estimates. The line point intercept method (Herrick et al. 2018) 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, and to remote sensing. It provides multiple canopy layers, including estimates for ground 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's Assessment, Inventory, and Monitoring Strategy and the NRCS's National Resources Inventory, so using this method allows data to be compared to a very large (over 30,000 plots as of 2018) dataset.

Care must be taken in interpreting ecological site descriptions developed prior to 1997 when the NRCS transitioned to using foliar cover (NRCS 1997) 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.

6. Relationship of the IIRH Protocol to Other Upland Rangeland Assessment, Inventory, and Monitoring Indicators, Protocols and Systems

A number of other rangeland assessment protocols are applied throughout the world. 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 are still in use today, although use has declined with increasing adoption of IIRH and the standardized NRI/AIM monitoring protocols. Most of the earlier methods emphasize plant species composition, although some include soil erosion indicators. Many protocols also focus on livestock forage production.

The following indicators, protocols and data collection systems are related to the IIRH protocol through their similarity of indicators and evaluation processes or through their use of the IIRH protocol as a component of their protocol. All of these continue to be widely used, though the use of the first two is declining due to a lack of consistency with the current focus on functional characteristics (Similarity Index) and the increasing availability of data that allow for quantitative determination of trend (Apparent Trend).

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 and annual production by species are used to calculate the similarity index. These production estimates are quantitative and are computationally similar to two IIRH protocol indicators—functional/structural groups and annual production—both of which can be rated qualitatively. The similarity index assesses the current plant community composition relative to the reference or desired community, whereas the IIRH protocol compares functional/structural groups within an evaluation area to the appropriate ecological site reference sheet description for the appropriate community phase within the reference state.

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 approach or depart from the desired community. Many of these indicators are similar to those in the IIRH protocol. Changes in apparent trend indicators assist the evaluator in speculating on the direction of change in the plant community.

Landscape Function Analysis (LFA): 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 ecological site or sites of interest. Additionally, landscape function analysis is a valuable monitoring tool, especially for ecological sites where there are transitions associated with changes in vegetation spatial structure and soil surface hydrology.

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. (2018). A spatially balanced, randomly located sampling design (see discussion on spatial extrapolation in Section 5.10) can provide land area estimates for attribute ratings of rangeland health and quantitative indicators. Many quantitative indicators associated with 17 qualitative indicators are measured (e.g., bare ground; refer to Table 4) allowing for these indicators to be monitored over time. Results are reported to Congress as part of the regular 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).

BLM Assessment, Inventory, and Monitoring Strategy: The BLM uses the same standard methods as NRI (Herrick et al. 2018) to monitor BLM rangelands as part of the BLM's 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. It often applies a randomized sampling design (see discussion on spatial extrapolation in Section 5.10). 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 often completed as a part of the Terrestrial AIM Program. AIM and IIRH data are captured electronically in the field and managed electronically, which helps ensure data quality and facilitates centralized data storage, analysis, and reporting.

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 local 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 during the IIRH protocol are often an important component of understanding upland ecological conditions and can be used in the rangeland health assessment process to evaluate 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.

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 that allow managers to identify appropriate strategies to promote a desired change 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.

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 and 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).

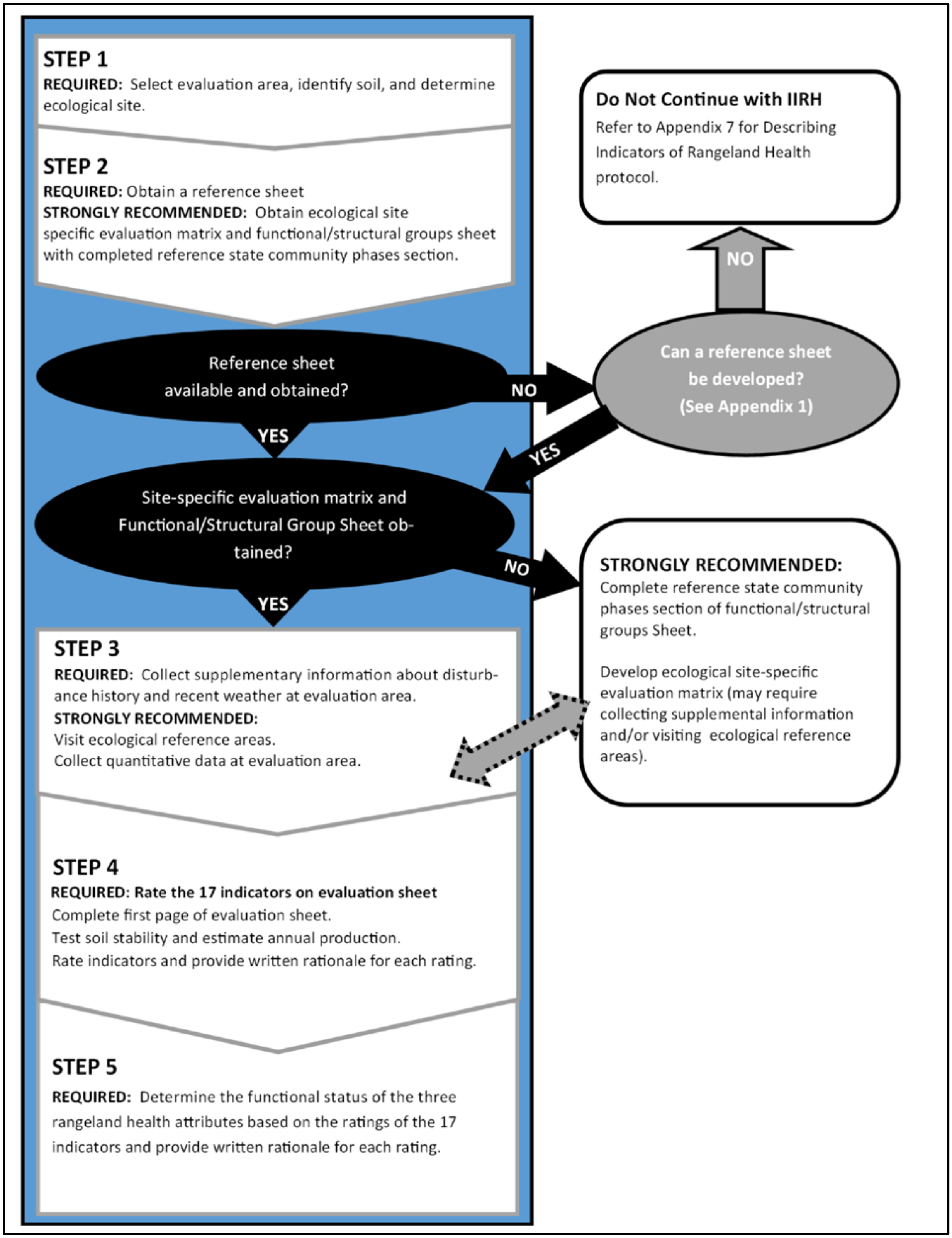
Proper Functioning Condition (PFC): Several widely applied qualitative assessment methods are available to evaluate riparian systems. The most widely applied riparian assessment in the United States is the proper functioning condition (PFC) method for lotic (flowing water) ecosystems (Dickard et al. 2015). Development of PFC began in 1988. Like the IIRH protocol, the PFC method 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. A separate PFC method is also available for lentic (nonflowing) ecosystems (Prichard et al. 2003).

7. IIRH Instructions and Steps

A rangeland health assessment using the IIRH protocol provides information on the function of ecological processes relative to the reference state for the ecological site or other functionally similar unit of that land area. This assessment provides information that is not generally available with other methods of evaluation. It gives an indication of the status of the three attributes of rangeland health on 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.

The instructions provide a step-by-step guide for users including actions required to complete each step. The action or concept of each step is then explained.

The flow chart in Figure 6 illustrates the entire process and can be used to help decide which steps to complete and the sequence of those steps. Use the “Checklist for the IIRH Protocol” (Appendix 4) to ensure the completion of all required steps.



STEP 1

REQUIRED: Select evaluation area, identify soil, and determine ecological site.

STEP 2

REQUIRED: Obtain a reference sheet

STRONGLY RECOMMENDED: Obtain ecological site specific evaluation matrix and functional/structural groups sheet with completed reference state community phases section.

Reference sheet available and obtained?

Can a reference sheet be developed? (See Appendix 1)

Do Not Continue with IIRH

Refer to Appendix 7 for Describing Indicators of Rangeland Health protocol.

Site-specific evaluation matrix and Functional/Structural Group Sheet obtained?

STRONGLY RECOMMENDED:

Complete reference state community phases section of functional/structural groups Sheet.

Develop ecological site-specific evaluation matrix (may require collecting supplemental information and/or visiting ecological reference areas).

STEP 3

REQUIRED: Collect supplementary information about disturbance history and recent weather at evaluation area.

STRONGLY RECOMMENDED:

Visit ecological reference areas.

Collect quantitative data at evaluation area.

STEP 4

REQUIRED: Rate the 17 indicators on evaluation sheet

Complete first page of evaluation sheet.

Test soil stability and estimate annual production.

Rate indicators and provide written rationale for each rating.

STEP 5

REQUIRED: Determine the functional status of the three rangeland health attributes based on the ratings of the 17 indicators and provide written rationale for each rating.

Figure 6. Flowchart for a rangeland health assessment using the IIRH protocol.

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

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 5.10 Spatial Extrapolation to Regions, Landscapes, and Management Units). However, locating evaluation areas non-randomly may be appropriate in some cases, such as when objectives are focused on a particular location or in a small, relatively uniform management unit. Finally, select the number of evaluation areas needed within each strata; the greater the confidence needed, the more evaluation areas should be assessed.

For further assessment planning considerations, as well as information on combining assessments with monitoring, see the Landscape Toolbox website (Appendix 11). The first edition of the "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems" (Herrick et al. 2005) also includes some general guidance.

Complete page 1 of the evaluation sheet (Appendix 5).

7.1.2 Describe the Evaluation Area(s)

Record information regarding the site location and basic site characteristics of an evaluation area on page 1 of the evaluation sheet (Appendix 5). Appendix 6 describes in detail how to determine the ecological site at the evaluation area, which is required to complete page 1 of the evaluation sheet. Page 2 of the evaluation sheet contains the indicator and attribute ratings and associated comments and is completed during steps 4 and 5. This type of information can also be documented and stored using electronic applications such as the Database for Inventory, Monitoring, and Assessment available on the Landscape Toolbox website (Appendix 11); and the Land-Potential Knowledge System (LandPKS) (Appendix 11). LandPKS 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. 2017).

The evaluation area should be large enough to accurately evaluate all indicators and should be anywhere from 1/2 to 1 acre (0.2 to 0.4 hectares) in size. An acre is approximately the size of an American football field without the end zones. Upon arrival at the location, the evaluator(s) should verify they are in the intended ecological site by digging a soil pit (see section 7.1.3 below).

Next, establish and clearly (temporarily) mark the boundaries of the evaluation area. Then, all evaluators should walk and observe biological and physical characteristics within the evaluation area. This enables the evaluator(s) to become familiar with the plant species, functional/structural group dominance hierarchy, soil surface features, rangeland health indicators, and the variability associated with the ecological site in the evaluation area. Remember, an assessment must evaluate conditions on only one ecological site, so it is preferable to select evaluation areas that encompass only one ecological site. However, if more than one ecological site occurs in the evaluation area, a separate assessment is completed for each ecological site.

Document surrounding offsite influences that may affect ecological processes within the evaluation area on page 1 of the evaluation sheet (Appendix 5). Offsite influences can include the topographic position of the evaluation area, adjacent roads, trails, watering points, gullies, and other disturbances. Carefully describe the topographic position (see Figure 6.3 in Appendix 6 for generic landscape units to describe topographic position) when documenting the potential offsite influences that may impact the evaluation area.

Included within the natural range of variability of an ecological site is a range of slopes and soil depths. The ecological potential of an evaluation area within that ecological site will vary based in part on soil properties. This variability can be associated with relatively minor differences in landscape position and soils (e.g., differences in aspect, slope (top versus the bottom of a slope), soil depth and texture and coarse rock fragments). Soil features that are important to soil/plant/air/water relationships are included on page 1 of the evaluation sheet, whether or not they are required for soil identification.

Document specific information on disturbances or land treatments (see 7.3 Step 3. Collect Supplementary Information), including timing and types, on page 1 of the evaluation sheet.

Record the community phase within the reference state that best fits the evaluation area on page 1 of the evaluation sheet (copied from Appendix 2 if available). Also, document the **relative dominance** of functional/structural groups expected in a community phase pathway between reference community phases on page 1 (copied from Appendix 2 if available). For example, a sagebrush steppe site in the reference state would have a different dominance rating for the deep-rooted perennial grass functional/structural group and for the functional/structural group that included sagebrush depending on the time since a wildfire (see Figure 3; specifically, the pathway (arrow) between community phases 1.1 and 1.2 in State 1). Specify whether plant species composition estimates are based on the current year's annual production, foliar cover, or biomass, and circle the appropriate one near the top of the sheet.

At this point, all components of page 1 should be filled in. Take photographs and include as an attachment to the evaluation sheet (or in an electronic file). Take at least two general view photographs in different directions (include some skyline for future point of reference). In addition, take photographs that illustrate important indicator values or anomalies. Record the time, date, orientation, and location of each photo.

7.1.3 Determine the Ecological Site

It is essential to use the reference sheet that corresponds to the appropriate ecological site to conduct an assessment. On page 1 of the evaluation sheet (Appendix 5), record the soil details from the ecological site description in the "soil and site verification" section on page 1 of the evaluation sheet. Then using observations from evaluation area's soil pit(s), complete the evaluation area's portion of the "soil and site verification" section on page 1 of the evaluation sheet. Compare these two descriptions to determine if the evaluation area's soils fit the description of the potential ecological site. A step-by-step process to determine the ecological site at an evaluation area is described in Appendix 6. See Figure 6.2 in Appendix 6 for a completed example. Soil maps may help predict soils and therefore ecological sites that are more likely to be found in the evaluation area, but due to their coarse detail they may be incorrect. Many **soil map units** are comprised of more than one soil map unit component, and therefore multiple ecological sites could be found within a soil map unit (Duniway et al. 2010).

In addition, **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. Inclusions may or may not be listed in the NRCS **soil survey**. Finally, even a single soil series can belong to more than one ecological site if the functionally significant properties (e.g., aspect and slope) vary significantly within the same soil series.

7.1.4 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 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. in press). 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 support completion of an IIRH assessment after a reference sheet has been developed.

7.2 Step 2. Obtain a Reference Sheet (Required), and Complete the Ecological Site-Specific Evaluation Matrix and Functional/Structural Groups Sheet (Strongly Recommended)

7.2.1 Obtain a Reference Sheet (Required)

The reference sheet (Appendix 1) describes the range of expected spatial and temporal variability of each indicator within the natural disturbance regime based on each ecological site (or equivalent). It serves as the primary reference for the IIRH assessment. Appendix 1 also includes a reference sheet checklist to assist in capturing this variability when a new reference sheet is developed or an existing one is revised.

Reference sheets are incorporated into most ecological site descriptions. If an ecological site can be identified, but an ecological site description is not available, additional expertise is required to develop the reference sheet. To help develop or revise a reference sheet, see the "Instructions for Reference Sheet Development or Revision" in Appendix 1. Note, it is not possible to conduct an IIRH assessment without a reference sheet. As previously discussed in 7.1 Step 1, the DIRH protocol (Appendix 7) may be used to collect information to assist in the future development of a reference sheet.

Development of the reference sheet requires more expertise than is usually required to conduct the IIRH protocol. 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 may be used in the development of the reference sheet.

7.2.2 Obtain or Develop the Evaluation Matrix for the Ecological Site (or Equivalent Unit) (Strongly Recommended)

The evaluation matrix (Appendix 3) includes five generic descriptors for each indicator, which reflect the range of departure from what is expected for the site: none to slight, slight to moderate, moderate, moderate to extreme, and extreme to total. The descriptor for "none to slight" comes from the reference sheet (Appendix 1) and reflects the natural range of variability, including the natural disturbance regime, of each indicator in the reference state.

We recommend the development of a unique evaluation matrix for each ecological site description. If an ecological site evaluation matrix is not available, generic descriptors may be used or adapted to better reflect current knowledge. To maintain consistency of indicator assessments on specific ecological sites, one of the following options is strongly recommended: (1) Add notes to the generic descriptors (Appendix 3) to clarify how each descriptor is interpreted for the site; or (2) Create an ecological site-specific evaluation matrix (instructions follow).

A site-specific evaluation matrix should be used for subsequent evaluations on the same ecological site, and any changes in it should be forwarded to the person responsible for maintaining ecological site descriptions in the state (usually the NRCS state rangeland management specialist). This will ensure these modifications are considered during revisions of ecological site descriptions.

Instructions for Development of an Ecological Site-Specific 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.

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 1). 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 or an extended drought." In a non-gravelly 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 rate 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 matrix assume an approximately linear relationship among departure categories, which is likely an incorrect assumption for a number of the indicators. Therefore, the relationship and shape of the departure curve need to be considered and incorporated into the ecological site-specific evaluation matrix.

1. Indicators associated with soil/site stability are likely to require more deliberation due to the inherently higher erosion potential on certain ecological sites. Table 5 provides an example of an evaluation matrix with 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.

Table 5. 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 most areas connected; only occasional areas where ground cover is contiguous; ground cover mostly patchy and sparse.	50-75% bare ground; bare areas are large (> 24" diameter) and usually connected.	30-50% bare ground; bare areas are 12-24" and sporadically connected.	21-30% bare ground; bare areas greater than 12" diameter but rarely connected; bare areas associated with surface disturbance are larger (> 15") and are rarely connected.	Less than 20% bare ground occurring in patches less than 10" diameter; larger bare patches also associated with ant mounds and small mammal disturbances.
Generic Descriptor	Much higher than expected; bare areas are large and generally connected.	Moderate to much higher than expected; bare areas are large and occasionally connected.	Moderately higher than expected; bare areas are of moderate size and sporadically connected.	Slightly to moderately higher than expected; bare areas are small and rarely connected.	Reference sheet narrative inserted here.

7.2.3 Obtain or Complete the Functional/Structural Groups Sheet for the Ecological Site (or Equivalent Unit) (Strongly Recommended)

It is strongly recommended to complete the functional/structural groups sheet (Appendix 2). In the sheet, include each reference state community phase in the ecological site, and document the **relative dominance** of functional/structural groups. Once completed, this sheet can be used repeatedly on the same ecological site. This will improve the consistency of indicator ratings among multiple teams working in multiple locations within the same ecological site. This sheet also provides documentation of specific reasoning behind the degree of departure rating for functional/structural groups (indicator 12) at an evaluation area.

Documenting the relative dominance of functional/structural groups and the species in the dominant and subdominant groups in the evaluation area assists evaluators in using the evaluation matrix (Appendix 3) to rate functional/structural groups (indicator 12). Also, documentation of this information provides additional data to support the IIRH assessment. The functional/structural groups sheet (Appendix 2) is an important resource for rating the following indicators: effects of plant community composition and distribution on infiltration and runoff (indicator 10), functional/structural groups (indicator 12), dead or dying plants or plant parts (indicator 13), and vigor with an emphasis on reproductive capability of perennial plants (indicator 17).

This sheet includes information on the species found within each functional/structural group, the relative dominance of the functional/structural groups within the plant community, and associated plant species for each community phase in a reference state and for the existing plant community at the evaluation area. This sheet is recommended in order to select the "closest fit" when rating relative dominance and total combined number of species expected in dominant and subdominant functional/structural groups in the evaluation matrix (Appendix 3).

Once the reference state component of the functional/structural groups sheet is developed, it can be used for IIRH assessments on the same ecological site across a **major land resource area**. It is recommended to work with the NRCS state rangeland management specialist to develop the reference state component of the sheet. In addition, this person may share the information with others working on the same ecological site.

Appendix 3 also describes how the functional/structural groups sheet is organized and used and provides a completed example.

7.3 Step 3. Collect Supplementary Information

Supplementary information improves an evaluator's ability to conduct an informed and accurate assessment. It is strongly recommended to collect the following types of supplementary information: (1) information from relevant ecological reference areas; (2) land treatment and/or disturbance history; and (3) quantitative data at the evaluation area.

7.3.1 Ecological Reference Areas (Strongly Recommended)

Ecological reference areas, if available, are a valuable resource as they can provide a visual representation of the expected status of each indicator given recent weather conditions. An ecological reference area is 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 from most disturbances. Ecological reference areas should be functioning at least as well as described in the reference sheet for a particular ecological site with respect to soil/site stability, hydrologic function, and biotic integrity.

These areas do not need to be **climax plant communities** or **relict** areas; however, the ecological processes and disturbance regimes should be functioning within the natural range of variability expected for a particular ecological site. The use of ecological reference areas is similar to a concept proposed by the Western Regional Coordinating Committee-40 on Rangeland Research, which is to use well-managed rangelands and appropriate relict areas as benchmarks for assessments (West et al. 1994). The concept of ecological reference areas is also an integral component in the development or revision of ecological site descriptions.

Examine ecological reference areas in the same year and season and on the same ecological site as the evaluation areas scheduled for an assessment. Consider and document distance between ecological reference areas and associated evaluation areas in terms of precipitation and elevation differences and those effects on indicator values. There may be more than one plant community phase in the reference state that has the potential to be used as an ecological reference area for the ecological site at an evaluation area. Take care to ensure that the reference community phase in the ecological reference area is a close fit to the evaluation area. For example, if a fire occurred 5 years ago in the evaluation area, an ecological reference area that experienced a recent fire would be an appropriate comparison for the evaluation area.

At each ecological reference area, identify the state and community phase, take photographs, collect relevant quantitative data (Table 4 and Appendix 10), describe the status of each indicator, and record whether or not it is believed that the ecological reference area reflects the natural range of variability, including the natural disturbance regime, of the reference state. The ecological reference area should be used as a reference only for indicators that would be rated as “none to slight” based on the appropriate reference sheet.

7.3.2 Land Treatments and/or Disturbance History (Required)

Before going to the field, check records and document natural disturbances and land treatments in or near the evaluation area. Wildfires are a good example of a natural disturbance that can drive plant community changes at the evaluation area. Document fire history and other disturbances and dates of occurrence on page 1 of the evaluation sheet (Appendix 5). Other natural disturbances that may have documentation 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 manipulation, such as use of mechanical equipment, herbicides, prescribed fire, or seeding. Summarize dates, types of treatments (including seed mixtures if applicable), results from monitoring studies (if available), and treatment polygons on page 1 of the evaluation sheet (Appendix 5). Consult agency or landowner records to capture this information. The U.S. Geological Survey maintains a digital database (see Appendix 11) that contains information on land treatments implemented on public lands managed by the BLM.

7.3.3 Quantitative Data (Strongly Recommended)

It is strongly recommended to collect quantitative data at the evaluation area. Table 6 provides examples of qualitative indicators and associated measurement methods that can be used to collect related quantitative values (see also Table 4 and Appendix 10). The stick method provides an option to collect quantitative data without equipment (Riginos and Herrick 2010).

Table 6. Qualitative indicators of rangeland health and associated measurement methods that can be used to collect related quantitative values.

Qualitative Rangeland Health Indicator	Measurement Method*	Quantitative Value
Bare ground (indicator 4)	**Line point intercept**	Bare ground percent
	Continuous 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 and runoff (indicator 10)	Production	Functional group composition by production
	Line point intercept	Functional group composition by cover
Functional/structural groups (indicator 12)	Production	Functional group composition by production
	Line point intercept	Functional 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)	Production	Total annual production
Invasive plants (indicator 16)	Production	Relative dominance
	Line point intercept	Cover of invasive species
	Belt transect	Density of invasive plants

*AIM Core Methods are bolded

7.4 Step 4. Rate the 17 Indicators on the Evaluation sheet (Required)

We strongly recommend that an ecological site-specific (or equivalent unit) evaluation matrix be developed and used for IIRH assessments (see Section 7.2.2 for instructions). In the interim, the generic evaluation matrix (Appendix 3) is used. This step describes the procedure to complete page 2 of the evaluation sheet (Appendix 5).

- Select the degree of departure descriptor on the evaluation matrix (Appendix 3) that most closely describes each indicator’s departure.
- Record the rating on page 2 of the evaluation sheet.

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 was taken from the appropriate reference sheet (Appendix 1). The reference sheet describes the range of expected spatial and temporal variability for each indicator within the natural disturbance regime based on the evaluation area’s ecological site (or equivalent). The use of the functional/structural groups sheet (Appendix 2) is strongly recommended since it provides the reference description of the functional/structural group’s indicator and is useful in evaluating several other indicators.

Narrative descriptors in the evaluation matrix (Appendix 3) are intended to aid in the determination of the degree of departure. The narrative descriptors for each indicator form a relative scale from “none to slight” to “extreme to total” departure. Not all indicator descriptors will match what is observed, requiring a “best fit” approach when making ratings. It is recommended that each indicator rating be supported with comments in the spaces provided on page 2 of the evaluation sheet (Appendix 5). In some instances, there may be no evidence of an indicator’s departure in the evaluation area, so those indicators are rated “none to slight.”

Descriptions of the 17 indicators used to evaluate rangeland health are provided in Section 7.4.1 through 7.4.17. Indicator photographs are included in Appendix Information for each indicator includes description and assessment information, associated quantitative measurements, and the indicator’s relationship to the three attributes of rangeland health. Additional information on many of the soil-related indicators can be found in the NRCS Rangeland Soil Quality Information Sheets (NRCS 2001) (see Appendix 11 for website information).

The recommended protocol to conduct an IIRH assessment is for each evaluator to conduct a general *reconnaissance* of the evaluation area to determine how much variability exists for each indicator on the site. If more than one ecological site is present in an evaluation area, either conduct a separate assessment on each ecological site or make minor adjustments to the evaluation area perimeter so that only one ecological site is included. While observing the evaluation area, observe the departure of the indicators relative to the ‘none to slight’ descriptor in the reference sheet. Refer to the evaluation matrix (Appendix 3) and determine which descriptor best defines the departure from the “none to slight” descriptor, and enter that rating on page 2 of the evaluation sheet (Appendix 5). If an indicator’s observed condition across the evaluation area most closely matches the “none to slight” description in the evaluation matrix, then give the “none to slight” rating to the indicator. For each indicator, include observations and the rationale for each rating in the comment section. Refer to Section 7.4.1 through 7.4.17 for detailed information about the 17 indicators.

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 these indicators so that similar questions about rangeland health are asked in different ways. An example of this is where the indicators bare ground, litter movement, and effects of plant community composition and distribution on infiltration and runoff 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.

7.4.1 Rills (Indicator 1)

Indicator Description and Assessment

Rills are small, intermittent water courses 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.

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 climate (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 area. 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).

There may be confusion in differentiating between a rill and a gully. 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 5).

Rating this indicator involves comparing the number, distribution, depth, and length of rills, as well as the degree of rill formation at the time of assessment to the reference ("none to slight" departure). Table 7 provides generic descriptors of the five departure categories in the evaluation matrix for rills.

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, well-defined throughout; may be connected into drainage patterns.	Moderate in number at frequent intervals; well-defined, longer, wider, and deeper in exposed and less vegetated areas.	Few at infrequent intervals; moderate width, depth, and length; occur in or near exposed or disturbed areas.	Scarce, scattered, and short; width and depth minimal; occur mostly in exposed areas.	Reference sheet narrative inserted here.

Measurements

Rills can be stratified based on slope ranges (e.g., 0–3%, 3–15%, > 15% slope) and quantified by measuring the number of rills that occur over a defined distance across (perpendicular to) a slope. The length 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 may 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. Routine formation of rills greater than expected for a site may indicate a reduction in infiltration capacity.

Biotic integrity: Not applicable.

Photographs (see Appendix 12)

7.4.2 Water Flow Patterns (Indicator 2)

Indicator Description and Assessment

Water flow patterns (sometimes referred to as sheetflow) are the path that water takes as it moves across the soil surface during periods when surface water from rain or snowmelt exceeds soil infiltration capacity. 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). The length and number of water flow patterns are controlled 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). This indicator's rating involves: (1) density and length of water flow patterns in the evaluation area; (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.

Distinguishing rills from water flow patterns

Rills and water flow patterns are sometimes difficult to distinguish from each other. Generally, rills are microchannels where water and soil movement are concentrated in a linear pattern that is deeper than it is wide, while water flow patterns are 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 transitions to a rill where slopes increase or if water becomes concentrated causing downcutting on both sides of the linear erosion feature. If unsure of the difference between these indicators, rate the evaluation area using one or the other and document the rationale in the comment section page 2 of the evaluation sheet (Appendix 5). Reflect departure for both, if both are present at levels not expected

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 and numerous; long and wide; unstable with active erosional and/or depositional areas; usually connected.	Widespread and numerous; long and wide; erosional and/or depositional areas common; occasionally connected.	Common; lengths and/or widths nearly match none to slight; minor erosional and/or depositional areas; infrequently connected.	Scarce; length and width match none to slight; some minor erosional and/or depositional areas; stable, short, and rarely connected.	Reference sheet narrative inserted here.

Measurements

Water flow patterns are difficult to measure, as they vary greatly by width, depth, and length and are influenced by the number and kinds of obstructions (e.g., living or dead plants, biological soil crust, persistent litter, or rocks) to water flow. The density and length of water flow patterns in the evaluation area can be measured using a continuous line intercept. Tongway (1994) describes a semiquantitative protocol that addresses water flow.

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, depth, and width is more 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, depth, 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, or pedestals/terracettes). 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.

Biotic integrity: Not applicable.

Photographs (see Appendix 12)

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. Exposure of plant roots on sides of a pedestal is considered an indication of significant erosion. Occurrence of pedestals at a level greater in number than what has been defined as expected for a site in the reference state (within the natural disturbance regime) indicates accelerated soil erosion and water loss from a site.

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. It is important to distinguish soil accumulations and nonerosional pedestals and not include them when assessing this indicator.

Terracettes are “benches” of soil deposition (may include incorporated litter or gravel) behind or between obstacles (persistent litter, rocks, or plant bases) caused by water (not wind) movement. Terracettes caused by livestock or wildlife paths or trails on hillsides are not considered erosional terracettes, thus they are not assessed for this indictor, but they can impact ratings of other indicators. For example, they can affect erosion by concentrating water flow and/or changing infiltration or soil compaction, but they are assessed using other indicators (e.g., water flow patterns, compaction layer, or soil surface loss and degradation).

As the degree of soil movement by water increases, terracettes may become more numerous, and the area of soil deposition becomes larger. The soil level behind a terracette will be higher in elevation than the soil below, indicating that soil was deposited by moving water and/or that soil was eroded below the terracette. This indicator is rated based solely on the departure in number of pedestals and/or terracettes in the evaluation area relative to the “none to slight” descriptor. Note, pedestals may occur in an evaluation area without terracettes and vice versa. 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 and/or terracettes are numerous; plant pedestals frequently have exposed roots.	Pedestals widespread and/or terracettes are common; some plant pedestals have exposed roots.	Pedestals common and/or terracettes occasionally present; exposed roots on plant pedestals uncommon.	Pedestals scarce and/or terracettes uncommon; exposed roots on pedestals uncommon.	Reference sheet narrative inserted here.

Measurements

One way to measure or document the density (i.e., number in a defined area) of these features is the belt transect method.

Relationship to Attributes of Rangeland Health

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

Hydrologic function: Pedestals caused by water erosion, as well as terracettes, can be important indicators of water movement across a site (Anderson 1974; Morgan 1986; Satterlund and Adams 1992; Hudson 1993). Pedestals may also be caused by wind erosion. Where wind erosion is the only cause, they 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 5).

Biotic integrity: Not applicable.

Photographs (see Appendix 12)

7.4.4 Bare Ground (Indicator 4)

Indicator Description and Assessment

Bare ground is exposed mineral soil that is susceptible to raindrop splash erosion. It is what remains after accounting for ground surface covered by vegetation (basal and canopy (foliar) cover), litter, standing dead vegetation, gravel/rock, and visible biological soil crust (e.g., lichen, mosses, algae) (Weltz et al. 1998). These materials intercept raindrops, reduce soil particle detachment, and soil movement by water and wind (Weltz et al. 1998).

A bare ground patch is an area where bare ground is concentrated in larger polygons than expected relative to the reference state (within the natural disturbance regime). Bare ground patches may include some ground cover (e.g., plants, litter, rock, and biological soil crusts) within their perimeter. Bare ground patches can be described and are evaluated in terms of the size and connectivity of polygons. It is important to remember that disturbances like ant mounds and rodent burrows are bare ground patches that may be part of the natural range of variability on many ecological sites.

The amount and distribution of bare ground is one of the most important contributors to soil/site stability; therefore, it 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). In general, a site with bare soil concentrated in a few large bare soil 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 of bare ground and size and connectivity of bare soil patches can vary seasonally, with changes in vegetation canopy (foliar) cover and litter amount. These vary in response to weather-driven plant production and to consumption and trampling by herbivores (Gutierrez and Hernandez 1996; Anderson 1974). 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	Much higher than expected; bare ground patches are large and generally connected.	Moderate to much higher than expected; bare ground patches are large and occasionally connected.	Moderately higher than expected; bare ground patches are of moderate size and sporadically connected.	Slightly to moderately higher than expected; bare ground patches areas are small and rarely connected.	Reference sheet narrative inserted here.

Measurements

Measure percent bare ground using line point intercept, step-point intercept transects (Herrick et al. 2018), 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. 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.

Relationship to Attributes of Rangeland Health

Soil/site stability: Occurrence of bare ground at a higher percentage, or greater concentration and size of bare ground patches, than expected increases potential for water erosion due to raindrop impact and soil particle disaggregation and movement and wind erosion 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, 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.

Photographs (see Appendix 12)

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, but 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). 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 and/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 down- and upslope, 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 actions (e.g., inappropriate grazing, vegetation removal, recreation vehicles, or road drainages) have caused gullies to form or expand (Morgan 1986). Gullies can be caused by offsite resource problems that can affect site function in the evaluation area. Continue to rate this indicator and document these offsite influences on page 1 of the evaluation sheet (Appendix 5) and in the comments.

There may be confusion in differentiating between a rill and a gully. Using the definition provided by Selby (1993), rills are less than 1 ft (30 cm) wide and 2 ft (61 cm) deep, and 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 appropriate documentation in the comment section on page 2 of the evaluation sheet (Appendix 5).

Gullies may be assessed by observing the numbers of gullies in an evaluation area (if there are more than one) and/or assessing the severity of erosion in individual gullies. The occurrence of deeper, wider, or 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; significant active bank and bottom erosion including downcutting and numerous nickpoints; gully depth significant; active headcut(s) may be present.	Intermittent vegetation on banks and/or bottom; moderate active bank and bottom erosion with moderate downcutting; nickpoints common; moderate or greater gully depth; active headcut(s) may be present.	Occasional vegetation on banks and/or bottom; occasional nickpoints and/or downcutting; moderate gully depth; headcuts absent.	Vegetation is stabilizing most banks and/or bottom; few nickpoints and/or downcutting; minimal gully depth; headcuts absent.	Reference sheet narrative inserted here.

Measurements

Gullies can be quantified by counting the number of gullies across a linear distance perpendicular to the slope or within the evaluation area. Gully width and depth can be measured at random or regular points along the reach of the gully. Similarly, the percent of incised banks along a set reach of a gully can be determined. Headcuts can be measured in terms of depth and width. Rate of movement of headcuts upslope can be monitored by measuring the movement of the headcut relative to a reference post near the headcut.

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 and/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 and/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.

Photographs (see Appendix 12)

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). **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 assessed with other soil/site stability indicators.

Wind-scoured areas, including blowouts, are generally found in plant interspace areas with a close correlation between soil cover, bare soil 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** that are more resistant to wind erosion may be exposed. Blowout areas appear as depressions where the soil has been eroded. 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. Wind-scoured and blowout areas will typically occur in areas where bare soil is concentrated (e.g., bare patches) with minimal persistent litter and biological soil crusts (Chepil 1946; Gillette et al. 1972).

Accelerated wind erosion, on an otherwise stable soil, increases as the surface crust (physical, chemical, or biological) is worn by disturbance or abrasion. Surface crusts are extremely important in protecting the soil surface from wind erosion on many rangelands with low canopy (foliar) cover. 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 transported off the site (Chepil 1945; Gillette et al. 1972; Gillette et al. 1974; Gillette and Walker 1977; Hagen 1984).

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 areas; (2) a decrease in the amount of soil organic matter that causes decreased soil aggregate stability (see 7.4.8 Soil Surface Resistance to Erosion (Indicator 8)); and (3) long, unsheltered, smooth soil surfaces that are exposed to wind (NRCS 2001).

Depositional areas are are locations where windblown soil accumulates and usually occur where soil is wind deposited under and downwind from plants or other obstructions, oftentimes forming a hummock-like landscape. Deposition of suspended soil particles is often associated with vegetation that provides roughness to slow the wind velocity and allow 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; Hennessey 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 (Hennessey et al. 1986; Morin and van Winkel 1996) and burying soil crusts and plants. In this situation, significant soil deposition would also be considered as degradation and considered in rating indicator 9, soil surface loss and degradation.

Wind-scoured and/or depositional areas are rated based on the frequency and/or extent of the areas and the degree of connectivity within the evaluation area. Document the relative proportion of the evaluation area that is affected by wind-scoured (including blowout) areas and/or depositional areas in the comment section on page 2 of the evaluation sheet (Appendix 5). 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 and/or soil deposition around most obstructions.	Common; wind scours frequently connected and/or soil deposition around many obstructions.	Occasionally present; wind scours infrequently connected and/or minor soil deposition.	Infrequent and few; wind scours rarely connected and/or soil deposition uncommon.	Reference sheet narrative inserted here.

Measurements

The length and width of wind-scoured areas, including blowouts, may be measured. The depth of wind-scoured areas or the height of deposits above what used to be the soil surface can also be measured. The proportion of the site susceptible to wind scours may be predicted with basal gap intercept; line point intercept or continuous line intercept can be used to document the proportion of the site affected by wind scour and/or deposition.

Relationship to Attributes of Rangeland Health

Soil/site stability: Wind-scoured and/or depositional areas outside the natural range of variability for an ecological site are signs of site degradation due to 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, indicating a loss in soil/site stability. Newly deposited soil may be susceptible to additional erosion. Deposited soil may bury surface horizons, effectively changing soil surface characteristics (see 7.4.9 Soil Surface Loss and Degradation (Indicator 9)).

Hydrologic function and biotic integrity: Not applicable.

Photographs (see Appendix 12)

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 document, it 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 is an indicator of the degree of wind and/or water erosion. Litter movement resulting from livestock, recreational vehicles, and other anthropogenic activities are not evaluated by this indicator.

Litter movement on a site is a function of slope and obstructions including vegetation. For example, alluvial fans and flood plains 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 and amount of litter moved and the distance that litter is moved by wind or water relate to the degree of litter redistribution and therefore the degree of erosion and redistribution of nutrients (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 greater 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). Likewise, limited areas of litter redistribution within a site is indicative of less erosion, whereas litter movement offsite is indicative of greater erosion. Litter often concentrates in areas where wind and/or water slows or in areas with obstructions. Looking for such accumulations is a good approach for detecting litter movement in an evaluation area.

Note the size classes and amount of litter moved, as well as the size of litter accumulations relative to the reference sheet when assessing this indicator. Table 13 provides generic descriptors of the five departure categories in the evaluation matrix for litter movement. See Section 7.2.2 for instructions to develop an ecological site-specific (or equivalent unit) evaluation matrix.

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 most size classes; large 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 and scattered; small accumulations around obstructions or in depressions.	Slight movement of small size classes; not usually accumulating around obstructions or in depressions.	Reference sheet narrative inserted here.

Measurements

Amounts and patterns of litter accumulation can be measured as litter cover using line point intercept 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) of litter moved can be measured directly, particularly in areas where moving litter accumulates. Care must be taken in consistently and correctly identifying these areas. The distance of movement is more difficult to measure because it is often difficult to identify where the litter originated. Measuring litter movement is likely more accurate and precise in experimental studies (e.g., rainfall manipulation, marking litter pieces) than under natural field conditions.

Relationship to Attributes of Rangeland Health

Soil/site stability: Litter movement from a point of origin is an indicator that water and/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.

Photographs (see Appendix 12)

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, which 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.

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). Conversely, the presence of highly erodible materials at the soil surface can dramatically increase soil erosion by water, even when 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., coarser-textured soils will generally form less stable aggregates than finer-textured soils). If soil surface resistance to erosion is 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, and an increased potential for runoff and erosion. All of these factors affect plant productivity. Reduced soil surface stability also usually reflects lower soil biotic integrity because of the disruption of soil organic matter inputs and biological decomposition processes.

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 on the reference sheet (Appendix 1), and stability should be evaluated under plants and in interspaces. In areas with low 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.” For root mat, moss, duff, or water, do not sample; record a stability class rating of 6 (Herrick et al. 2018) (Appendix 8).

Use Appendix 8 to complete the soil stability test to rate this indicator. When defining the departure category, it is necessary to take into account the potential range of variability. (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).

When rating this indicator, keep in mind, 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. 2018). Within-plot variability is expected to be lower (fewer samples required) in more homogenous systems like the short-grass steppe and Mojave Desert. Table 14 provides generic descriptors of the five departure categories in the evaluation matrix for soil surface resistance to erosion. See Section 7.2.2 for instructions to develop an ecological site-specific (or equivalent unit) evaluation matrix.

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 and moderately reduced beneath plant canopies.	Significantly reduced in at least half of plant interspaces or moderately reduced throughout.	Some reduction in plant interspaces or slight reduction throughout.	Reference sheet narrative inserted here.

Measurements

Soil surface resistance to erosion is quantitatively evaluated using the soil stability test (Appendix 8), which reflects differences in the susceptibility of soil aggregates to a loss of structure (slaking) in water (Herrick et al. 2001; Herrick et al. 2018). Twelve to 18 random 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.

Appendix 8 also describes a semiquantitative test that can be completed with a bottle cap. This technique takes longer and is not as accurate as performing the soil stability test. However, it is a viable option.

As previously noted, 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).

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 therefore less likely to be detached by raindrop impact, overland flow, or wind.

Hydrologic function: Higher stability also means that individual soil particles (especially clays) are less likely to be dispersed in water. Dispersed particles may form physical crusts, which limit infiltration, while higher stability helps maintain high 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.

Photographs (see Appendix 12)

7.4.9 Soil Surface Loss and Degradation (Indicator 9)

Indicator Description and Assessment

The soil surface is an important aspect of a site because it often controls water infiltration and available plant nutrients. Soil erosion (wind and water) is also affected because reduced infiltration increases runoff, which increases the energy available to remove soil. The soil surface horizon is also where seed germination and plant establishment occur. 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). 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. 1982).

Soil surface loss and degradation is one of the most important indicators of long-term change in rangeland health. A departure for this indicator often persists after vegetation has recovered. The degree of soil surface loss and degradation may help determine whether a site has the capability to recover ecosystem functionality or whether a physical threshold has been crossed.

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 are 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. For the purposes of this indicator, this distinction is unnecessary—the objective is to determine to what extent the functional characteristics of the surface layer have been degraded.

Evidence of soil surface structure degradation (Karlen and Stott 1994) and organic matter loss (Dormaar and Willms 1998) includes (1) reduced thickness of the surface horizon; (2) change to a lighter soil color; and (3) structural changes reflected by a reduction in the number, length, or size diversity of soil pores and/or peds (Satterlund and Adams 1992; O'Hara et al. 1993).

Specifically, the criteria to assess this indicator include:

Criteria 1. Thickness of surface horizon: Evaluation sites 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. Use a change in color, texture, and/or structure to identify the bottom of the soil surface horizon. Color changes can be identified by comparing the soil surface horizon to the appropriate soil map unit component of the evaluation area. Note that on some evaluation area soils, the surface horizon may have been nearly or totally lost.

Criteria 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 sites 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.

Criteria 3. Reduction in the number, length, and size diversity of soil pores: 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.

Criteria 4. Soil deposition over the A 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. Evaluate deposited soil surface horizons using the preponderance of evidence of the first three criteria. For example, a positive increase in soil surface horizon depth (criteria 1) by sand deposition may be outweighed by the negative changes in soil organic matter (criteria 2) and structure (criteria 3).

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 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 evaluation area; soil surface structure similar to or more degraded than subsurface; no distinguishable difference between surface and subsurface organic matter content.	Severe soil loss and/or degradation throughout evaluation area; minor differences between soil organic matter content and structure of surface and subsurface layers.	Moderate soil loss and/or degradation in plant interspaces with some degradation beneath plant canopies; soil organic matter content is markedly reduced.	Slight soil loss and/or soil structure shows slight signs of 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 a soil pit using the appropriate scale relative to the soil map unit component description or the ecological site description if it includes this information. Identification of soil surface horizon boundaries is important when measuring horizon depth. Color can be measured using a Munsell soil color chart. Care must be taken to ensure evenly distributed light without sun glare and that the correct dry and/or moist colors are compared.

Number, length, and size of soil **micropores** (small pores in the soil that cause water to be immobile) are not measurable in the field, but **macropores** (larger pores that promote water movement) are easily visible. For soil surface structure, describe comparisons between descriptions in the reference sheet and the soil surface horizon in the evaluation area.

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.

Photographs (see Appendix 12)

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

Indicator Description and Assessment

This indicator reflects effects of differences in 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 before it runs off. **Infiltration**, as used for this indicator, includes both the entry of water into soil and the movement of water into the soil profile. The vegetation composition and distribution are strongly related to spatial and temporal variability in infiltration and **runoff** 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).

Changes in plant community composition (see Appendix 2. Functional/Structural Groups Sheet) and the distribution of plants of varying sizes and structures, both above and below ground, can influence (positively or negatively) the ability of a site to capture and store precipitation. Plant rooting patterns, litter production and associated decomposition processes, height, basal area, and spatial distribution can all affect infiltration and/or runoff. In the Edwards Plateau in Texas, shifts in plant composition between bunchgrass and short grasses over time have the greatest potential to influence infiltration (Thurow et al. 1986, 1988a, 1988b). An example of a composition change that reduces infiltration and increases water runoff is the conversion of desert grasslands to shrub-dominated communities (Schlesinger et al. 1990).

Infiltration and runoff are also 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 water infiltration; however, snow entrapment and soil water storage may be reduced by this type of vegetation conversion. 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.

Assess this indicator by comparing the functional/structural groups and their associated species composition and distribution at the evaluation area with the appropriate reference state community phase (including modifications based on time since a disturbance) in the functional/structural groups sheet (Appendix 2). Rate the degree to which changes in functional/structural groups and their associated species composition and distribution have negatively affected infiltration or runoff in the evaluation sheet (Appendix 5).

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

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

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

* Assume that decreased infiltration causes a corresponding increase in runoff.

Measurements

Plant community composition can be quantified with either line point intercept or production measurements. Distribution can be inferred from basal gap intercept data. Infiltration can be measured using infiltrometers (Herrick et al. 2018). Runoff is not easily measured on areas as small as evaluation areas.

Relationship to Attributes of Rangeland Health

Hydrologic function: Plant community composition and distribution relative to infiltration and runoff is used to reflect the unique contributions of functional/structural groups and their associated species to changes in water infiltration and runoff.

Soil/site stability and biotic integrity: Not applicable.

Photographs (see Appendix 12)

7.4.11 Compaction Layer (Indicator 11)

Indicator Description and Assessment

A **compaction layer** is a near-surface layer of dense soil caused by the repeated impact on or disturbance of the soil surface. It can be caused by repeated application of weight or pressure at or below (e.g., plow pan) 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 repeatedly causes an impact to the soil surface can cause a compaction layer. 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 by digging a hole (generally less than 1 foot deep) and observing the soil structure and root morphology. Plant roots will often be restricted or found growing laterally at the upper boundary of the compaction layer. Once a compaction layer has been confirmed by direct observation, 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).

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 should be described in the soil survey description associated with the site.

Departure is assessed by identifying the presence or absence of a compaction layer, distribution of the layer across the evaluation area, and the 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; severely restricts water movement and root penetration.	Widespread; greatly restricts water movement and root penetration.	Moderately widespread; moderately restricts water movement and root penetration.	Infrequently present or is thin; weakly restricts water movement and root penetration.	Reference sheet narrative inserted here.

Measurements

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 may be impacted when the compaction layer reduces infiltration to the point that surface runoff increases, which increases the potential for water erosion. Compaction also reduces pore space and affects soil structure, affecting soil aeration and water holding capacity.

Hydrologic function: Compaction layers may restrict infiltration of water through the soil profile, thus negatively impacting hydrologic function.

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.

Photographs (see Appendix 12)

7.4.12 Functional/Structural Groups (Indicator 12)

Indicator Description and Assessment

This indicator describes plant communities based on ecological functions and plant structures that are considered to be in balance with the soil and climate characteristics of a site. Plant species may be placed in functional/structural groups based on similar characteristics of shoot (height, woody, herbaceous, bud locations, etc.) or root (fibrous versus tap) structure, photosynthetic pathway, nitrogen fixing ability, or life cycle (Chapin 1993; Dawson and Chapin 1993; Solbrig et al. 1996). Plant functional group composition and diversity are principle factors that explain plant productivity, plant total nitrogen, and light penetration (Tilman et al. 1997). Plant community resistance to invasive plant invasions and resilience to disturbances is enhanced through a mixture of functional and structural plant groups (Pokorny et al. 2005; Chambers et al. 2017.

Function typically refers to the ecophysiological role that plants play on a site. This would include the plant's life cycle (e.g., annual, monocarpic perennial, or perennial), phenology, photosynthetic pathway, nitrogen fixation, or facilitating water infiltration.

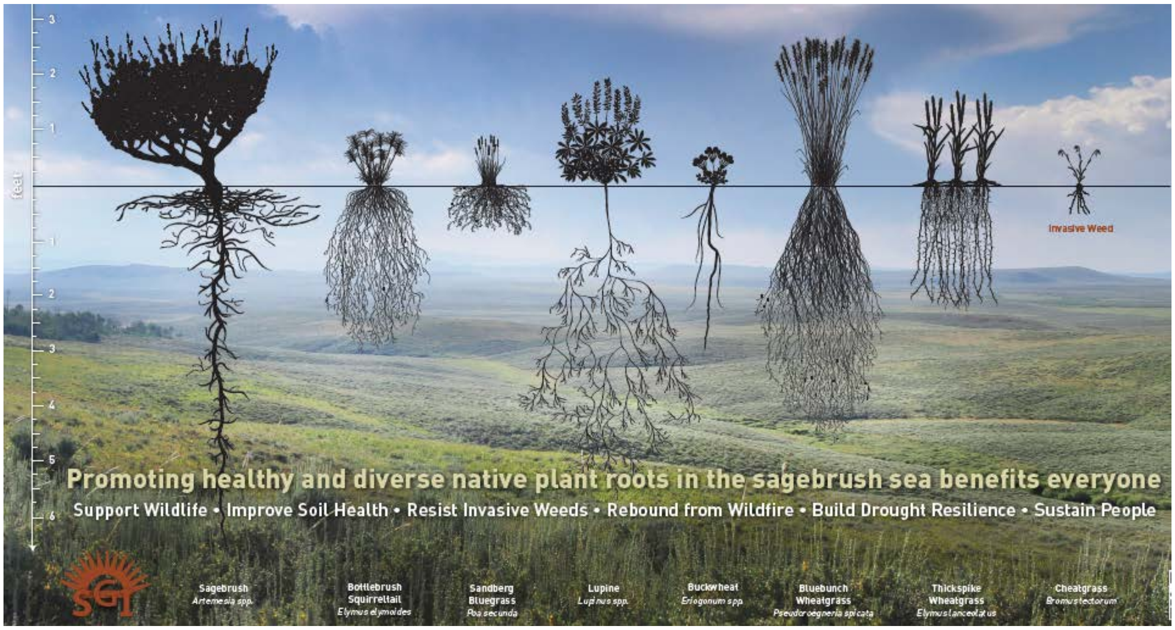


Figure 7. Root morphology of common plants in a sagebrush steppe ecosystem (Sage Grouse Initiative 2016).

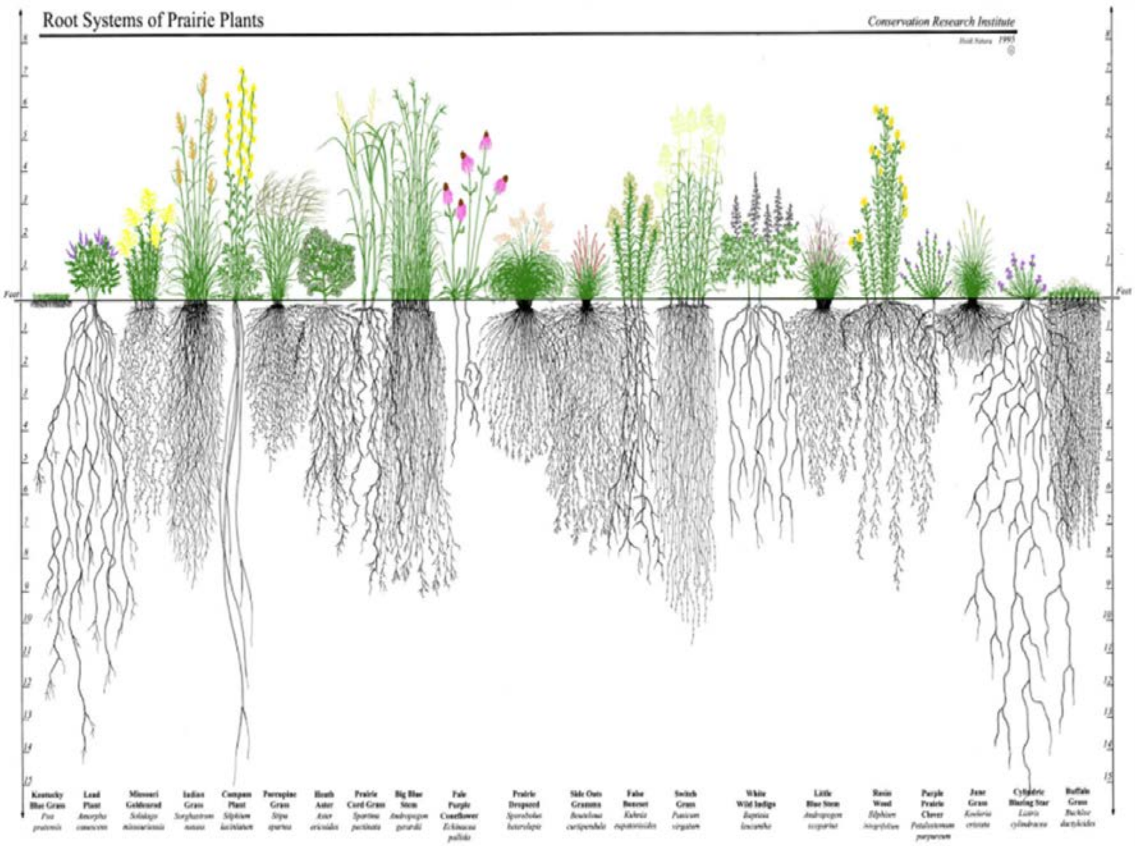


Figure 8. Root morphology of common plants in a mixed prairie (Natura 1995).

Structure refers to plant growth forms (e.g., trees, vines, shrubs, grass, forbs, and nonvascular plants, such as biological soil crusts) within the community. Structure may be subdivided to group species with similar growth 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 (Figures 7 and 8). Function and structure may be interrelated as evidenced by effects of plant canopy and rooting structure on precipitation capture, infiltration (amount and depth), and runoff.

It is strongly recommended to document the relative functional/structural group dominance in each community phase (also known as dominance hierarchy) in the reference state in the functional/structural groups sheet (Appendix 2). In addition to the blank sheet, Appendix 2 also includes an example of a completed functional/structural groups sheet.

Some more recent ecological site descriptions provide a list of plant species and data from multiple locations on the same ecological site that can be used to determine the functional/structural groups present and which groups are dominant, subdominant, minor, or trace components within each community phase in the reference state (Caudle et al. 2013). Older range site descriptions may have data for only one plant community phase e.g., the “historic climax plant community”. Even when data are only available for one community phase, the state-and-transition model that describes the community phases and their disturbance pathways can be used to develop approximations of the dominance of plant functional/structural groups in the other reference state community phases.

Evaluators are strongly encouraged to use the functional/structural groups sheet (Appendix 2) in the assessment of the evaluation area. Record the species observed in the evaluation area (from which the number of species present can be determined) by functional/structural group in the sheet.

When evaluating a site, 4 of the 17 indicators require an interpretation regarding changes in the dominance rating of functional/structural groups, or in the numbers of species within the dominant and subdominant functional/structural groups. It is important to use the same measure of dominance in the evaluation area as was used in the reference sheet. For example, if percent composition was based on production to rank the functional/structural group dominance because the ecological site description used production, then use percent composition by production when evaluating this indicator. Remember that relationships between cover and production are not similar among different plant species or functional/structural groups; therefore, dominance rankings based on cover and production will not be the same.

Changes in functional/structural groups for the appropriate community phase in the reference state may occur through one or more processes. These changes include: (1) **relative dominance** among functional/structural groups, (2) occurrence and dominance of functional/structural groups not expected at the ecological site, (3) reductions in the number of functional/structural groups, or (4) reductions in the number of species within dominant and subdominant functional/structural groups. For example, changes in the relative dominance of functional/structural groups may appear as a change from grass to shrub dominance or shift from cool to warm season plants. Additionally, if the numbers of species in functional/structural groups, especially in the dominant and subdominant functional/structural groups, have been greatly reduced, this may indicate loss of biotic integrity (Chambers et al. 2017). Both the presence of functional/structural groups and the number of species within the groups have a significant effect on ecosystem processes (Tilman et al. 1997).

Nonnative species are assigned to functional/structural groups using the same criteria as native species and are generally included in the same functional/structural groups as natives with similar function and structure. Nonnative and introduced plants may possess unique characteristics that affect ecological processes much differently than their native counterparts, requiring inclusion in a different or new functional/structural group. For example, knapweed is a nonnative perennial forb that warrants consideration for inclusion in a separate functional/structural group due to its ability to invade and greatly increase in undisturbed, climax bunchgrass communities (Lacey et al. 1990; Lawton 1994).

Rating this indicator using the functional/structural groups sheet:

1. The use of the functional/structural groups sheet (Appendix 2) is strongly recommended due to the difficulty in rating this indicator without it. Fill out the reference state section of the

functional/structural groups sheet before going to an evaluation area. At the evaluation area, determine which community phase in the reference state best fits the evaluation area based on knowledge of past disturbance regimes (e.g., time since last fire, drought, insect or disease impacts, etc.) and relative dominance of species found in the reference state. In the reference state section of the sheet, circle the community phase number that best fits the evaluation area (see example in Appendix 2). In the blank row (*) at the end of the relative dominance table in the reference state section, modify the relative dominance of the circled “closest fit” community phase (if a modification is needed). This modification allows evaluators to document the changes in relative dominance that occur in the transition zone (which can be due to changes in time since a disturbance) between the appropriate plant community phases in the reference state (see additional instructions in Appendix 2).

2. Inspect the evaluation area, and in the evaluation area portion of the sheet, record the species observed in the appropriate functional/structural groups.

3. In the evaluation area portion at the bottom of the sheet, record the observed relative dominance of the functional/structural groups in the evaluation area.

4. If a pathway between reference community phases was documented on page 1 of the evaluation sheet (Appendix 5), record the “closest fit” reference community phase and the modified relative functional/structural group dominance. This information will serve as a reference to rate the functional/structural groups indicator in the evaluation matrix (Appendix 3) (i.e., will be used as the “none to slight” category descriptor).

5. In the evaluation matrix (Appendix 3), rate the functional/structural groups indicator by rating each of the four subindicators. Use the subindicator that shows the greatest departure to select the indicator rating. The four subindicator ratings are not averaged. Table 18 provides generic descriptors of the five departure categories in the evaluation matrix for functional/structural groups. See Section 7.2.2 for instructions to develop an ecological site-specific (or equivalent unit) evaluation matrix.

Rating this indicator without using the Functional/Structural Groups Worksheet:

The use of the F/S Groups Worksheet is strongly recommended due to the difficulty in rating this indicator without it. However, if the F/S Groups Worksheet is not used, the evaluation area team will be required to discuss and document on Page 1 of the Evaluation Sheet the best fit for the reference state community phase that will function as the reference for the evaluation area. They will also have to discuss and document on Page 1 of the Evaluation Sheet the disturbances that have occurred on the evaluation area and develop a relative dominance for the F/S Groups expected for the site based on the time since or effects of the disturbance to use as a reference for the evaluation. This information serves as the reference for rating the F/S Groups indicator.

They will need to do Steps 2 and 3 at the evaluation area in order to complete the rating of this indicator. It is strongly recommended to use the F/S Groups worksheet to record this information so as to document the relative dominance of F/S Groups and the species associated with them. Step 5 above is then completed as described above.

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.	One or more dominant F/S groups is now 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.	F/S groups sheet information inserted here.
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 F/S groups	Severely reduced (missing ≥ 76% of F/S groups).	Greatly reduced (missing 51-75% of F/S groups).	Moderately reduced (missing 26-50% of F/S groups).	Slightly reduced (missing ≤ 25% of F/S groups).	F/S groups sheet information inserted here.
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%).	F/S groups sheet information inserted here.

* With species composition greater than 0 lb/acre or greater than 1% cover.

Measurements

Commonly used measures of plant dominance associated with ecological site descriptions include production and foliar cover. Cover is not equivalent to production or biomass. Composition measurements should match those used for developing the reference sheet. The number of species can be derived from either of these measurements, as well as from developing a species list for an evaluation area and documenting it in the functional/structural groups sheet (Appendix 2).

Relationship to Attributes of Rangeland Health

Soil/site stability and hydrologic function: Not applicable.

Biotic integrity: This indicator describes plant communities based on ecological functions and plant structures that are considered to be in balance with the soil and climate characteristics of a site (Chapin 1993; Dawson and Chapin 1993; Solbrig et al. 1996). A change in the dominance hierarchy or number of species in functional/structural groups may have a negative effect on ecosystem processes. A diversity of functional and structural groups appropriate to a site can promote community resistance to invasive plant invasions and resilience to disturbances (Pokorny et al. 2005; Chambers et al. 2014).

Photographs (see Appendix 12)

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

Indicator Description and Assessment

Plant mortality (dead plants) and dead or dying stems, branches, leaves, etc., are a natural phenomenon in all perennial plant communities. The proportion of dead or dying plants or plant parts may vary considerably over time depending on natural disturbance regimes. For example, a multiyear drought may result in a differential loss of plants that exceeds losses in years of less extreme departures in precipitation and growing season condition. Improper management during drought periods can increase dead or dying plants or plant parts above the natural range of variability expected for a drought (Thurow and Taylor 1999).

The natural disturbance regime affects plant lifespans and, in some instances, the ratio of dead to live plant parts. Little is known about the lifespan of many plant species under the natural disturbance regime (Svejcar et al. 2014), which makes determining departure from the reference state difficult.

Dying plant parts are natural for perennial plants, such as those perennial grasses that tend to age as a ring with a dead center. Likewise, many shrubs will have dead branches while most of the plant is alive. Since the amount of dead plants or plants with dead or dying plant parts is greatly influenced by the natural disturbance regime, it is important to determine departure from the expected value in the reference sheet by evaluating management effects on this indicator (see Section 5.9 Management Influences on Indicators). An ecological reference area for the ecological site provides a good reference to separate weather versus management influences.

Vigor and reproductive capability of perennial plants are not included in the rating of this indicator since they are covered in indicator 17, which is vigor with an emphasis on reproductive capability of perennial plants.

Decadent is a term used in Version 4 and has been changed to Dead or Dying Plant Parts since plant decadence is a natural process that occurs as plants age. Decadent means that some of the plant remains alive while other parts are obviously dead.

A factor that affects the rating of this indicator is the distribution of the plants exhibiting departure from the reference sheet. A greater concern exists if most of the dead or dying plants or plant parts are concentrated in one or more functional/structural groups, especially if it is a dominant or subdominant group. For example, consistently greater dead or dying plants or plant parts in the dominant cool season bunchgrass functional/structural group (relative to the natural disturbance regime) may be indicative of an adverse effect on community composition, especially if replacement of these grass species does not occur.

Rate only those plants that are currently present on a site. For example, a shrub component recently removed by wildfire would not be rated. Table 19 provides generic descriptors of the five departure categories in the evaluation matrix for dead or dying plants or plant parts. See

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	Extensive mortality and/or dying plants/plant parts concentrated in one or more functional/structural groups.	Widespread mortality and/or dying plants/plant parts concentrated in one or more functional/structural groups.	Moderate mortality and/or dying plants/plant parts concentrated in one or more functional/structural groups.	Occasional mortality and/or dying plants/plant parts concentrated in one or more functional/structural groups.	Reference sheet narrative inserted here.

Measurements

The relationship between dead and 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) is best 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 in assessing an evaluation area's population dynamics. If **recruitment** is not occurring and existing plants are either dying or dead, stand integrity is expected to decline, and undesirable plants (e.g., weeds or invasive plants) may increase (Pyke 1995; Svejcar et al. 2014).

Photographs (see Appendix 12)

7.4.14 Litter Cover and Depth (Indicator 14)

Indicator Description and Assessment

Litter is 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 a dead plant part, not litter (sometimes referred to as “standing dead”). Litter is still recognizable as the plant part (e.g., leaf of grass). If dead plant material is so decomposed that it cannot be recognized, it is considered duff, which is not counted in 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). Usually, most litter is seen in close proximity to the plant where it was produced. Also, there is usually a range of litter decomposition, from recently produced litter evident on the soil surface, to decayed litter that has become duff incorporated in the upper soil layers (O or A horizons).

The potential amount of litter is proportional to the productivity of an ecological site, given weather conditions (primarily precipitation), with more litter accumulation after wet years and less accumulation after dry years. The amount and kind of litter are also affected by whether the plant community is herbaceous or woody. 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. In contrast, the shrub community stores part of its annual growth as woody stems that may remain on the plant for many years. However, shrub litter may be more persistent.

To evaluate this indicator, the amount of herbaceous and woody litter present is compared to the amount that would be expected for the same 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, sites that have undergone a plant community change can produce and accumulate more litter than expected. For example, an introduced annual grass invasion in a perennial grass/shrub-dominated community results in a greater amount of litter than expected for a site. Litter in excess of the amount described in a reference sheet is also a departure. Both the overall cover and depth of litter are considered when assessing this indicator. 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 or extensive relative to site potential and weather.	Greatly reduced or increased relative to site potential and weather.	Moderately more or less relative to site potential and weather.	Slightly more or less relative to site potential and weather.	Reference sheet narrative inserted here.

Measurements

Litter amount can be measured as cover using line point intercept. Measurements of litter depth can be made at points distributed across the evaluation area.

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.

Photographs (see Appendix 12)

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 current weather conditions. Annual production, as used in this document, is the net quantity of aboveground vascular plant material produced within a year. It is not a measurement or estimate of total standing biomass (which includes the previous year's production). It is an indicator of the energy captured by plants and its availability for secondary consumers in an ecosystem, given current weather conditions. Annual production potential changes with plant communities or ecological sites (Whittaker 1975), biological diversity (Tilman and Downing 1994), and latitude (Cooper 1975). The amount of plant production, along with the kinds of plants, is an important factor in delineating an ecological site and change in total annual production. Annual production by species has long been a measure of change in rangeland condition.

Comparisons to the reference sheet are based on total annual production, no matter when the site is assessed. If utilization of vegetation has occurred or plants are in early stages of growth, estimate the annual production removed or expected, and include this amount when estimating the total site production. Appendix 9 describes a method to determine annual production. Additional methods are described in the "National Range and Pasture Handbook" (NRCS 2006).

Do not include **standing dead vegetation** (produced in previous years) or live tissue (woody stems) not produced in the current year as annual production. Only include standing dead plants produced during the current year (e.g., annuals) in the annual production evaluation. All species (e.g., native, seeded, and invasive species) that are or were alive in the year of the evaluation are included in determining total aboveground annual production. Therefore, the type of vegetation does not matter. Invasive species are addressed in a separate indicator in terms of impacts on ecological processes. Rickard and Vaughan (1988) found that conversion of a sagebrush steppe plant community to an exotic annual grassland greatly affected vegetation structure and function but not aboveground biomass production.

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

Table 21. Example of the values required to determine the departure rating for annual production.

Values from Example Ecological Site Description			
	Low	**Representative Value***	**High**
Pounds/Acre	500	800	1,100

* The representative value is the total annual production expected for a "normal" growing year. 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.

For example, evaluators estimated annual production in the evaluation area to be 450 lb/acre. The growing conditions (precipitation, temperatures) during the production year would be expected to produce the representative value of 800 lb/acre (Table 21). 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 3). Enter the departure rating in the evaluation sheet (Appendix 5).

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*	Less than 20% 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 a site-specific evaluation matrix, use these same percentage categories.

Measurements

For individuals performing rangeland health assessments, it is important to take time to estimate annual production on each ecological site before conducting the first rangeland health assessment on a particular ecological site.

There are at least three ways to determine annual production: total harvest, double sampling (combination of harvesting and estimating), and estimating using weight units (NRCS 2006). Total harvest involves clipping all vegetation from a number of plots and separating and weighing the current year's growth. For double sampling, estimate the current year's production in a series of plots, and then clip a portion of the plots to correct estimates. Estimating is best done by counting weight units within a series of plots (see Appendix 9). Adjustments to the estimates are done to account for phenological development using species growth curves and to account for any production removed by animals. Rating the annual production indicator requires using one of the three methods described above to become proficient in estimating current 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. This is the only indicator that is directly linked to the ecological process of energy flow.

Photographs (see Appendix 12)

7.4.16 Invasive Plants (Indicator 16)

Indicator Description and Assessment

Plants that are invasive to the evaluation area 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) and may or may not be nonnative. **Invasive plants** are plants that are not part of or may be a minor component (if native) of the reference state's expected plant composition. They have the potential to become a dominant or codominant species on the site if their establishment and growth is not actively controlled by management interventions. Once invasive species become dominant or codominant on the site, they control ecological processes and often create feedbacks, which sustain their dominance. 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. An example is Russian thistle, which on many ecological sites is an early successional species that often greatly increases after a disturbance (agricultural activities, wildfire, and droughts) but rarely dominates over time.

Some native plants that are normally controlled by the natural disturbance regime can 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 have the potential to exceed the natural range of variability (within the natural disturbance regime) in the reference state and are considered as invasive plants in the assessment.

Plants that have been purposefully introduced to an ecological site and that do not spread into and become dominant in surrounding areas are not considered invasive on that ecological site. However, these 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 invasive in the warm and dry portions of the Great Basin but may be invasive in the northern Great Plains.

Some invasive plants (e.g., knapweed) are capable of invading undisturbed, climax bunchgrass communities (Lacey et al. 1990), further emphasizing their use as an indicator of new ecosystem stress. Even highly diverse, species-rich plant communities are susceptible to exotic species invasion (Stohlgren et al. 1999).

Assess this indicator by selecting the best fit departure descriptor in the evaluation matrix (Table 23 and Appendix 3). It is important to document the invasive species by name and the relative abundance of each invasive species in the evaluation areas in the comment section on page 2 of the evaluation sheet (Appendix 5).

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	Dominate the evaluation area.	Common throughout the evaluation area.	Scattered throughout the evaluation area.	Uncommon in the evaluation area; present primarily in disturbed areas.	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, annual production, and/or density.

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).

Photographs (see Appendix 12)

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). Reproductive capability is dependent on a plant having adequate vigor and the ability to reproduce given the constraints of climate and herbivory. Since reproductive potential is linked to the growth of the remainder of the plant (White 1979), inflorescence (e.g., seed stalks) and flower production become 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 reduce in density and size as plant vigor declines (Goebel and Cook 1960).

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 an assessment is done in the absence of reproductive structures. 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 climatic conditions.

It is important to evaluate only noninvasive perennial plants (not annuals) present in the evaluation area. See Section 7.4.16 Invasive Plants (Indicator 16) for a detailed description of invasive plants. Vigor and reproductive capability of invasive species are not rated. 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. On page 2 of the evaluation sheet (Appendix 5), rate evaluation areas that have no perennial plants as "extreme to total," since they no longer have the capacity to produce perennial plants. Additionally, only rate plants that are currently at the site. For example, if deep-rooted, perennial bunchgrasses should be a dominant functional/structural group in an evaluation area and they are only present in minor amounts, only make your rating based on the plants occupying the site at the time of the evaluation.

Determine if vigor and reproductive capability issues are concentrated in certain functional/structural groups (Appendix 2) when rating this indicator. Document the functional/structural groups for which the rating applies in the comment section for this indicator on page 2 of the evaluation sheet (Appendix 5). For example, consistently lower vigor and reproductive capability in a deep-rooted, perennial bunchgrass functional/structural group in a sagebrush steppe system may be indicative of poor recruitment potential and a lack of resistance to invasive annual grasses. Additionally, do not modify a rating to reflect future deferment or rest for 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 take into account that the grazed pasture will be rested the following year.

Since reproductive capability of perennial plants is greatly influenced by weather, it is important to determine departure from the reference sheet (Appendix 1) by evaluating management effects outside the natural range of variability (see Section 5.9 Management Influences on Indicators). Ecological reference areas on the same ecological site provide a good comparison to separate weather versus management influences.

Recruitment is not assessed with this indicator since plant recruitment from seed is an episodic event on many rangeland ecological sites. However, evidence of recruitment (seedlings or vegetative spread) of perennial native or seeded plants is recorded in the comment section on page 2 of the evaluation sheet but is not considered in rating the reproductive capability of perennial plants.

One of the factors affecting plant vigor and reproductive capability includes dead or dying plants or plant parts, since vigor is reflected primarily by the size of a plant and its parts (SRM 1999). However, totally dead plants should not be included in the rating of this indicator; assess dead plants in indicator 13, dead or dying plants or plant parts. Table 24 provides generic descriptors of the five departure categories in the evaluation matrix for vigor with an emphasis on reproductive capability of perennial plants.

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	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/structural groups is extremely reduced.	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/structural groups is greatly reduced.	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/structural groups is moderately reduced.	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/ structural groups is slightly to moderately reduced.	Reference sheet narrative inserted here

Measurements

This indicator can be measured in various ways. Mueggler (1975) recommended 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) included 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. They found that vigorous plants produced more vegetative material and had a higher level of seed production than low vigor plants. Bilbrough and Richards (1993) used 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 vigor and reproductive capability are key components in ensuring that, when favorable climatic conditions are present, recruitment can occur to balance plant mortality. 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).

Photographs (see Appendix 12)

7.4.18 Optional Indicators

The 17 indicators previously described represent the baseline indicators that 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 functionality of the system(s) being evaluated, relative to at least one of the three attributes.

Optional indicators must be ecologically, not management, related. 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.

When considering the development and use of optional indicators, the expected improvement in evaluation of the attributes must be weighed against the benefits of maintaining a consistent protocol. Coordinate the development of optional indicators with the NRCS State Range Specialist. Table 25 includes examples of two optional indicators, biological soil crusts and vertical vegetation structure.

Table 25. Generic descriptors of the five departure categories for the optional indicators of biological soil crusts and vertical vegetation structure.

Optional Indicator	Extreme to Total	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
Biological soil crusts	Found only in protected areas; very limited suite of functional groups.	Largely absent; occurring mostly in protected areas.	In protected areas and with a minor component in interspaces.	Evident throughout the site but continuity is broken.	Largely intact and nearly matches site capability.
Vertical Vegetation Structure	Number of height classes greatly reduced and/or most height classes lost and/or dramatic increase in number of height classes expected for site and/or dramatic reduction in the number or density of individuals across several height classes.	Number of height classes significantly reduced and/or more than one height class lost and/or addition of more than one height class not expected for site and/or significant reduction in the number or density of individuals across height classes.	Number of height classes moderately reduced and/or one height class lost and/or addition of height class not expected for site and/or moderate reduction in the number or density of individuals across several height classes.	Number of height classes slightly reduced and/or slight reduction in the number or density of individuals across several height classes.	Number and type of height classes and the number and density of individuals in each height class closely match that expected for the site.

The biological soil crusts indicator could be applied where these crusts play a particularly important biological or physical role (e.g., for nitrogen fixation or soil stabilization). The vertical vegetation structure indicator is useful where variability in vertical vegetation structure within functional/structural groups affects wind erosion.

7.5 Step 5. Determine the Functional Status of the Three Rangeland Health Attributes (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 evaluator(s) 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 in an evaluation area. Make interpretations of the indicators, and select the degree of departure of the rangeland health attributes (soil/site stability, hydrologic function, and biotic integrity) at the bottom of page 2 of the evaluation sheet (Appendix 5). Make this summary rating by reviewing the indicator ratings and comments from all of the sheets, to arrive at a single degree of departure for each attribute.

There is some redundancy built into the indicators so that similar questions about rangeland health are asked in different ways. An example of this is where the indicators bare ground, litter movement, and effects of plant community composition and distribution on infiltration and runoff help determine whether an evaluation area is more susceptible to loss of soil and site stability from runoff and soil erosion than would be indicated by just one of these indicators. This helps address two challenges. The first is that some indicators may at times be difficult to observe (e.g., pedestalling after intensive grazing, wind movement after an intense storm). The second is that 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 of the four indicators in the “moderate” category is particularly important, based on knowledge of ecological site properties and processes, a rating of “moderate” may be supported.

It is also important to evaluate Lack of evidence of departure due to impossibility (e.g., gullies in a lake plain) justifies discounting an indicator when rating the attributes using the preponderance of evidence approach and describe this discounting in the attribute rating’s comments. It is required to rate all 17 indicators to determine the degree of departure for the three attributes of rangeland health.

Record justification for the attribute ratings at the bottom of page 2 in the site evaluation sheet (Appendix 5).

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 were related to both wind and water erosion.

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

Indicator	Relationship to 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 and/or wind. Increased occurrence of terracettes is evidence of reduced soil stability resulting in accelerated erosion by water. Significant 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 and/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 or 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 or 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 functionality 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 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 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 and/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 or 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 and/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 functionality or whether a physical threshold has been crossed.
10. Effects of Plant Community Composition and Distribution on Infiltration and Runoff	Plant community composition and distribution relative to infiltration and runoff reflect the unique contributions of functional/structural groups and their associated species to changes in infiltration and runoff. Plant rooting patterns, litter production and associated decomposition processes, height, basal area, and spatial distribution can all affect infiltration and/or runoff. 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.

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

Indicator	Relationship to 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 or 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 functionality 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 site can promote community resistance to plant invasions and resilience to disturbances (Pokorny et al. 2005; Chambers et al. 2014). A change in the dominance hierarchy or number of species in functional/structural groups may have a negative effect on ecosystem processes. Reduction in the numbers of species in functional/structural groups, especially in the dominant and subdominant functional/structural groups, may indicate loss of biotic integrity. The greater number of functional groups and the number of species 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. 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. Reduced annual production may be linked with reduced plant vigor, reduced litter, and/or changes in functional/structural groups.
16. Invasive Plants	Invasive plants may impact an ecosystem's type and abundance of species, their interrelationships, 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).
17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants	Plant vigor and reproductive capability are key components in ensuring that, when favorable climatic 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).

After Completing the Assessment

Once a rating is made for each attribute of rangeland health, managers may use the attribute evaluation to identify where more information (monitoring and/or inventory data) is required. If available, this information should be reviewed. If this information is not available, the information should be collected. Areas with a “moderate” departure rating are often ideal for implementing monitoring studies since they should be the most responsive to management activities. However, additional monitoring may be useful regardless of the departure rating, dependent upon future changes in uses or management of an area. For more information and applications of the IIRH assessment, see previous sections: 3. Intended Applications of Version 5; and 6. Relationship of the IIRH Protocol to Other Upland Rangeland Assessment, Inventory, and Monitoring Protocols.

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 monitoring and inventory information (see Section 5.7.2), 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 is needed in many ecosystems to quantify indicator attributes and identify thresholds for rangeland health. Once this information is available, the assessment of rangeland health will become more quantitative and less reliant on qualitative assessment of the indicators. With further research and application of the IIRH protocol, this technical reference will continue to experience further revisions. As the understanding of ecological dynamics (e.g., as described in state-and-transition model diagrams) grows, interpretation of the indicators progresses. As the concept of rangeland health continues to evolve and mature, 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).

age class distribution: the distribution of different ages of the same species or group of species on a site.

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 year. 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: the process of estimating or judging the value or functional status of ecological processes (e.g., rangeland health) in a location at a moment in time.

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 related 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.

badland: a land type consisting of steep or very steep barren land, usually broken by an intricate maze of narrow ravines, sharp crests, and pinnacles resulting from serious erosion of soft geologic materials (SRM 1999).

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 soil patches: an area where bare ground is concentrated in larger polygons than expected relative to the reference state (within the natural disturbance regime). Bare ground patches may include some ground cover (e.g., plants, litter, rock, and biological soil crusts) within their perimeter.

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, microfungi) 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 document, 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).

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 1997). 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 is reversible and attributable to succession, natural disturbances, short-term climatic variation, and facilitating practices such as grazing 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 the repeated 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).

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, stones, and bedrock. Ground cover plus bare ground totals 100 percent. Synonym: ground cover.

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: locations 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 to assist in the preparation of a reference sheet to conduct future rangeland health assessments. There is no predefined reference for this protocol.

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 3).

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: plant species or species groups that, by means of their number, coverage, or size, have considerable influence or control upon the conditions of existence of associated species (SRM 1999). Daubenmire (1968) defines dominant species as "those species whose removal would bring about the greatest readjustments in the edaphic, aerial, and biotic character of their ecosystem. They are often the tallest plants" and "where there is little difference in size, dominance is determined primarily by numbers of individuals." For purposes of this technical reference, dominant plants are those of the greatest size per unit area as measured by biomass, production, or cover.

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).

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: the amount of energy that is captured by plants and moved through the food chain via 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 stream systems: areas that receive more runoff than typical upland ecological sites, but the soil-water dynamics are generally similar to other upland sites receiving run-on water. They implicitly include, though do not focus on, the drainageways.

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 evaluation of rangeland health attributes takes place.

evaluation matrix: a form used to determine departure from the reference sheet (none to slight category) and the functional/structural groups sheet for each of the 17 indicators.

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

exclosure: an area fenced to exclude animals (SRM 1999).

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

foliar cover: the percentage of ground covered by the vertical projection of the aerial portion of plants. Small openings in the canopy and intraspecific overlap are excluded. Foliar cover is always less than canopy cover; either may exceed 100 percent (NRCS 1997) (see Figure 5).

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

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.

Function: refers to the ecophysiological role that plants play on a site. This would include the plant's life cycle (e.g., annual, monocarpic perennial, or perennial), phenology, photosynthetic pathway, nitrogen fixation, or facilitating water infiltration.

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 1) 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, stones, and bedrock. Ground cover plus bare ground totals 100 percent. Synonym: cover.

gully: a furrow, channel, or miniature valley, usually with steep sides through which water commonly flows during and immediately after rains or snowmelt (SRM 1999). Small channels eroded by concentrated water flow. 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: 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: rangeland health.

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.

hydrophobic soil: soils that are water repellant, often due to dense fungal mycelial mats or hydrophobic substances vaporized and reprecipitated during fire (SSSA 1997).

indicators: components of a system 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 too difficult, inconvenient, or expensive to measure.

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

intermittent stream systems: streams that flow continuously for some part of the year.

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: plants that are not part of (if exotic), or are a minor component of (if native), the original plant community or communities that have the potential to become a dominant or codominant species on the site if their future establishment and growth is not actively controlled by management interventions. Species that become dominant for only 1 to several years (e.g., short-term response to drought or wildfire) are 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: areas with a pasture or management unit, often nonrandomly selected to monitor specific management objectives in land use or grazing plans. Extrapolation of rangeland health assessments 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(s): large, connected geographical regions that have similar environmental characteristics and that may include part or all of one or more watersheds.

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 document, 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.

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).

modal concept (as it applies to ecological site descriptions): an ecological site description reflects the modal (most common) conditions for an ecological site (see Figure 2). The physical aspects (exposure, slope, landform, soil surface texture, etc.) and biological values (species composition by weight, foliar cover, annual production, etc.) reflect modal, not extreme, values. 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.

natural disturbance regime: the frequency and intensity of natural disturbance events that would have occurred on an ecological site prior to European influence upon that ecological site (ca. 1600 (Winthers et al. 2005). Natural disturbances include, but are not limited to, insect outbreaks, wildfires, native wildlife (herbivory, burrowing, etc.), indigenous human activity, and weather cycles and extremes (including droughts and unusually 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 the presence of nonnative species, accelerated erosion, soil organic matter loss, changes in nutrient availability, or soil structure degradation outside of the range associated with natural disturbance regimes.

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.

pedestal (erosional): plants or rocks that appear elevated as a result of soil loss by wind or water erosion (does not include plant or rock elevation as a result of 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).

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

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 decadence: in a plant community, decadence refers to an overabundance of dead or dying plants relative to what is expected for a site given the natural range of variability in disease, climate, and management influences. This technical reference version replaces this term with "dead or dying plants or plant parts."

plant mortality: the death of a plant, or in a plant community, the death of a number of plants in the community.

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.

quantitative rangeland health assessment: the determination of the functional status of an attribute(s) through measurement of vegetation, soil, or landscape characteristics that are indicators or can be used to derive indicators. Quantitative assessments have a known level of precision and accuracy and require a quantitative reference.

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. Marshes and wet meadows are not assessed with this protocol.

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 normal variability (SRM 1999). Synonym: healthy rangeland.

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

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

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 rangeland health assessments and is required in order to conduct an assessment.

reference sheet checklist: tool to assist in the development or revision of reference sheets by documenting the natural range of variability, including the natural disturbance regime, for each indicator.

reference state: 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. 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.

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 stresses like nitrogen deposition and disturbances like 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 water course 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.

structure: refers to plant growth forms (e.g., trees, vines, shrubs, grass, forbs, and nonvascular plants, such as biological soil crusts) within the community. Structure may be subdivided to group species with similar growth 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

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, climate, and management influences).

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 association: 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 miscellaneous areas, plus allowable inclusions in either case. The individual bodies of component soils and miscellaneous areas are large enough to be delineated at the scale of 1:24,000. Several bodies of each kind of component soil or miscellaneous area are apt to occur in each delineation, and they occur in a fairly repetitive and describable pattern (SSSA 1997).

soil classification: the systematic arrangement of soil units into groups or categories on the basis of their characteristics. Broad groupings are made on the basis of general characteristics and subdivisions on the basis of more detailed differences in specific properties (SSSA 1997).

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 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 process (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: an area or collection of areas within a soil survey that represents the same type of soil(s). A soil map unit is usually comprised of multiple soil types that occur in association with each other. See soil association and soil complex.

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/site stability: the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and/or 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 surface resistance to erosion: the ability of a surface soil to resist erosion by water. Resistance increases in part with increasing soil organic matter and/or the presence of biological soil crusts. It can be evaluated by performing a soil stability test (Appendix 8).

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).

standing dead vegetation: the total amount of dead plant material, in aboveground parts, per unit of space, at a given time (NRCS 1997). 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 within 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).

structure (soils): 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).

structure (vegetation): the height and area occupied by different plants or life forms in a community.

subdominant (subordinate) species: Daubenmire (1968) defines subordinate species as “those species, which if removed singly, would not occasion much rearrangement with their ecosystem.” For the purposes of this technical reference, subdominant plants are those within a community with less size per unit area, as measured by biomass, production, or cover.

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.

terracette: “benches” of soil deposition (may include incorporated litter or gravel) behind or between obstacles (persistent litter, rocks, or plant bases) caused by water (not wind) movement.

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.

transition: a shift between two states. Transitions are not 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 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: path(s) that water takes as it moves across the soil surface during periods when surface water from rain or snowmelt exceeds soil infiltration. Sometimes referred to as sheetflow or overland flow.

weather: the current state of the atmosphere with regard to wind, temperature, cloudiness, moisture, pressure, etc.

well-managed rangelands: rangelands that have properly functioning ecological processes, biotic integrity, and soil stability associated with human uses of the land.

wind-scoured area: areas, 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 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 1. Reference Sheet

Author(s)/participant(s): ____

Contact for lead author: ____________________________________

Date: _________ **MLRA:** _______ **Sub-MLRA:** _______ **Ecological site:** __________ This must be verified based on soils and climate (see ecological site description). Current plant community cannot be used to identify the ecological site.

Composition (indicators 10 and 12) based on (check one):

☐Cover (produced during current year) ☐ Annual Production ☐ Biomass

Data used (methods, when collected, data 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. Continue descriptions on separate sheet.

1. Rills:

2. Water flow patterns:

3. Pedestals and/or terracettes:

4. Bare ground:

5. Gullies:

6. Wind-scoured areas 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 and runoff:

11. Compaction layer:

12. Functional/structural groups:

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:

Instructions for Reference Sheet Development or Revision

Before beginning the development or revision of a reference sheet, check with the NRCS state rangeland management specialist to find out if a final or draft reference sheet is available.

- If revisions to an **existing reference sheet** are necessary, follow the same protocol as for reference sheet development, and send the completed draft, with all rationales for changes, to the NRCS state rangeland management specialist. If an assessment must be made before a reference sheet can be officially revised, use the existing approved reference sheet, or discuss the issues with the state rangeland management specialist. Document the reasons for using a modified reference sheet during the field season. It is also recommended to document the modifications and rationale internally (agency, organization, etc.). Use the reference sheet checklist that follows to determine the completeness of a reference sheet.

- If a **draft reference sheet** is available, it may be used. Provide comments or suggest modifications to the NRCS state rangeland management specialist using the reference sheet checklist/evaluation matrix as a guide to organize input.

- If **no reference sheet** exists, develop one using the following steps, and send it to the NRCS state rangeland management specialist.

Steps required to develop or revise a reference sheet include:

Step 1. Assemble (virtually or in person) a diverse group of experts with extensive knowledge of the ecological site.

Individuals should 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 and data from ecological reference areas, including data used to support ecological site descriptions. Local monitoring and inventory data is a valuable resource for looking at the variability in plant community composition. In addition, AIM and NRI data may be useful. Ecological reference areas may be identified from existing inventory and monitoring sites or by asking people with local knowledge. Categorizing sites by disturbance and management history and other factors may be useful to identify ecological reference areas.

Step 3. Define and categorize the functional/structural groups for the ecological site (or equivalent).

Instructions for completing the functional/structural groups sheet are in Appendix 2.

Step 4. Visit one or more ecological reference areas (optional).

Visiting one or more ecological reference areas is useful for developing or revising a reference sheet (see Section 7.3 Step 3. Collect Supplementary Information). Visits to ecological reference areas can improve the ability to recognize the indicators in the field and to field check 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 3 in Section 5.3 States, Transitions, and Disturbances).

Step 5. Describe the status of each indicator in the reference state.

Using the Reference Sheet Checklist as a guide, describe the status and natural range of variability, including the range of variability associated with the natural disturbance regime, of each indicator in the reference state. This becomes the “none to slight” departure category in the evaluation matrix. 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, insect outbreaks, wildfires, native wildlife (herbivory, burrowing, etc.), indigenous human activity, and weather cycles and extremes (including droughts and unusually wet periods, temperatures, snow and wind events).

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 primary production potential. For additional information, see Section 5.1 Landscape Context and Section 5.2 Natural Range of Variability.

Cite data or other information, when available, to support the descriptor (e.g., the ecological site description). Specify whether plant community composition estimates are based on current year’s production, foliar cover, or biomass (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 rocks in measurements of bare ground.

Reference Sheet Checklist

This checklist is designed to be used in the development of new reference sheets and updating existing ones. The characteristics listed under each indicator should be incorporated into the reference sheet for each community phase functioning under the natural disturbance regime in a particular reference state.

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/or terracettes per unit area
   - ☐ Size of pedestals and terracettes
   - ☐ Slope effect on pedestals and terracettes
   - ☐ Disturbance/weather effects on pedestals and terracettes
   - ☐ Association with landscape position, water flow patterns, or bare areas
4. **Bare Ground**
   - ☐ Percent bare ground cover range
   - ☐ Frequency and size of bare areas
   - ☐ Connectivity of bare areas
   - ☐ Maximum bare area size and amount resulting from natural disturbances
   - ☐ Changes in percent bare ground following natural disturbances and weather variability (e.g., droughts or wet periods).
5. **Gullies**
   - ☐ Number of gullies
   - ☐ Depth of gullies
   - ☐ Slope effect on gullies
   - ☐ Disturbance/weather effects on gully activity
   - ☐ Landscape position
6. **Wind-Scoured and/or Depositional Areas**
   - ☐ Proportion of site with wind-scoured and/or depositional areas
   - ☐ Size of blowouts, depth of deposition

- ☐ 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, locations, and frequency 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
- ☐ Disturbance effects on soil stability
- ☐ Difference in soil stability ratings between perennial plant canopy and interspaces

9. Soil Surface Loss and Degradation

- ☐ Depth of A horizon (and O horizon, if expected)
- ☐ Structure and color of A and B horizons
- ☐ Organic matter content of A horizon

10. Effects of Plant Community Composition and Distribution on Infiltration and Runoff

- ☐ Relative dominance of functional/structural groups
- ☐ Interaction of slope and vegetation on infiltration and runoff
- ☐ Expected community changes from natural disturbance and weather variability
- ☐ Distribution of functional/structural groups on site

11. Compaction Layer

- ☐ Thickness of compaction layer (if any in reference state)
- ☐ Soil features that may be mistaken for compaction

12. Functional/Structural Groups

- ☐ Dominance hierarchy of functional/structural groups within each phase of the reference state (including completed relative dominance section of functional/structural groups sheet)
- ☐ Expected shifts in dominance hierarchy resulting from natural disturbance and weather

13. Dead or Dying Plants or Plant Parts

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

14. Litter Cover and Depth

- ☐ Percent of litter cover range in reference phase(s)
- ☐ Average litter depth
- ☐ Size classes of litter
- ☐ Effect of disturbance, weather, and natural herbivory on litter accumulation
- ☐ Distribution of litter in interspaces and under plant canopy

15. Annual Production

- ☐ Expected annual production ranges (low, representative, and high)
- ☐ Differences in production across precipitation range for site
- ☐ Effect of natural disturbances and weather on production
- ☐ Proportion of production from each functional/structural group

16. Invasive Plants

- ☐ List of 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
- ☐ Effect of disturbance and weather on susceptibility of vegetation community to plant invasion
- ☐ Composition of native invasive plants (if any) expected in each phase of the reference state

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

- ☐ Proportion of reproductive plants by perennial functional/structural group
- ☐ Effect of weather and disturbance on vigor and reproductive capability of perennial plants

Appendix 2. Functional/Structural Groups Sheet

State_______ **Office**_________________ **Ecological site**________________________________ **Ecol. site code**
________ **Observers**____
Date________________
Evaluation site ID and/or name: ____
Dominance in ESD based on: Foliar Cover ____ Annual Production ____ Biomass ____

Species list of functional/structural groups in the **Reference State**

Functional/Structural Group	Species List
Biological soil crust[1]	

Reference State - Relative dominance of functional/structural groups for each community phase

Relative dominance annotations: *Use the following annotations in the narrow columns to describe the relative dominance of the listed functional/structural groups:* **=** *"equal";* **>** *"greater than";* **>>** *"much greater than"*

Phase	Dominant	>> > =	Subdominant	>> > =	Minor	>> > =	Trace
1.1							
1.2							
1.3							
*							

Circle the community phase that most closely matches the evaluation area. ***Revise functional/structural groups relative dominance for the community phase circled to represent changes in dominance given the time since disturbance(s) (see page 1 of site evaluation sheet).

Species list of functional/structural groups in the **Evaluation Area**

Functional/Structural Group	Species List
Biological soil crust[1]	

Evaluation Area - Relative dominance of functional/structural groups

Dominant	>> > =	Subdominant	>> > =	Minor	>> > =	Trace

Biological soil crust [1] - dominance is evaluated solely on cover, not composition by weight

Example of Completed Functional/Structural Groups Sheet

State_______ **Office**___________________ **Ecological site**________________________________ **Ecol. site code** _____
Observers____
Date________________
Evaluation site ID and/or name: ____
Dominance based on: Foliar Cover ____ Annual Production ____ Biomass ____

Species list of functional/structural groups in the **Reference State**

Functional/Structural Group	**Species List**
Deep-rooted C_3 grasses	Bluebunch wheatgrass, Thurber's needlegrass, Indian ricegrass, bottlebrush squirreltail
Shallow-rooted C_3 grasses	Sandberg bluegrass
Non-sprouting shrubs	Wyoming big sagebrush, bitterbrush
Resprouting shrubs	Green rabbitbrush, rubber rabbitbrush
Perennial forbs	Arrowleaf balsamroot, *Astragalus* spp., tapertip hawksbeard, *Lupinus* spp., western yarrow, *Aster*
Biological soil crust[1]	Moss, lichens

Reference State - Relative dominance of functional/structural groups for each community phase

Phase	Dominant	>> > =	Subdominant	>> > =	Minor	>> > =	Trace
[✓ 1.1]	Deep-rooted C_3 grasses	>	Resprouting shrubs and perennial forbs	>>	Shallow-rooted C_3 grasses and annual forbs	>	Annual forbs and non-sprouting shrubs
1.2	Nonsprouting shrubs	=	Deep-rooted C_3 grasses	>>	Perennial forbs	>	Sprouting shrubs and annual forbs
1.3	Nonsprouting shrubs	>>	Shallow-rooted C_3 grasses	>	Deep-rooted C_3 grasses	>	Perennial forbs, resprouting shrubs, and annual forbs
*1.1 transition to 1.2	Deep-rooted C_3 grasses	>	Nonsprouting shrubs and perennial forbs	>	Sprouting shrubs and shallow-rooted C_3 grasses	>>	Annual forbs

Circle the community phase that most closely matches the evaluation area. *Revise functional/structural groups relative dominance for the community phase circled to represent changes in dominance given the time since disturbance(s) (see page 1 of site evaluation sheet).

Species list of functional/structural groups in the **Evaluation Area**

Functional/Structural Group	**Species List**
Deep-rooted C_3 grasses	Bottlebrush squirreltail, Thurber's needlegrass
Shallow-rooted C_3 grasses	Sandberg bluegrass
Non-sprouting shrubs	Wyoming big sagebrush
Resprouting shrubs	Green rabbitbrush, rubber rabbitbrush
Perennial forbs	*Aster* spp., *Lupinus* spp.
Biological soil crust[1]	Moss

Evaluation Area- Relative dominance of functional/structural groups

Dominant	>> > =	Subdominant	>> > =	Minor	>> > =	Trace
Nonsprouting shrubs	>>	Shallow-rooted C_3 grasses	>	Resprouting shrubs	>	Perennial forbs, deep-rooted C_3 grasses

Biological soil crust [1] - dominance is evaluated solely on cover, not composition by weight

Instructions for Completing the Functional/Structural Groups Sheet

Completion of the functional/structural groups sheet is strongly recommended for conducting IIRH assessments. For sites with plant community composition data, assign the appropriate plant community phases of the reference state in the reference state section of the sheet. Generally, the best available plant community composition data for most ecological sites is based on annual production and is reported in NRCS ecological site descriptions. If using BLM AIM data, then the community composition data is based on foliar cover.

Step 1. Use the functional/structural groups sheet to categorize plant species into appropriate functional/structural groups for the ecological site.

Ecological site descriptions may have potential functional/structural groups, which may be used or modified. If no functional/structural groups are listed or if a revision is being considered, first group the plant species by structural groups (e.g., trees, vines, shrubs, grasses, forbs, and lichen/moss). Further subdivision may be useful using height groups, vegetative spread (e.g., bunchgrass versus rhizome/stolons), or root structure (e.g., tap versus fibrous). Then, examine these groups to determine if important plant functional categories might aid in capturing how groups provide physiological functions within the plant community. Physiological functions might include photosynthetic pathways (C_3, C_4, and CAM), nitrogen fixation, sprouting ability, etc. In general, single-species groups are not recommended unless that species is a potentially important dominant species in the ecological site.

After determining the functional/structural groups and incorporating them into the functional/structural groups sheet, populate the species list using the plant species composition table(s) in the ecological site description and other information sources (if available).

It may be necessary to lump smaller functional/structural groups to produce meaningful distinctions in the dominance group hierarchy (see information that follows).

Step 2. Determine the relative dominance of the functional/structural groups for each community phase of the reference state.

Calculate the relative dominance of the functional/structural groups (dominant, subdominant, minor, or trace) by dividing the annual production of each group by the total annual production in the same community phase, and then multiply by 100 for a percentage. As a rule of thumb, groups within ±10% of each other have similar rankings in dominance. The dominant group(s) has the largest relative dominance. Rank groups with lower dominance in order of dominance using an approximate 10% dominance breakpoint to separate dominant from subdominant groups and subdominant from minor or trace groups. The minor or trace groups may be separated by less than 10% dominance. The trace group generally is less than 1% dominance. More than one functional/structural group may be assigned to each dominance category in a community phase. Complete this step for each community phase within the natural disturbance regime in the reference state.

Step 3. Complete the relative dominance portion for each reference community phase in the functional/structural groups sheet.

Some ecological site descriptions have a “community phase composition” section that includes species composition by weight for each community phase in the reference state. The community phases in the reference sheet are connected by pathways, where the functional/structural group dominance may change slowly or quickly as one community phase proceeds on the pathway to another, which depends on the driver of pathway change.

Once developed, the functional/structural groups sheet for an ecological site should reflect the natural range of variability for the composition of the plant species groups for the reference state. This sheet will become a part of the reference sheet for indicator 12 (functional/structural groups) when new or revised reference sheets are developed. Share the functional/structural groups sheet with the NRCS state rangeland management specialist.

Recommended Process to Assess Functional/Structural Groups Indicator

Step 1. Obtain or complete the “reference state” section at the top of the functional/structural groups sheet before going to the evaluation area.

Step 2. At the evaluation area, complete the “evaluation area” section at the bottom of the functional/structural groups sheet.

Step 3. Fill out page 1 of the site evaluation sheet (Appendix 5), including the section on identifying the reference community phase that most closely matches the evaluation area. Based on an understanding of disturbance regimes at the evaluation area, “fine tune” the relative dominance of functional/structural groups in the chosen “best fit” reference community phase. It is recommended to complete this step using the functional/structural groups sheet.

Step 4. Fill in the “none to slight” category in the evaluation matrix (Appendix 3) with the functional/structural groups relative dominance developed in step 3.

Step 5. Rate the functional/structural groups indicator. Of the four subindicators, the one with the greatest departure is chosen as the final rating.

Appendix 3. Evaluation Matrix

	Departure from Reference Sheet				
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
1. Rills	Numerous, well-defined throughout; may be connected into drainage patterns.	Moderate in number at frequent intervals; well-defined, longer, wider, and deeper in exposed and less vegetated areas.	Few at infrequent intervals; moderate width, depth, and length; occur in or near exposed or disturbed areas.	Scarce, scattered, and short; width and depth minimal; occur mostly in exposed areas.	Reference sheet narrative inserted here.
2. Water Flow Patterns	Extensive and numerous; long and wide; unstable with active erosional and/or depositional areas; usually connected.	Widespread and numerous; long and wide; erosional and/or depositional areas common; occasionally connected.	Common; lengths and/or widths nearly match none to slight; minor erosional and/or depositional areas; infrequently connected.	Scarce; length and width match none to slight; some minor erosional and/or depositional areas; stable, short, and rarely connected.	Reference sheet narrative inserted here.
3. Pedestals and/or Terracettes	Pedestals extensive and/or terracettes are numerous; plant pedestals frequently have exposed roots.	Pedestals widespread and/or terracettes are common; some plant pedestals have exposed roots.	Pedestals common and/or terracettes occasionally present; exposed roots on plant pedestals uncommon.	Pedestals scarce and/or terracettes uncommon; exposed roots on pedestals uncommon.	Reference sheet narrative inserted here.
4. Bare Ground	Much higher than expected; bare soil patches are large and generally connected.	Moderate to much higher than expected; bare soil patches are large and occasionally connected.	Moderately higher than expected; bare soil patches are of moderate size and sporadically connected.	Slightly to moderately higher than expected; bare soil patches are small and rarely connected.	Reference sheet narrative inserted here.
5. Gullies	Sporadic or no vegetation on banks and/or bottom; significant active bank and bottom erosion including downcutting and numerous nickpoints; gully depth significant; active headcut(s) may be present.	Intermittent vegetation on banks and/or bottom; moderate active bank and bottom erosion with moderate downcutting; nickpoints common; moderate or greater gully depth; active headcut(s) may be present.	Occasional vegetation on banks and/or bottom; occasional nickpoints and/or downcutting; moderate gully depth; headcuts absent.	Vegetation is stabilizing most banks and/or bottom; few nickpoints and/or downcutting; minimal gully depth; headcuts absent.	Reference sheet narrative inserted here.

Departure from Reference Sheet					
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 and/or soil deposition around most obstructions.	Common; wind scours frequently connected and/or soil deposition around many obstructions.	Occasionally present; wind scours infrequently connected and/or minor soil deposition.	Infrequent and few; wind scours rarely connected and/or soil deposition uncommon.	Reference sheet narrative inserted here.
7. Litter Movement (Wind or Water)	Extreme movement of most size classes; large 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 and scattered; small accumulations around obstructions or in depressions.	Slight movement of small size classes; not usually accumulating around obstructions or in depressions.	Reference sheet narrative inserted here.
8. Soil Surface Resistance to Erosion	Extremely reduced throughout.	Significantly reduced in most interspaces and moderately reduced beneath plant canopies.	Significantly reduced in at least half of plant interspaces or moderately reduced throughout.	Some reduction in plant interspaces or slight reduction throughout.	Reference sheet narrative inserted here.
9. Soil Surface Loss and Degradation	Soil surface horizon very thin to absent throughout evaluation area; soil surface structure similar to or more degraded than subsurface; no distinguishable difference between surface and subsurface organic matter content.	Severe soil loss and/or degradation throughout evaluation area; minor differences between soil organic matter content and structure of surface and subsurface layers.	Moderate soil loss and/or degradation in plant interspaces with some degradation beneath plant canopies; soil organic matter content is markedly reduced.	Slight soil loss and/or soil structure shows slight signs of degradation, especially in plant interspaces; minor change in soil organic matter content.	Reference sheet narrative inserted here.

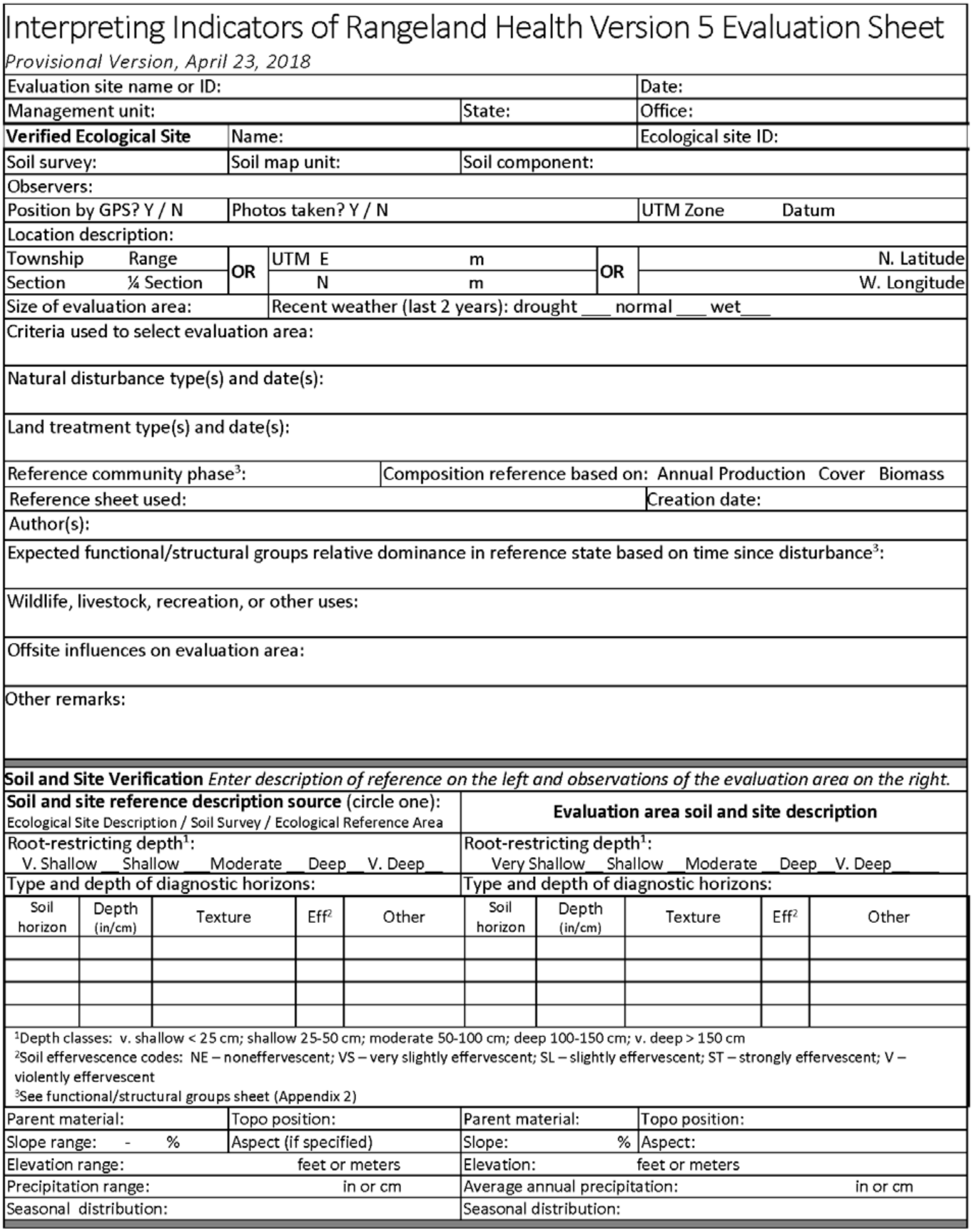
Departure from Reference Sheet					
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
10. Effects of Plant Community Composition and Distribution on Infiltration and Runoff	Changes in plant community (functional/structural groups) composition and/or distribution are expected to result in a severe reduction in infiltration and a significant increase in runoff.	Changes in plant community (functional/structural groups) composition and/or distribution are expected to result in greatly decreased infiltration and a large increase in runoff.	Changes in plant community (functional/structural groups) composition and/or distribution are expected to result in moderate reduction in infiltration and a moderate increase in runoff.	Changes in plant community (functional/structural groups) composition and/or distribution are expected to result in moderate reduction in infiltration and slight to moderate increase in runoff.	Reference sheet narrative inserted here.
11. Compaction Layer	Extensive; severely restricts water movement and root penetration.	Widespread; greatly restricts water movement and root penetration.	Moderately widespread; moderately restricts water movement and root penetration.	Infrequently present or is thin; weakly restricts water movement and root penetration.	Reference sheet narrative inserted here.
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.	One or more dominant F/S groups is now 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.	F/S groups sheet information inserted here.
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 F/S groups	Severely reduced (missing ≥ 76% of F/S groups).	Greatly reduced (missing 51-75% of F/S groups).	Moderately reduced (missing 26-50% of F/S groups).	Slightly reduced (missing ≤ 25% of F/S groups).	F/S groups sheet information inserted here.
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%).	F/S groups sheet information inserted here.

Departure from Reference Sheet					
Indicator	**Extreme to Total**	**Moderate to Extreme**	**Moderate**	**Slight to Moderate**	**None to Slight**
13. Dead or Dying Plants or Plant Parts	Extensive mortality and/or dying plants/plant parts concentrated in one or more functional/structural groups.	Widespread mortality and/or dying plants/plant parts concentrated in one or more functional/ structural groups.	Moderate mortality and/or dying plants/plant parts concentrated in one or more functional/ structural groups.	Occasional mortality and/or dying plants/plant parts concentrated in one or more functional/ structural groups.	Reference sheet narrative inserted here.
14. Litter Cover and Depth	Largely absent or extensive relative to site potential and weather.	Greatly reduced or increased relative to site potential and weather.	Moderately more or less relative to site potential and weather.	Slightly more or less relative to site potential and weather.	Reference sheet narrative inserted here.
15. Annual Production	Less than 20% 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	Dominate the evaluation area.	Common throughout the evaluation area.	Scattered throughout the evaluation area.	Uncommon in the evaluation area; present primarily in disturbed areas.	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	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/ structural groups is extremely reduced.	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/ structural groups is greatly reduced.	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/ structural groups is moderately reduced.	Plant vigor and capability to produce seed or vegetative tillers within one or more functional/ structural groups is slightly to moderately reduced.	Reference sheet narrative inserted here

Appendix 4. Checklist for the IIRH Protocol

	Task	Required or Recommended	Mark When Completed
Before going to the field	Identify evaluator(s).	Required	
	Select evaluation area(s).	Required	
	Assemble soils information and ecological site description(s).	Required	
	Obtain or develop reference sheet(s).	Required	
	Obtain ecological site-specific evaluation matrix and functional/structural groups sheet with completed reference state section.	Strongly Recommended	
	If a reference sheet is not available, stop until it is developed (Appendix 1)		
	Use the reference sheet checklist (Appendix 1) to review reference sheets for completeness, and identify any information missing from reference sheet indicator descriptions.	Required	
	If not already available, develop the ecological site-specific evaluation matrix and complete (may require collecting supplemental information and/or visiting ecological reference areas).	Strongly Recommended	
	If functional/structural groups sheet is not available, develop functional/structural groups relative dominance for each community phase in the reference state portion of this sheet (Appendix 2).	Strongly Recommended	
	Gather information about disturbance history and recent weather at evaluation areas (fire history, vegetation treatments, precipitation records, etc.).	Required	
	Identify any potential ecological reference areas to be visited.	Recommended	
	Visit ecological reference areas	**Recommended**	
At the evaluation area	Delineate evaluation area.	Required	
	Verify soil and determine the ecological site.	Required	
	Complete first page of site evaluation sheet (Appendix 5).	Required	
	Each evaluator independently observes conditions throughout the evaluation area.	Required	
	Measure soil stability and enter calculated soil stability values on page 2 of the site evaluation sheet under indicator 8.	Required	
	Measure or estimate annual production and enter value on page 2 of the site evaluation sheet under indicator 15.	Required	
	Collect additional quantitative data (bare ground and litter cover at a minimum) and take photos.	Optional	
	Identify the reference phase that best fits the evaluation area; complete the species list and relative dominance of functional/structural groups for the evaluation area in the functional/structural groups sheet.	Required	
	Rate the 17 indicators. Include written observations and rationale for all ratings under the comment section on page 2 of the site evaluation sheet.	Required	
	Rate the 3 attributes of rangeland health based on the ratings of the 17 indicators; provide written rationale for the ratings.	Required	

Appendix 5. Evaluation Sheet



Interpreting Indicators of Rangeland Health Version 5 Evaluation Sheet

Provisional Version, April 23, 2018

Evaluation site name or ID:			Date:
Management unit:		State:	Office:
Verified Ecological Site	Name:		Ecological site ID:
Soil survey:	Soil map unit:	Soil component:	
Observers:			
Position by GPS? Y / N	Photos taken? Y / N		UTM Zone Datum
Location description:			
Township Range Section ¼ Section	**OR**	UTM E m N m	**OR** N. Latitude W. Longitude
Size of evaluation area:	Recent weather (last 2 years): drought ___ normal ___ wet___		
Criteria used to select evaluation area:			
Natural disturbance type(s) and date(s):			
Land treatment type(s) and date(s):			
Reference community phase[3]:	Composition reference based on: Annual Production Cover Biomass		
Reference sheet used:		Creation date:	
Author(s):			
Expected functional/structural groups relative dominance in reference state based on time since disturbance[3]:			
Wildlife, livestock, recreation, or other uses:			
Offsite influences on evaluation area:			
Other remarks:			

Soil and Site Verification *Enter description of reference on the left and observations of the evaluation area on the right.*

Soil and site reference description source (circle one): Ecological Site Description / Soil Survey / Ecological Reference Area	**Evaluation area soil and site description**
Root-restricting depth[1]: V. Shallow__ Shallow ___Moderate __ Deep__ V. Deep__	Root-restricting depth[1]: Very Shallow__ Shallow __Moderate __Deep__ V. Deep___
Type and depth of diagnostic horizons:	Type and depth of diagnostic horizons:

Soil horizon	Depth (in/cm)	Texture	Eff[2]	Other	Soil horizon	Depth (in/cm)	Texture	Eff[2]	Other

[1] Depth classes: v. shallow < 25 cm; shallow 25-50 cm; moderate 50-100 cm; deep 100-150 cm; v. deep > 150 cm

[2] Soil effervescence codes: NE – noneffervescent; VS – very slightly effervescent; SL – slightly effervescent; ST – strongly effervescent; V – violently effervescent

[3] See functional/structural groups sheet (Appendix 2)

Parent material:	Topo position:	Parent material:	Topo position:
Slope range: - %	Aspect (if specified)	Slope: %	Aspect:
Elevation range: feet or meters		Elevation: feet or meters	
Precipitation range: in or cm		Average annual precipitation: in or cm	
Seasonal distribution:		Seasonal distribution:	

3

See functional/structural groups sheet (Appendix 2)

Departure from Expected	**Code**	**Instructions**
None to Slight…………	N-S	(1) Assign 17 indicator ratings. If indicator not present, rate None to Slight.
Slight to Moderate……	S-M	(2) In the three grids below, write the indicator number in the appropriate column for each indicator that is 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:____%	S	H		
5. Gullies	S	H		
6. Wind-scoured, blowouts and/or depositional areas	S			
7. Litter movement	S			
8. Soil surface reisistance to erosion Interspace :___ Plant Canopy:___	S	H	B	
9. Soil surface loss or degradation	S	H	B	
10. Plant community composition and distribution relative to infiltration and runoff		H		
11. Compaction layer	S	H	B	
12. Functional/structural groups			B	
a. Relative dominance ____				
b. F/S groups not expected for the site ____				
c. # 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 Cover____ %		H	B	
15. Annual production (__Pounds or __Kilograms) Estimated:_____ ÷ Expected_____ = ____%			B	
16. Invasive plants			B	
17. Vigor with an emphasis on reproductive capability of perennial plants			B	

Soil and Site Stability (S)
(10 indicators)

Attribute Rating: _____ **Rationale:**

E-T	M-E	M	S-M	N-S	

Hydrologic Function (H)
(10 indicators)

Attribute Rating: _____ **Rationale:**

E-T	M-E	M	S-M	N-S	

Biotic Integrity (B)
(9 indicators)

Attribute Rating: ____ **Rationale:**

E-T	M-E	M	S-M	N-S	

Departure from Expected	**Code**	**Instructions**
None to Slight…………	N-S	(1) Assign 17 indicator ratings. If indicator not present, rate None to Slight.
Slight to Moderate……	S-M	(2) In the three grids below, write the indicator number in the appropriate column for each indicator that is 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 in interspaces
3. Pedestals and/or terracettes	S H S-M	Occasional pedestaled bunchgrasses in interspaces
4. Bare ground: _15_%	S H M	Expected is 3-5%; observed is much higher
5. Gullies	S H N-S	None noted
6. Wind-scoured, blowouts and/or depositional areas	S N-S	None noted
7. Litter movement	S S-M	Displacement of fine material up to 2' associated with water flow patterns
8. Soil surface reisistance to erosion Interspace: 2.6_ Plant Canopy: _3.2	S H B M	Expected is 5-6, observed consistently 1-2 categories lower
9. Soil surface loss or degradation	S H B S-M	A-horizon is thinner and ligher in color than expected
10. Plant community composition and distribution relative to infiltration and runoff	H N-S	Shrub and perennial grass composition and distribution are adequate to facilitate normal infiltration processes
11. Compaction layer	S H B S-M	Some platy structure and root restriction noted in interspaces
12. Functional/structural groups a. Relative dominance:_S-M b. F/S groups not expected for the site: _M c. # F/S groups: _N-S d. Spp # in dom & subdom F/S groups: S-M	B M	Red brome is not expected for this site, and is now a minor component; the relative dominance of expected F/S groups has also shifted towards shrubs, with a decrease in perennial grasses.
13. Dead or dying plants or plant parts	B N-S	The amount of plant mortality is as expected for this site
14. Litter cover and depth cover _28_%	H B N-S	Expected litter amount is 30%
15. Annual production (X Pounds or __Kilograms) Estimated: 550 ÷ Expected:1,000 = _55_%	B M	Expected production is 1,000#/acre; site is at 55% of expected
16. Invasive plants	B M-E	Red brome is throughout the site
17. Vigor with an emphasis on reproductive capability of perennial plants	B N-S	Perennial plants at this site are producing seed and have good vigor

Soil and Site Stability (S)
(10 indicators)

Attribute Rating: _S-M_ Rationale:

					Bare ground is
					higher than
					expected and
					soil stability
					has declined
			11		
			9		
			7	6	
		8	3	5	
		4	2	1	
E-T	M-E	M	S-M	N-S	

Hydrologic Function (H)
(10 indicators)

Attribute Rating: _S-M_ Rationale:

					Bare ground is
					higher than
					expected and
					soil stability
					has declined
					soil compaction
			11	14	and loss of A
			9	10	horizon
		8	3	5	
		4	2	1	
E-T	M-E	M	S-M	N-S	

Biotic Integrity (B)
(9 indicators)

Attribute Rating: _M_ Rationale:

					Red brome has
					invaded and
					impacts biotic
					integrity & site
					productivity
		15		17	
		12	11	14	
	16	8	9	13	
E-T	M-E	M	S-M	N-S	

Appendix 6. 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, but soil maps only help predict the soils (and therefore ecological sites) that might be found in the evaluation area.

The first step in listing the ecological sites likely to occur at an evaluation area involves reviewing the soil survey for the evaluation area's soil map unit. 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 component (soil series), and each soil 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. Finally, a single soil series can belong to more than one ecological site if the physiographic characteristics (e.g., aspect and slope) vary significantly within the same soil series.

After reviewing the soils data and listing the possible ecological sites in an evaluation area, make the ecological site determination 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. Document this process by completing the "soil and site verification" section of the site evaluation sheet (Appendix 5). See the following detailed steps of this process.

Steps for identifying soils and ecological sites when a soil survey and ecological site correlations are available:

Step 1. Obtain a soil map. The availability of soil surveys in paper and electronic format varies across the Western United States. Third-order soil surveys, which are most commonly available, 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.

- These data may be downloaded from the NRCS Soil Data Mart. Accessing the soil surveys from this location allows direct work with other shapefiles in ArcGIS.
- Another option is to use Web Soil Survey (https://websoilsurvey.sc.egov.usda.gov), which 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.
- 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. Determine the ecological sites of the area of interest. 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. MLRAs are grouped into land resource regions of the United States. 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 identified in Figure 6.1.

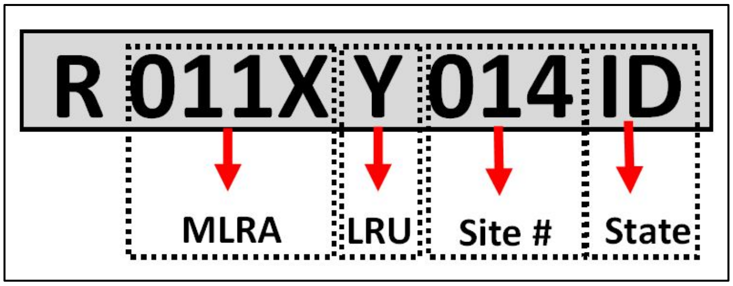


Figure 6.1. Components of an ecological site description code. "R" at the beginning of the code denotes a rangeland ecological site.

Always remember that the ecological site map will represent the site correlated with the dominant soil in each soil complex. It is up to the user to determine what other ecological sites might occur within each soil map unit. The minor soil components and inclusions may represent different ecological sites.

- ArcGIS users may use the Soil Data Viewer plugin, which enables creation of ecological site shapefiles from the soil survey spatial data (SSURGO database) and allows use of the ecological site maps with local datasets.
- 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.

Step 3. Obtain the ecological site description(s). After compiling the list of ecological sites expected in the field, refer to the Ecological Site Information System (https://esis.sc.egov.usda.gov/) or the Ecosystem Dynamics Interpretive Tool (https://edit.jornada.nmsu.edu) to obtain ecological site description reports. Note, the Ecological Site Information System will be replaced by the Ecosystem Dynamics Interpretive Tool. 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 series descriptions of the expected soils, as they usually contain more detail and may help with interpretation of soil profile observations.

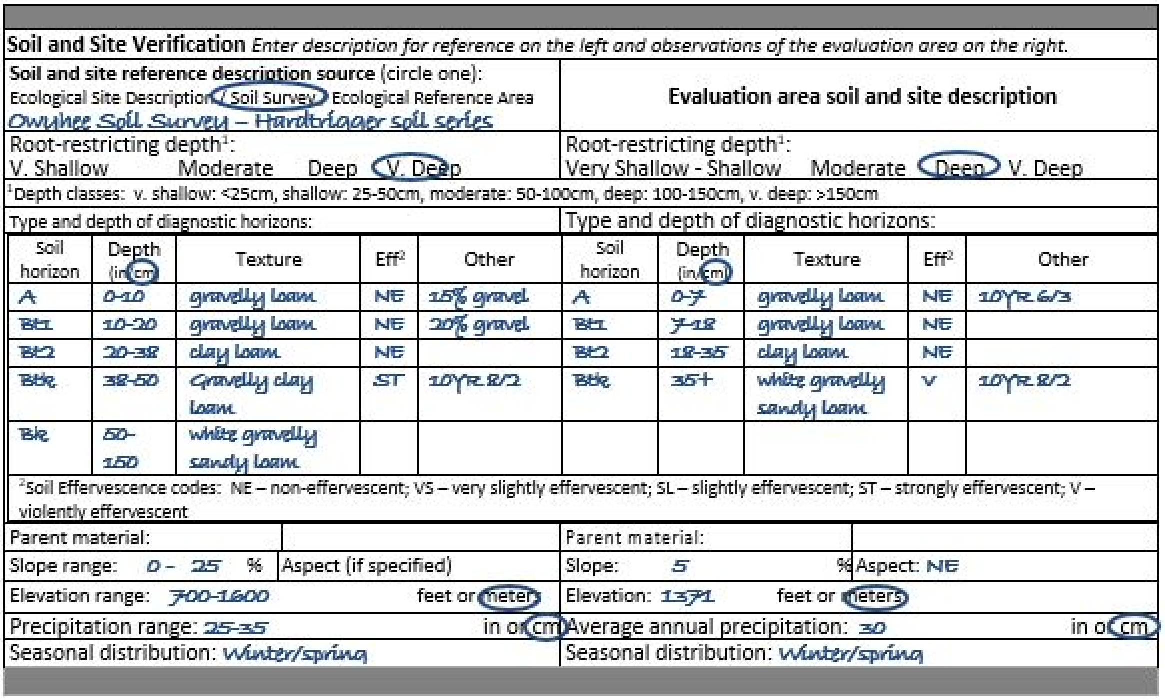
Step 5. At the evaluation area, compare the physiographic characteristics to the soils description in the ecological site description (i.e., are the ranges in elevation, slope, aspect, etc., within those described for the ecological site?).

Step 6. If the evaluation area matches the basic physiographic characteristics outlined in step 5, complete the left side of the “soil and site verification” section of the site evaluation sheet (Appendix 5) as shown in the example in Figure 6.2. Also, circle the soil and site reference description source, and record the expected conditions in each blank field.

Step 7. On the right side of the “soil and site verification” section, document observations of the evaluation area’s soil and physiographic characteristics. See Figure 6.3 to help determine the topographic position of the evaluation area. The evaluation area’s characteristics should fit within the description of the reference 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 holes 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 is usually required to distinguish ecological sites in most areas. “Shallow” ecological sites are often distinguished by soils less than 20 inches in depth. It is strongly recommended to excavate more than 20 inches; 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. Refer to Table 6.1, Figure 6.4, and Figure 6.5 to assist in determining soil effervescence, texture, and structure. Find additional information about soil properties in the “Field Book for Describing and Sampling Soils” (Schoeneberger et al. 2012).
- 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.

Step 8. To complete the ecological site determination, compare the observations on the right side of the form to those on the left from the reference source. If the soil characteristics observed in the evaluation area have major differences from those described in the reference source, determine whether another reference source, such as a different ecological site description or soil series, better matches the evaluation area characteristics. If the evaluation area matches the characteristics described in the reference source, record the ecological site determination in the appropriate field at the top of the site evaluation sheet.



Soil and Site Verification *Enter description for reference on the left and observations of the evaluation area on the right.*

Soil and site reference description source (circle one):
Ecological Site Description [✓ Soil Survey] Ecological Reference Area
Owyhee Soil Survey – Hardtrigger soil series

Evaluation area soil and site description

Root-restricting depth[1]:
V. Shallow Moderate Deep [✓ V. Deep]

Root-restricting depth[1]:
Very Shallow - Shallow Moderate [✓ Deep] V. Deep

[1] Depth classes: v. shallow: <25cm, shallow: 25-50cm, moderate: 50-100cm, deep: 100-150cm, v. deep: >150cm

Type and depth of diagnostic horizons:					Type and depth of diagnostic horizons:				
Soil horizon	Depth (in [✓ cm])	Texture	Eff[2]	Other	Soil horizon	Depth (in [✓ cm])	Texture	Eff[2]	Other
A	0-10	gravelly loam	NE	15% gravel	A	0-7	gravelly loam	NE	10YR 6/3
Bt1	10-20	gravelly loam	NE	20% gravel	Bt1	7-18	gravelly loam	NE	
Bt2	20-38	clay loam	NE		Bt2	18-35	clay loam	NE	
Btk	38-50	Gravelly clay loam	ST	10YR 8/2	Btk	35+	white gravelly sandy loam	V	10YR 8/2
Bk	50-150	white gravelly sandy loam							

[2] Soil Effervescence codes: NE – non-effervescent; VS – very slightly effervescent; SL – slightly effervescent; ST – strongly effervescent; V – violently effervescent

Parent material:		Parent material:	
Slope range: 0 - 25 %	Aspect (if specified)	Slope: 5 %	Aspect: NE
Elevation range: 700-1600 feet or [✓ meters]		Elevation: 1371 feet or [✓ meters]	
Precipitation range: 25-35 in or [✓ cm]		Average annual precipitation: 30 in or [✓ cm]	
Seasonal distribution: Winter/spring		Seasonal distribution: Winter/spring	

Figure 6.2. Example of a completed soil and site verification section, documenting an evaluation area that fits closely to the reference source.

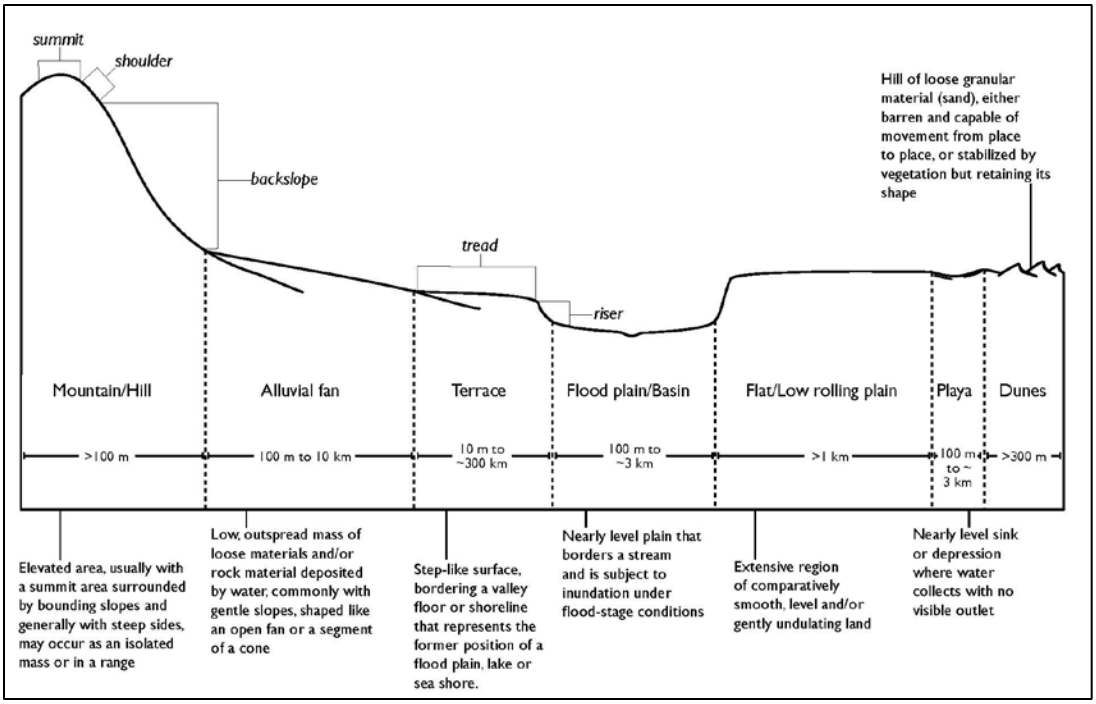
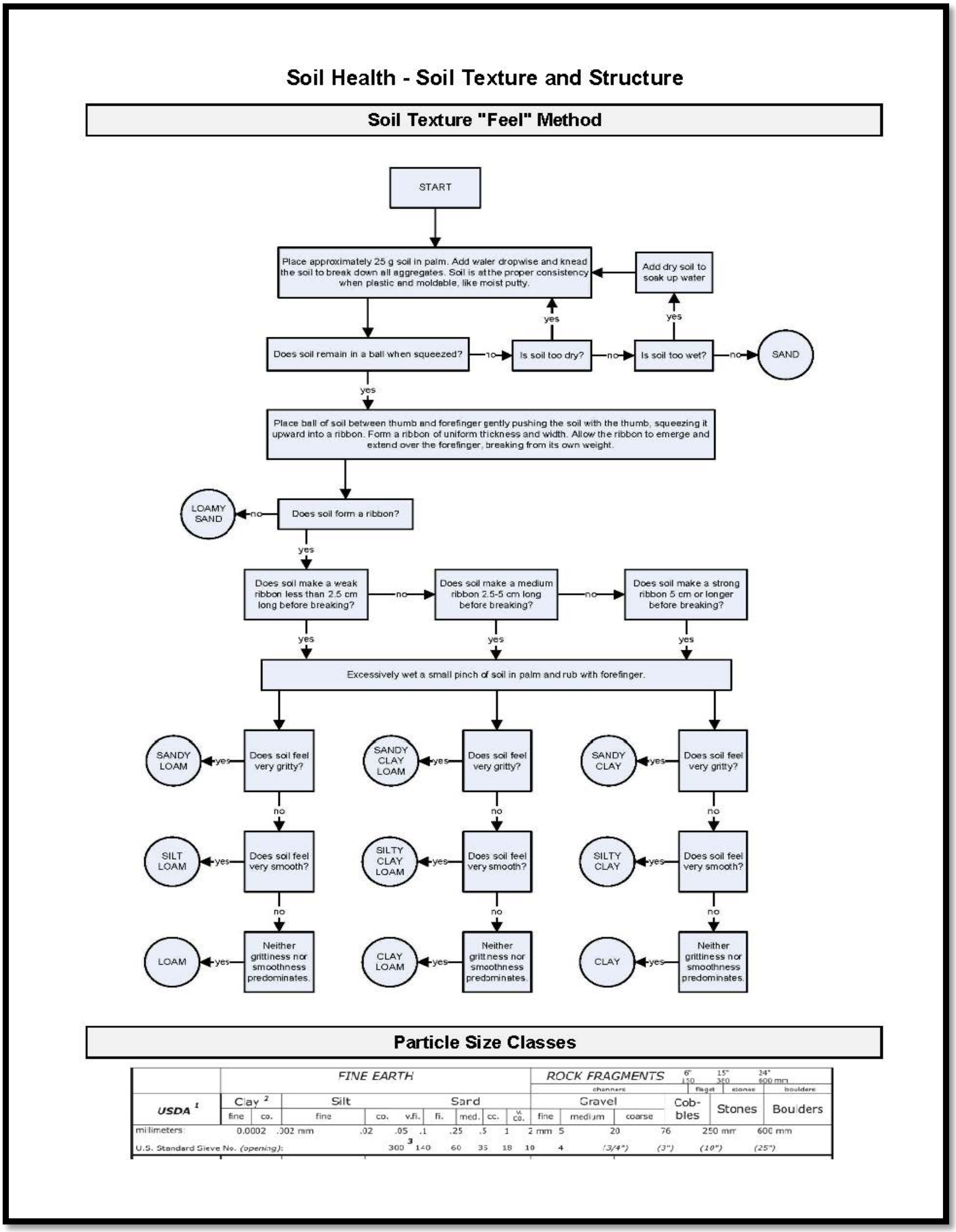


Figure 6.3. Generic landscape units (mountain/hill, alluvial fan, terrace, flood plain/basin, flat/low rolling plain, playa, dunes) to describe topographic position (Herrick et al. 2018).

Table 6.1. Effervescence classes used to describe the entire soil matrix using 1 M HCl (Soil Science Division Staff 2017).

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

Figure 6.4. A flow diagram for selecting soil texture by feel analysis (Thien 1979).


Soil Health - Soil Texture and Structure

Soil Texture "Feel" Method

START

Place approximately 25 g soil in palm. Add water dropwise and knead the soil to break down all aggregates. Soil is at the proper consistency when plastic and moldable, like moist putty.

Add dry soil to soak up water

Does soil remain in a ball when squeezed?

Is soil too dry?

Is soil too wet?

Place ball of soil between thumb and forefinger gently pushing the soil with the thumb, squeezing it upward into a ribbon. Form a ribbon of uniform thickness and width. Allow the ribbon to emerge and extend over the forefinger, breaking from its own weight.

Does soil form a ribbon?

Does soil make a weak ribbon less than 2.5 cm long before breaking?

Does soil make a medium ribbon 2.5-5 cm long before breaking?

Does soil make a strong ribbon 5 cm or longer before breaking?

Excessively wet a small pinch of soil in palm and rub with forefinger.

Does soil feel very gritty?

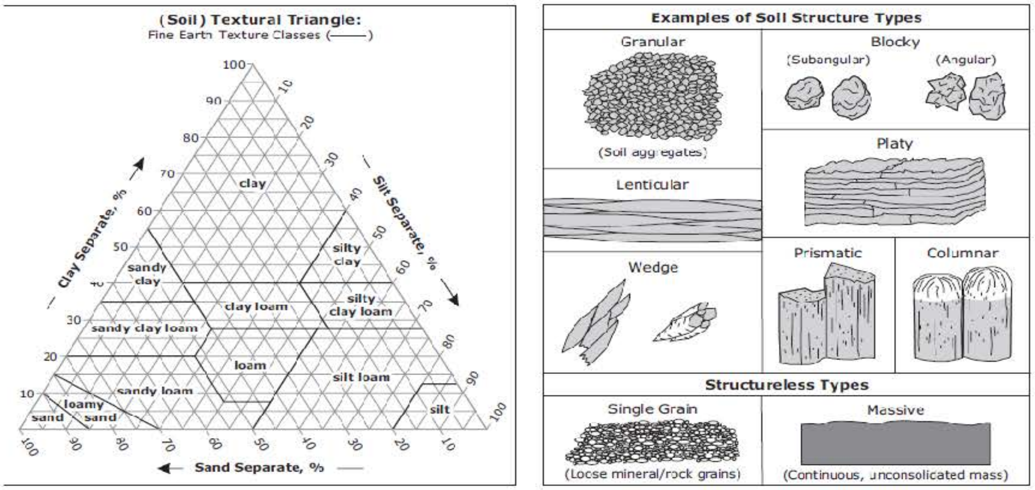
Does soil feel very smooth?

Neither grittiness nor smoothness predominates.

Figure 6.5. Diagrams for soil texture, structure, grade, and size (Schoeneberger et al. 2012).

Soil Texture Triangle

Soil Structure



Soil Structure Grade

Grade	Code	Criteria
Structureless	0	No discrete units observable in place or in hand sample.
Weak	1	Units are barely observable in place or in a hand sample.
Moderate	2	Units well formed and evident in place or in a hand sample.
Strong	3	Units are distinct in place (undisturbed soil) and separate cleanly when disturbed.

Soil Structure Size

Size Class	Code		Criteria: structural unit size [1] (mm)		
	Conv.	NASIS	Granular, Platy [2], (Thickness)	Columnar, Prismatic, Wedge [3] (Diameter)	Angular & Subangular Blocky and Lenticular (Diameter)
Very Fine (Very Thin) [2]	vf (vn)	VF (VN)	< 1	< 10	< 5
Fine (Thin) [2]	f (tn)	F (TN)	1 to < 2	10 to < 20	5 to < 10
Medium (Medium)	m (m)	M (M)	2 to < 5	20 to < 50	10 to < 20
Coarse (Thick) [2]	co (tk)	CO (TK)	5 to < 10	50 to <100	20 to < 50
Very Coarse (Very Thick) [2]	vc (vk)	VC (VK)	≥ 10	100 to<500	≥ 50
Extremely Coarse	ec (—)	EC (—)	—	≥500	—

Appendix 7. Describing Indicators of Rangeland Health

Much of the information in this appendix comes from a manuscript that is currently under review for publication in the journal *Ecological Indicators*.

An IIRH assessment cannot be completed without a reference sheet, and a reference sheet cannot be generated without an ecological site description 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. 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 7.1 provides information to help determine when to use the DIRH protocol instead of the IIRH protocol.

Table 7.1. Determination of when to use the DIRH protocol instead of the IIRH protocol to collect information.

Soil Survey/ Ecological Site Description Status Class	**Soil Survey Status**	**Ecological Site Description Status**	**Identify Soil Map Unit Component?**	**Identify Ecological Site?**	**Complete IIRH? (Version 4 or Later)****	**Complete All Other Methods?**
1	A soil survey exists.	Ecological site description exists.*	Yes	Yes	Yes	Yes
2	No soil survey exists, but soils are comparable to soil 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	Yes
3	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.	Yes

*If a soil survey exists, it should at least identify ecological sites.
** Develop a reference sheet if one does not exist.
*** All ecological site descriptions within the major land resource area have not been completed, and the ecological site description for the National Resources Inventory point does not exist.

Instructions for Completing the Describing Indicators of Rangeland Health Protocol

Step 1. Describe site characteristics that determine land potential, including climate, topography, and relatively static soil properties. Climate information can generally be obtained with location alone using models. For example, the Land-Potential Knowledge System 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. 2017). 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 Land-Potential Knowledge System 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 standard BLM AIM/NRCS NRI (Bureau of Land Management Assessment, Inventory, and Monitoring/Natural Resources Conservation Service National Resources Inventory) methods (Herrick et al. 2018) together 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 data using a simpler method.

Table 7.2. Describing indicators of rangeland health (DIRH) matrix based on indicators included in "Interpreting Indicators of Rangeland Health" Version 4 (Pellant et al. 2005), with indicator names updated based on Version 5. Quantitative methods (*) are described in the "Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems" (Herrick et al. 2018). 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 water courses 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.
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 in-flow paths; occasional exposed roots.	Common inflow paths. Roots rarely exposed.	Few in flow 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 for at least 100m (may be divided among up to 4 transects)*.				
(b) Bare patch size. A bare 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, rock, and biological soil crusts) within the patch	Very large (>2m diameter)	Large (1-2m diameter)	Moderate (0.25-1m diameter)	Small (0.1-0.25m diameter)	Very small (<0.1m diameter)
(c) Bare patch (defined as for 4b) 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, Blowout and/or Depositional Areas	Widespread throughout area (>50% 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	Fine litter moved very long distances (> 6 m); large	Fine litter moved long distances (< 6 m); large litter moved short	Fine litter moved moderate distances (< 3 m); large litter moved	Fine litter moved short distances (< 1.5 m).	Fine litter moved very short distances (<

Indicator	**Class 5**	**Class 4**	**Class 3**	**Class 2**	**Class 1**
accumulation in low, flat (water) or protected (wind) areas.	litter moved moderate distances (< 3 m).	distances (< 1.5 m).	very short distances (< 0.6 m).		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 (Appendix 9).				
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 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 and Runoff.	Use line point intercept data and canopy gap intercept data from #4*.				
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* 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*.				
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*.				
16. Invasive Plants	Use line point intercept data from #4*.				
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.

Appendix 8. Soil Stability Test

The following instructions are excerpted from Herrick et al. 2018

The soil stability test provides information about the degree of soil structural development and erosion resistance. It also reflects soil biotic integrity, because the "glue" (organic matter) that binds soil particles together must constantly be renewed by soil organisms and plant roots. This test measures the soil's stability when exposed to rapid wetting.

The soil stability test is a standard method that must be completed to rate the soil surface resistance to erosion indicator. Subsurface stability is an optional method that should be included where (a) disturbance is common and subsurface stability differs from surface (e.g., where biological soil crusts dominate) or (b) there is particular interest in subsurface organic matter inputs and cycling (e.g., for restoration projects).

Stability is affected by soil texture, so it is important to limit comparisons to similar soils that have similar amounts of sand, silt, and clay. We recommend viewing the soil stability training video (https://jornada.nmsu.edu/monit-assess/training/videos) in addition to reading the following methods.

MATERIALS

- **Complete soil stability kit(s)**
- **Deionized water (or distilled or reverse osmosis) 1 L (~32 oz)**
- **Electronic device for paperless data collection (preferred) or clipboard, Soil Stability Test Data Sheet, and pencil(s)**
- **Stopwatch**

STANDARD METHODS (RULE SET)

1. Randomly select 18 sampling points and decide whether you will collect surface samples only (1 box) or surface and subsurface samples (2 boxes).

Rules

1.1 Use 18 randomly selected points along the transects used for line point and gap intercept measurements.

1.2 Record sampling locations (points) under "Pos" on the data sheet.

1.3 Always sample one box length from any vegetation measurement line.

1.4 Collect an additional set (9 or 18) of subsurface samples if you are interested in soil erodibility after disturbance.

2. Determine the dominant soil canopy class over at least 50% of the random points and enter this into the "Veg" column on the data sheet.

Rules

2.1 The area to be classified is effectively as large as the sample area (6-8 mm (~1/4 in) in diameter).

2.2 Record the presence or absence of vegetation canopy over the sample (Table 8.1). Canopy is recorded as present if there is at least 50 percent canopy over the sample.

3. Collect a Surface Sample.

Rules

3.1 Excavate a small trench (10-15 mm (1/2 in) deep) in front of the area to be sampled. Make the trench as long and wide as the sample scoop (Figure 8.1). If litter is resting over the sample point, carefully remove it before sampling.

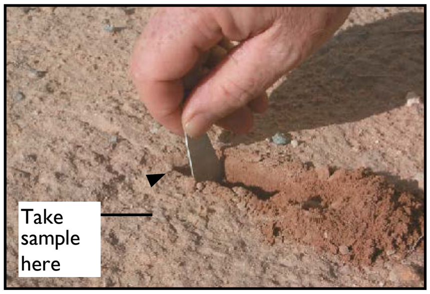


Figure 8.1. Excavate small trench.

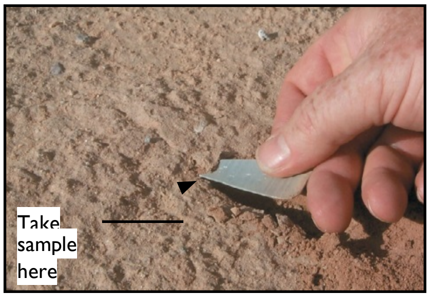


Figure 8.2. Collect surface sample.

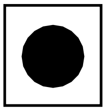
Figure 8.3. Place sample in sieve.

Table 8.1. Record the soil canopy cover code for each soil sample point. For some canopy covers, no soil sample is collected and a value of "6" is recorded on the data sheet.

SOIL COVER	CODE	ACTION
No perennial plant canopy (e.g., annuals and lichens)	**NC**=No cover	Sample (see rules 3.6-3.8 for additional guidance)
Perennial plant canopy	**C**=Cover ----------*OR*---------- **G** = perennial grass canopy and grass/ shrub canopy mixture **F** = perennial forb **SH** = shrub canopy **T**= tree canopy	
Root mat Moss Duff Water	**M** = "root mat"	Do not sample; record a stability value of "6"
Rock fragment (gravel, cobble, stone, boulder, bedrock)	No data recorded	Move a standard distance away and attempt to sample again (see rule 3.4)

3.2 Gently push the sample scoop horizontally into the 10-15 mm deep exposed vertical face of the small trench, lift out a soil fragment, and trim it (if necessary) to the correct size (Figure 8.2).

3.3 The soil fragment needs to be 2-3 mm (<1/8 in) thick and 6-8 mm (1/4 in) in diameter (Figures 8.4, 8.5, and 8.6). This is the diameter of a wood pencil eraser. Try to fit sample in this dot (6-8 mm diameter).



3.4 Collect samples at the exact point. Move the sample point only if it has been disturbed during previous measurements or the soil surface is protected by a rock or embedded litter. Move the point a standard distance (e.g., 15 cm, 0.5 ft) and note this change on the data sheet.

3.5 Minimize shattering by: (a) slicing the soil around the sample before lifting; (b) lifting

Figure 8.4. Ensure correct sample size.

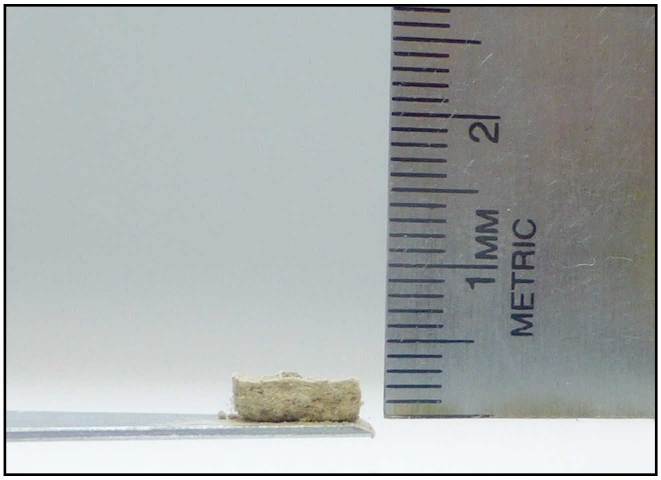


Figure 8.5. Samples are 2-3 mm (<1/8 in) thick.

Riparian Note

No changes are needed for this method in riparian systems.

out a slightly larger sample than required, and trimming it to size in the palm of your hand; and/or (c) misting the sample area before collection (see 3.6).

3.6 If the soil sample is too weakly structured to sample (falls through the sieve), mist it lightly with deionized water (use an atomizer or equivalent) and then take a sample. Perfume and plastic hair spray bottles work well for this. If the sample still will not hold together, record a "1" on the data sheet. Do not assume that a soil is unstable before spraying. Coarse textured soils and disturbed surfaces may appear unstable when dry but could be stable when wet.

3.7 If the soil surface is covered by a lichen or visibly darkened cyanobacterial crust, include the crust in the sample. Roots may also be included in the sample.

3.8 If the sample mark falls on a plant base, collect the sample from within the plant base when feasible; otherwise sample as close as possible to the plant base.

3.9 Gently place the sample upright in a dry sieve (Figures 8.3, 8.4, 8.8); place sieve in the appropriate cell of a dry box (Figure 8.9). Leave box lid open.

4. Optional: Collect a subsurface sample (see step 1).

Rules

4.1 Sample directly below the surface sample.

4.2 Use the flat, square (handle) end of the scoop to gently excavate the previous trench (in front of the surface sample) to a depth of 40-50 mm (1 1/2 - 2 in).

4.3 Directly below the surface sample, remove soil so that a "shelf" is created with the top step 25 mm (1 in) below the soil surface (Figure 8.6).

4.4 Use the scoop to lift out a subsurface sample from below (Figure 8.7).

4.5 The soil fragment must be 2-3 mm (< 1/8 in) thick and 6-8 mm (1/4 in) in diameter (Figures 8.5 and 8.6).

4.6 See steps 3.5-3.6. If you encounter a rock, record "R" and move to the next sample.

4.7 Place the sample upright in a dry sieve; place sieve in appropriate cell of a dry box. Leave box lid open.

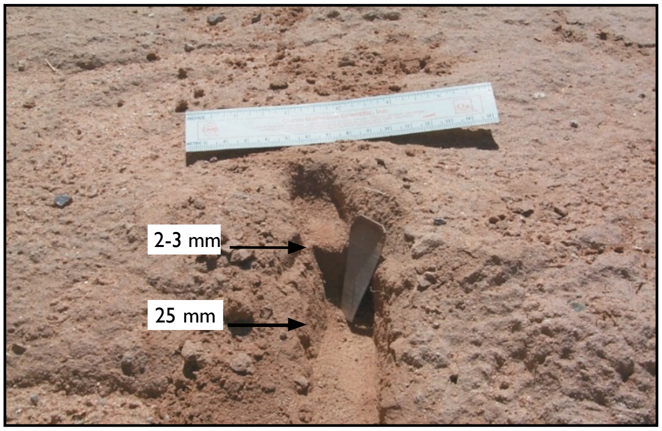


Figure (8.6. Excavate trench for subsurface sample

Figure 8.7. Collect subsurface sample.

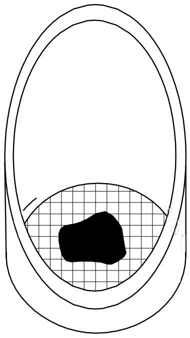


Figure 8.8. Sample in sieve, drawn to scale. Sample shape may vary from round to square to slightly irregular as shown above.

5. Make sure all surface and subsurface samples are dry.

Rules

5.1 Samples must be dry before testing. If samples are not dry after collecting, allow to air dry with the lid open.

5.2 Do not leave lid closed on sunny days. Excessive heat can artificially increase or decrease stability.

6. Fill the empty (no sieves) box with deionized or distilled water (Figure 8.9).

Rules

6.1 Fill each compartment to the top.

6.2 The water should be approximately the same temperature as the soil.

Quality Assurance

- ✓ Each data sheet is complete. Observer, recorder, position, vegetation cover category, and soil stability values are recorded.
- ✓ Samples are correct diameter and thickness and are dry at the beginning of the test.
- ✓ Samples are not broken or have not flipped over on the sieve before the test. Retake a sample if it is accidentally broken by mishandling.
- ✓ Soil stability values make sense relative to plot observations.

NRI

- If the NRI data collection method is selected, collect 9 surface samples.
- If the plot can be used for ESD documentation, collect 18 surface samples.
- 5 samples from the NE/SW transect.
- 4 samples from the NW/SE transect.

Figure 8.9. Place first sample in water.

Figure 8.10. Complete soil stability kit with water and samples.

Table 8.2. Stability class ratings. Percent soil remaining on the sieve for stability classes 4-6 refers to the percentage of the total volume remaining for the original size of the sample before immersion. See Figure 34 for photos illustrating stability classes 1, 4, 5, and 6.

Stability class	Criteria for assignment to stability class
1	50% of structural integrity lost (melts) within 5 seconds of immersion in water, and < 10% remains after 5 dipping cycles; or soil too unstable to sample (falls through sieve).
2	50% of structural integrity lost (melts) 5-30 seconds after immersion, and < 10% remains after 5 dipping cycles.
3	50% of structural integrity lost (melts) 30-300 seconds after immersion; or < 10% of soil remains on the sieve after 5 dipping cycles.
4	10–25% of soil remains on the sieve after 5 dipping cycles.
5	25–75% of soil remains on the sieve after 5 dipping cycles.
6	75–100% of soil remains on the sieve after 5 dipping cycles.

7. Test the samples.

Rules

7.1 Lower the first sieve with the sample into the respective water-filled compartment—upper left corner of sample box to upper left corner of water box (Figure 8.9).

7.2 From the time the sieve screen touches the water surface to the time it rests on the bottom of the box, 1 second should elapse.

7.3 Start the stopwatch when the first sample touches the water. Use Table 8.2 to assign samples to stability classes.

7.4 Follow the sequence of immersions on the data sheet, adding one sample every 15 seconds, requiring a total of 10 minutes for 18 samples. Beginners may want to immerse a sample every 30 seconds, and then dip samples at 30 second intervals. This allows nine samples to be run in 10 minutes, or 20 minutes to test one box of 18 samples

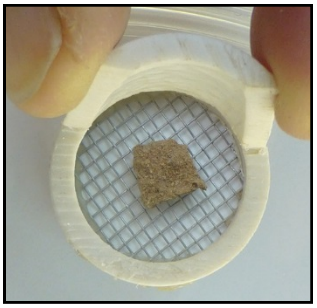
7.5 Observe the fragments from the time the sample hits the water until 5 minutes (300 seconds) has elapsed, then assign a stability class based on Table 8.2.

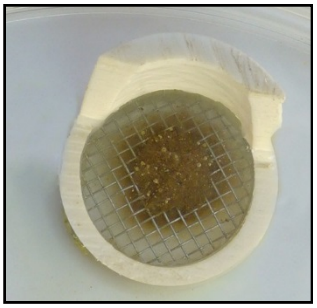
7.6 After 5 minutes have elapsed for each sample, in sequence, raise each sieve completely out of the water and then lower it to the bottom without touching the bottom of the tray. Repeat this immersion and dipping a total of five times for each sieve. Do this even if you have already rated the sample a 1, 2, or 3 (it is possible to increase the rating if after sieving, > 10% of soil remains on sieve). Assign a stability class based on Table 8.2.

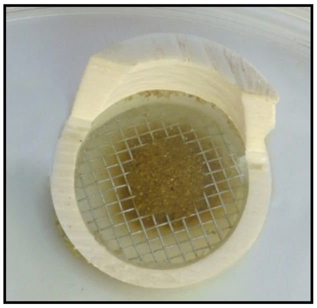
7.7 For the dipping rate, it should take 1 second for each sieve to clear the water's surface and 1 second to return to near the bottom of the box. The process is strictly timed so dipping 5 times takes 10 seconds, allowing an additional 5 seconds to write the value on the data sheet before processing the next sample.

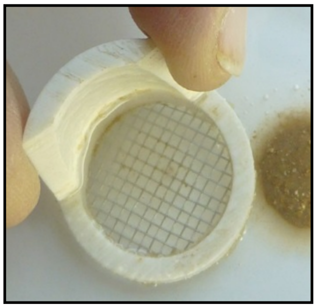
7.8 Hydrophobic samples (i.e., samples that float in water after attempting to push under) are rated 6 and circled on the data sheet.

SEQUENCE FOR STABILITY CLASS 1

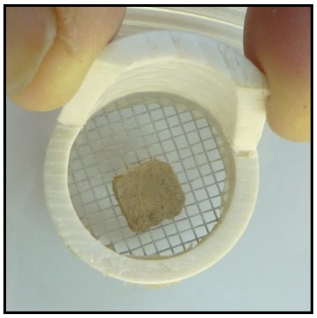

Original sample

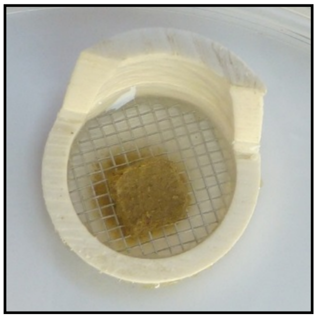

After 5 seconds

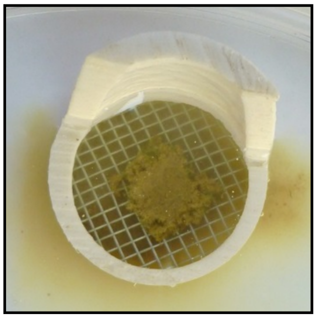

After 5 minutes

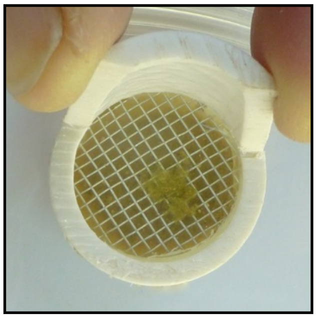

After 5 dips

SEQUENCE FOR STABILITY CLASS 4

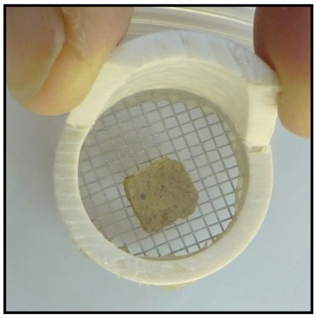

Original sample

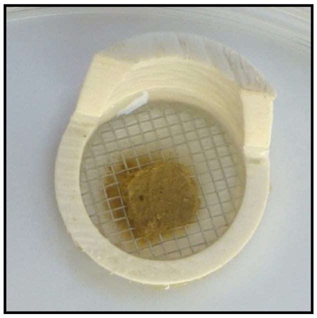

After 5 seconds

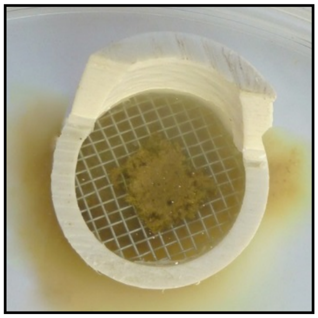

After 5 minutes

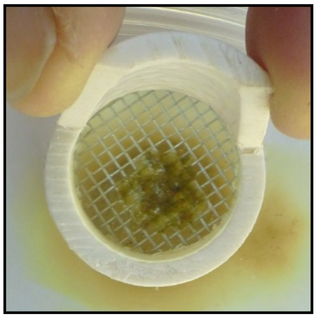

After 5 dips

SEQUENCE FOR STABILITY CLASS 5

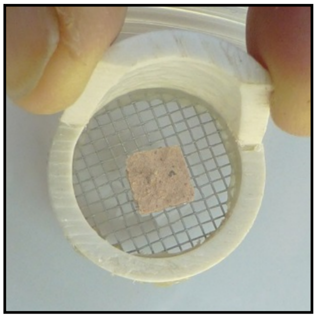

Original sample

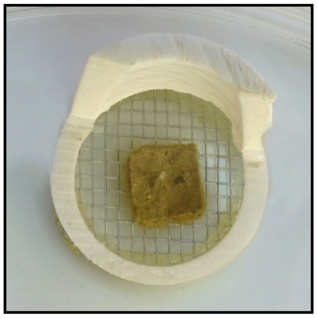

After 5 seconds

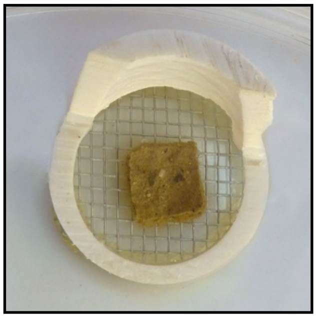

After 5 minutes


After 5 dips

SEQUENCE FOR STABILITY CLASS 6


Original sample


After 5 seconds


After 5 minutes

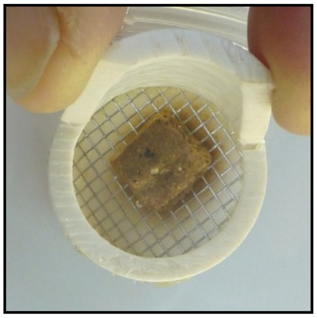

After 5 dips

Figure 8.11. The photos illustrate the key steps of testing a soil sample for four different stability rankings.

Important note: Original size of peds shown in these samples is 7 mm x 7 mm. The samples may swell or appear larger under water. Be sure to follow the size guidelines (6-8 mm or 1/4 in) in Rule 3.3 and Figure 8.6.

SOIL STABILITY INDICATOR CALCULATIONS

1. Calculate the average stability for all samples.

Rules

1.1 Add together all stability values. Divide this sum by the total number of samples taken. Record this value as the average stability for "All samples" on the data sheet.

2. Calculate the average stability for protected samples (Veg = C or G, F, Sh, T).

Rules

2.1 Add together all values that were protected by canopy (Veg = C or G, F, Sh, T). Divide this sum by the number of samples in this group. Record this value as the average stability for "Protected samples" on the data sheet.

3. Calculate the average stability for unprotected samples (Veg = NC).

Rules

3.1 Add together all stability values that were classified as no canopy (Veg = NC). Divide this sum by the number of samples in this group. Record this value as the average stability for "Unprotected samples."

4. Averages must be calculated separately for surface and subsurface samples. See Table 8.3 for an example.

Table 8.3. Data form and calculations example for soil surface samples.

Surface

Line 1		In time	Dip time	Class	Line 1		In time	Dip time	Class	Line 2		In time	Dip time	Class	Line 2		In time	Dip time	Class
Pos	Veg				Pos	Veg				Pos	Veg				Pos	Veg			
7	NC	0:00	5:00	3	28	NC	0:45	5:45	3	6	F	1:30	6:30	5	24	M	2:15	7:15	6
14	Sh	0:15	5:15	5	35	Sh	1:00	6:00	4	12	NC	1:45	6:45	1	30	Sh	2:30	7:30	3
21	G	0:30	5:30	6	42	G	1:15	6:15	5	18	Sh	2:00	7:00	4	36	NC	2:45	7:45	1

Notes: Line 2 Position 12 sample collected 1 m SE from original position due to a boulder on the transect

Line	All samples		Protected samples (Samples with Veg = C, G, F, Sh,T, or M)		Unprotected samples (Samples with Veg = NC)	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
1	4.3		5.0		3.0	
2	3.3		4.5		1.0	
Plot Avg.	3.8		4.8		2.0	

SOIL STABILITY TEST BASIC INTERPRETATION

Increases in stability of both **surface** and **subsurface** samples reflect increased soil erosion resistance and resilience. Surface stability is correlated with current erosion resistance, while subsurface stability is correlated with resistance following soil disturbance. Sites with average values of 5.5 or higher generally are very resistant to erosion, particularly if there is little bare ground and there are few large gaps. Maximum possible soil stability values may be less than 6 for very coarse sandy soils. High values usually reflect good hydrologic function. This is because stable soils are less likely to disperse and clog soil pores during rainstorms. High stability values are also strongly correlated with soil biotic integrity. Soil organisms make the "glue" that holds soil particles together. In most ecosystems, soil stability values decline first in areas without cover (Veg = NC). In more highly degraded systems, soil stability values also decline in areas with cover (Veg = C or G, F, Sh, T).

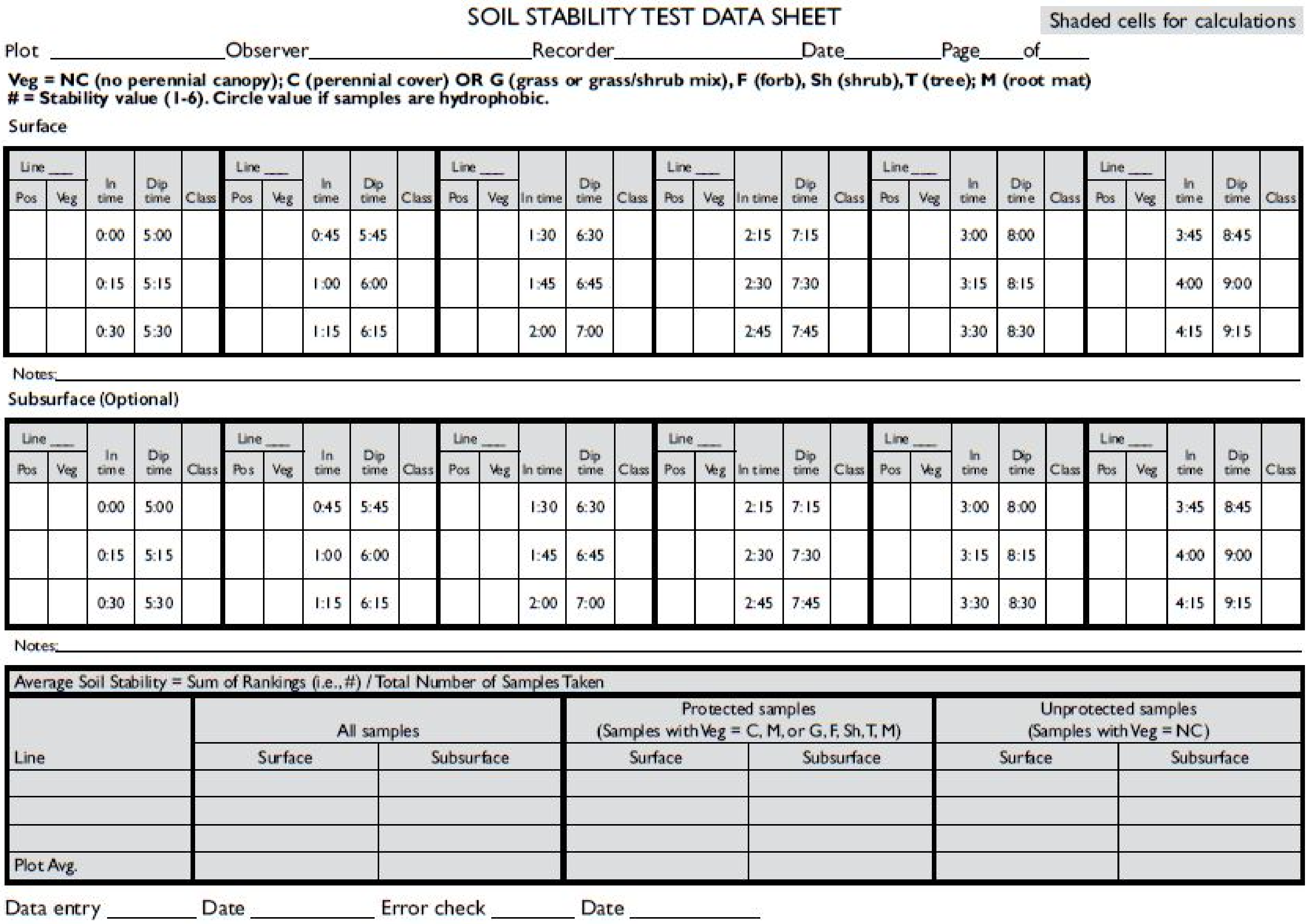
TYPICAL EFFECT ON EACH ATTRIBUTE OF AN INCREASE IN THE SOIL STABILITY INDICATOR VALUE

Indicator	Attributes		
	Soil and site stability*	Hydrologic function**	Biotic integrity
All samples	↑	↑	↑
Veg = C	↑	↑	↑
Veg = NC	↑	↑	↑

* Large increases in water repellency (after a very hot fire) can negatively affect soil and site stability by increasing the amount of runoff water available to erode soils downslope.

** Usually positive, but can be negative for hydrophobic (water-repellent) soils.

Note that samples are collected and run left to right on this form



SOIL STABILITY TEST DATA SHEET

Shaded cells for calculations

Plot ________________Observer____________________________Recorder_______________________Date__________Page____of_____

Veg = NC (no perennial canopy); C (perennial cover) OR G (grass or grass/shrub mix), F (forb), Sh (shrub), T (tree); M (root mat)
 # = Stability value (1-6). Circle value if samples are hydrophobic.

Surface

Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class
Pos	Veg				Pos	Veg				Pos	Veg				Pos	Veg				Pos	Veg				Pos	Veg			
		0:00	5:00				0:45	5:45				1:30	6:30				2:15	7:15				3:00	8:00				3:45	8:45	
		0:15	5:15				1:00	6:00				1:45	6:45				2:30	7:30				3:15	8:15				4:00	9:00	
		0:30	5:30				1:15	6:15				2:00	7:00				2:45	7:45				3:30	8:30				4:15	9:15	

Notes:____

Subsurface (Optional)

Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class	Line ___		In time	Dip time	Class
Pos	Veg				Pos	Veg				Pos	Veg				Pos	Veg				Pos	Veg				Pos	Veg			
		0:00	5:00				0:45	5:45				1:30	6:30				2:15	7:15				3:00	8:00				3:45	8:45	
		0:15	5:15				1:00	6:00				1:45	6:45				2:30	7:30				3:15	8:15				4:00	9:00	
		0:30	5:30				1:15	6:15				2:00	7:00				2:45	7:45				3:30	8:30				4:15	9:15	

Notes:____

Average Soil Stability = Sum of Rankings (i.e., #) / Total Number of Samples Taken						
	All samples		Protected samples (Samples with Veg = C, M, or G, F, Sh, T, M)		Unprotected samples (Samples with Veg = NC)	
Line	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
Plot Avg.						

Data entry _________ Date ____________ Error check ________ Date _____________

Note that samples are collected and run top to bottom on this form

SOIL STABILITY TEST DATA SHEET (Alternative Form)

Evaluation Site ID and/or Name: ________________________________ Date:_________

Recorder: ___________________ Observer: ___________________

Surface____ Subsurface ____

Line	Pos	Veg	In/ Dip	Class	Pos	Veg	In/ Dip	Class	Pos	Veg	In/ Dip	Class	Pos	Veg	In/ Dip	Class	Pos	Veg	In/ Dip	Class	Pos	Veg	In/ Dip	Class
			0:00 5:00				0:15 5:15				0:30 5:30				0:45 5:45				1:00 6:00				1:15 6:15	
			1:30 6:30				1:45 6:45				2:00 7:00				2:15 7:45				2:30 8:00				2:45 8:15	
			3:00 8:30				3:15 8:45				3:30 9:00				3:45 9:15				4:00 9:30				4:15 9:45	

- * When a rock fragment is encountered, move a standard distance away and attempt to sample again
- * Line and Position (Pos) are recorded when collecting samples along one or more transects
- * Veg Codes = NC (no perennial canopy), G(perennial grass or grass/shrub mix), F(forb), Sh (shrub), T (tree). M = Moss (Automatic Class = 6)
- * Soils too unstable to sample = Automatic Class 1.
- * Circle class value if sample is hydrophobic.

Stability Class	Criteria for assessment of stability class
1	50% of structural integrity lost within 5 seconds of immersion AND <10% remains after 5 dipping cycles, OR soil too unstable to sample
2	50% of structural integrity lost within 5-30 seconds of immersion AND <10% remains after 5 dipping cycles
3	50% of structural integrity lost within 30-300 seconds of immersion OR <10% remains on sieve after 5 dipping cycles
4	10-25% of soil remains on sieve after 5 dipping cycles
5	25-75% of soil remains on sieve after 5 dipping cycles
6	75-100% of soil remains on sieve after 5 dipping cycles

CALCULATED STABILITY VALUES

Line	All Samples	Protected Samples	Unprotected Samples
Plot Avg.			

Notes: ____

____

Bottle Cap Test

When a soil stability kit is not available, a semiquantitative test can be completed with a bottle cap. This test generally takes longer than the stability kit unless several individuals in a team are completing it simultaneously. Use the tip of a knife to remove several small (maximum 1/4 inch diameter, 1/8 inch deep) soil surface fragments from beneath plants and interspaces. Place each in a separate bottle cap filled with water. Fragments with extremely low stability (stability values of 1-2) will "melt" within 30 seconds of contact with the water, and the water will become cloudy as the soil particles disperse. Fragments with moderate stability (stability values of 3-4) will appear to retain their integrity until the water in the bottle cap is agitated or gently swirled. Highly stable aggregates (stability values of 5-6) will retain their shape, even when agitated indefinitely. For multiple samples, or where more precision is desired, the soil stability kit should be used to test 9 to 18 samples (Herrick et al. 2001).

Appendix 9. Estimating Annual Production

An estimate of annual production is needed at each evaluation area to rate indicator 16, annual production. Three basic methods for estimating annual production include: (1) double sampling, an approach that includes estimating by weight units and harvesting to correct estimates (NRCS 2006); (2) harvesting, an approach that involves clipping plots and air drying harvested material to obtain a measure of dry matter production (NRCS 2006); and (3) estimating by weight units. All three methods can be used to estimate or measure annual production in order to rate departure from expected annual production in an evaluation area (in conjunction with the appropriate ecological site description).

Brief instructions of the three methods follow. Detailed guidance and forms to record data are available in the NRCS “National Range and Pasture Handbook” (NRCS 2006) and in the “Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems,” second edition (Herrick et al. 2018). Some basic information needed to apply these techniques is precedes the instructions on the methods.

Adjustments in annual production

Express all production data as 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 may require drying or the use of locally developed conversion tables. It is often necessary to determine plant production when plant growth is not ideal for making such determinations. Some units are grazed at the time of making the determination, or it is the beginning of the growing season, or the plants are dormant.

In some areas, estimates must be made at different stages of plant growth. In some years production is obviously much higher or much lower than normal because of weather extremes. In making production estimates, therefore, it is often necessary to mentally reconstruct plant growth as it would most likely appear if undisturbed at the end of an average growing season. Adjustments or reconstruction must be made for percent of growth made during the year, percent of growth grazed or otherwise lost, and for air dry percentages. Comparing grazed vs. ungrazed plants of the same species in the area can help determine amount lost to grazing. Using the community growth curves in the ecological site descriptions can help determine the amount of growing season completed and knowing the local growing conditions (precipitation amounts and temperature pattern for the current year) can help adjust the production numbers for the local growing conditions for the year.

Converting Weight to Pounds Per Acre

The weight of vegetation on plots measured in square feet or in acres can be estimated and harvested in grams or in pounds. To convert grams per plot to pounds per acre, use the following conversions:

1.92-square feet plots—multiply grams by 50
2.4-square feet plots—multiply grams by 40

4.8-square feet plots—multiply grams by 20
9.6-square feet plots—multiply grams by 10
96.0-square feet plots—multiply grams by 1

The relationship of weight to volume is not constant; therefore, annual production and composition determinations are based on weight estimates, not on comparison of relative volumes.

1) Estimating and Harvesting (Double Sampling Method)

The double sampling method can be used in making most annual production and composition determinations. Use the following procedure.

1. Select a study area consisting of one soil taxonomic unit.
2. Select plots to be examined at random.
3. The number of plots selected depends on the purpose for which the estimates are to be used. For the purposes of this technical reference, select a minimum of 5 plots.
4. Adapt size and shape of plots to the kind of plant cover to be sampled. Plots can be circular, square, or rectangular. The area of a plot can be expressed in square feet, acres, or square meters.

If vegetation is relatively short and plot markers can be easily placed, 4.8-, and 9.6-square feet plots are well-suited to determine annual production in pounds per acre. The 9.6-square feet plot is generally used in areas where vegetation density and production are relatively light. Smaller plots are satisfactory in areas of homogeneous, relatively dense vegetation like that occurring in meadows and throughout the plains and prairie regions. Plots larger than 9.6 square feet should be used where vegetation is very sparse and heterogeneous.

If the vegetation consists of trees or large shrubs, larger plots must be used. If the tree or shrub cover is uniform, a 20.8 x 20.8-feet (0.01 acre) plot is suitable. If vegetation is mixed, two plot sizes generally are necessary. A series of 2 or more square or rectangular plots of 0.01 acre and a smaller plot, such as a 9.6-square feet plot nested in a designated corner of each larger plot, is suitable. The 0.01-acre plot is used for trees or large shrubs, and the smaller plot for lower growing plants. Weights of the vegetation from both plots are then converted to pounds per acre.

After plots are selected, estimate and record the weight of each species in each plot using the weight unit estimate method. When estimating or harvesting plants, include all parts of plants whose stems originate in the plot, including all aboveground parts that extend beyond a plot boundary. Exclude all parts of herbaceous plants and shrubs whose stems originate outside a plot, even though their foliage may overlap into the plot.

After weights have been estimated on all plots, select the plots to be harvested. The selected plots should include all or most of the species in the estimated plots. If an important species occurs on some of the estimated plots, but not on the harvested plots, it can be clipped individually on one or more plots. The number of plots harvested depends on the number estimated. To adequately correct the estimates, research indicates at least 1 plot should be harvested for each 7 estimated. At least 2 plots are to be harvested if 10 are estimated, and 3 are to be harvested if 20 are estimated. Harvest, weigh, and record the weight of each species in the plots selected for harvesting. Harvest all herbaceous plants originating in the plot at ground level. Harvest all current leaf, twig, and fruit production of woody plants originating in the plots. If harvesting forage production only, then harvest to a height of 4.5 feet above the ground on forest land sites.

Correct estimated weights by dividing the harvested weight of each species by the estimated weight of the corresponding species on the harvested plots. This factor is used to correct the estimates for that species in each plot. A factor of more than 1.0 indicates that the estimate is too low. A factor lower than 1.0 indicates that the estimate is too high. After plots are estimated and harvested and correction factors for estimates are computed, determine air-dried percentages by air drying the harvested materials or by selecting the appropriate factor from an air-dried percentage table. Values of each species are then corrected to air-dried pounds per acre or kilograms per hectare for all plots. Then, compute average weight and percentage composition for the sample area.

2) Harvesting Method

This method is similar to the double sampling method except that all plots are harvested. The double sampling procedures for estimating weight by species and the subsequent correction of estimates do not apply. If the harvesting method is used, perform selection and harvest of plots and conversion of harvested weight to air-dried pounds per acre or kilograms per hectare according to the procedures described for double sampling.

3) Weight Unit Estimate Method

For IIRH assessments, departure ratings for the Annual Production indicator are categorized based on 20% reductions from expected values provided in the reference sheet (see evaluation matrix in Appendix 3). Estimating annual production by weight units should provide evaluators with enough information to adequately estimate the departure in annual production on an evaluation area. The weight unit method is an efficient means of estimating annual production and lends itself readily to self-training. This protocol is based on procedures described in the NRCS "National Range and Pasture Handbook" (NRCS 2006) but has been modified to include just using weights for an annual production estimate. Once individuals gain experience estimating annual production on a particular ecological site using this protocol, it may be possible to use a simple ocular estimate to rate the annual production indicator in future assessments. Periodic calibration is recommended and can be accomplished by making an ocular estimate of annual production based on weight units in a plot and then clipping the plot to adjust the ocular estimate to the measured values.

Use the following procedure to establish a weight unit for a species:

1. Decide on a weight unit (in pounds or grams) that is appropriate for the species (or group of species with similar characteristics (e.g., annual grasses).

2. 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. For example, a unit of 5 to 10 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 weight of each weight unit. Utilize a rubber band to keep the weight unit together.
4. Repeat this process until the desired weight unit can be estimated with reasonable accuracy.
5. Periodically harvest and weigh to check estimates of annual production.

Use the following procedure to estimate annual production of a single plot.

1. Estimate production by counting the weight units of each species in the plot. For the purposes of this technical reference, use a minimum of 5 plots.
2. Convert weight units for each species or group of similar species (e.g., annual grasses) to grams or pounds.
3. Periodically, harvest and weigh each species to check weight unit estimates of production.
4. Keep the harvested materials, when necessary, for air drying and weighing to convert from field (green) weight to air-dried weight and to use on future plots on the same ecological site.
5. Use the form at the end of this appendix to record weight units by species and to calculate total annual production on a plot.

Data Collection Table for Weight Unit Estimates

Table to estimate total annual production using weight units for rating the Annual Production departure in Interpreting Indicators of Rangeland Health.

		Number of Weight Units in Each Plot										
Species	Weight Unit (gr) or (lb)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	No. of Wgt. Units x Wgt. Unit Wgt.	% dry wgt.	% growth adjustment	% use adjustment[2]	Plot Size sq ft	Total lb/acre
Fescue	4 gr	2	5	4	3	4	72 gr	80%	0	85%	9.6	
							72 gr	58	58	49	X 10^1	490

10^1 This is the conversion factor for 9.6 square foot plots.

[2] For use adjustment calculations, use the percent of the plant that remains (e.g., 15% of the plant removed means 85% remains) to calculate this value.

Field Form: Estimating Annual Production- Weight Units

State_______ **Office**_________________ **Ecological site**_______________________________ **Ecol. site code**
________ **Observers**____
Date________________
Evaluation site ID and/or name: ____

		Number of Weight Units in Each Plot										
Species or Species Group	Weight Unit (gr) or (lb)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	No. of Wgt. Units x Wgt. Unit Wgt.	% dry wgt.	% growth adjustment	% use adjustment[1]	Plot Size sq ft	Total lb/acre
Total Pounds per Acre Estimated in the Evaluation Area												

Estimating Annual Production- Weight Units

Use the following procedure to establish a weight unit for a species:

1. Decide on a weight unit (in pounds or grams) that is appropriate for the species (or group of species with similar characteristics (e.g., annual grasses).
2. 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. For example, a unit of 5 to 10 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 weight of each weight unit. Utilize a rubber band to keep the weight unit together.
4. Repeat this process until the desired weight unit can be estimated with reasonable accuracy.
5. Periodically harvest and weigh to check estimates of annual production.

Use the following procedure to estimate annual production of a single plot.

1. Estimate production by counting the weight units of each species in the plot. For the purposes of this technical reference, use a minimum of 5 plots.
2. Convert weight units for each species or group of similar species (e.g., annual grasses) to grams or pounds.
3. Periodically, harvest and weigh each species to check weight unit estimates of production.
4. Keep the harvested materials, when necessary, for air drying and weighing to convert from field (green) weight to air-dried weight and to use on future plots on the same ecological site.
5. Use the form at the end of this appendix to record weight units by species and to calculate total annual production on a plot.

Data Collection Table for Weight Unit Estimates

Table to estimate total annual production using weight units for rating the Annual Production departure in Interpreting Indicators of Rangeland Health.

		Number of Weight Units in Each Plot										
Species	Weight Unit (gr) or (lb)	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	No. of Wgt. Units x Wgt. Unit Wgt.	% dry wgt.	% growth adjustment	% use adjustment[1]	Plot Size sq ft	Total lb/acre
Fescue	4 gr	2	5	4	3	4	72 gr	80%	0	85%[2]	9.6	
Calculations							72 gr	58	58	49	X 10[1]	490

10[1] This is the conversion factor for 9.6 square foot plots.

[2] For use adjustment calculations, use the percent of the plant that remains (e.g., 15% of the plant removed means 85% remains) to calculate this value

Appendix 10. Selected Quantitative Measures to Support the 17 Indicators

Table 10.1 lists selected quantitative indicators and associated measurement methods that may be completed in the field using readily available vegetation sampling equipment. The qualitative measurements can be used to support interpretations of many of the 17 qualitative indicators of rangeland health. These quantitative measurements are also valuable in developing or revising reference sheets and ecological site descriptions. Core methods used by the Bureau of Land Management and the Natural Resources Conservation Service national monitoring programs are in bold. The table also provides an interpretation of the relationship between the qualitative and quantitative indicators (from Pyke et al. 2002). Also, in Section 5.7.2, see Table 4, which relates quantitative indicators to the three attributes of rangeland health. Additional quantitative measurements may apply to each indicator but are not often collected as part of the IIRH protocol. Some of these additional measurements are discussed in the "Measurements" section narratives for each indicator in Sections 7.4.1 through 7.4.17.

Table 10.1. Qualitative indicators and associated measurement methods that can support interpretations of the 17 qualitative indicators. (1) NRCS 2006; (2) Herrick et al. 2018.

Qualitative Indicator	Quantitative Indicator	Measurement (References)	Interpretation
1. Rills	None		
2. Water flow patterns	Percent basal cover	**Line point intercept (2)**	Basal cover is negatively correlated with water flow patterns because plant bases slow water movement.
	Proportion of basal gaps > 25, 50, 100, 200 cm	Basal gap intercept (2)	Basal gaps are positively correlated with water flow patterns because water gains energy as it moves unobstructed across larger gaps.
3. Pedestals and/or terracettes	Density of pedestals or terracettes (#/unit area)	Belt transect (1) (2)	Increased occurrence of pedestals or terracettes can be detected by measuring density of these features.
4. Bare ground	Percent bare ground	**Line point intercept (2)**	Bare ground is positively correlated with runoff and erosion.
	Proportion of line in canopy gaps > 25, 50, 100, 200 cm	**Canopy gap intercept (2)**	The bare ground qualitative indicator is also positively correlated with canopy gaps because bare ground in large gaps usually has a larger effect on many functions than bare ground in small gaps.
5. Gullies	Width-to-depth ratio and side slope angle	Channel profiles (2)	Lower width-to-depth ratios and higher side slope angles both reflect more severe or active gully erosion.
	Headcut movement	Headcut location (2)	Higher rates of headcut movement reflect greater gully erosion.
6. Wind-scoured and/or depositional areas	Proportion of site affected by wind-scoured or depositional areas	**Line point intercept (2), canopy gap intercept (2)**, continuous line intercept	Greater proportion of site affected by wind-scoured areas or blowouts shows more severe wind erosion. Large gaps in vegetation indicate susceptibility to wind erosion.

Qualitative Indicator	Quantitative Indicator	Measurement (References)	Interpretation
7. Litter movement	Proportion of litter cover in interspaces vs. under canopies	**Line point intercept (2)**	Higher proportion of litter in the interspaces may be positively related to litter movement.
	Proportion of basal gaps > 25, 50, 100, 200 cm	**Basal gap intercept (2)**	Basal gaps can be positively related to redistribution or loss of litter.
8. Soil surface resistance to erosion	Average soil surface stability	**Soil stability test (2)**	Surface aggregate stability is positively related to the soil's resistance to wind and water erosion.
9. Soil surface loss and degradation	Average soil subsurface stability	**Soil stability test (subsurface) (2)**	Subsurface soil structure degrades and organic matter declines as surface soil is lost; thus, subsurface aggregate stability is negatively related to soil surface loss or degradation.
	Depth of A horizon	**Direct measurement**	Reductions in surface horizon depth indicate loss of soil surface.
10. Effects of plant community composition and distribution on infiltration and runoff	Percent composition	**Line point intercept (2),** annual production (1)	Changes in species composition can be related to changes in infiltration. For example, root and shoot morphology of tussock vs. stoloniferous plants.
	Proportion of basal gaps > 25, 50, 100, 200 cm	**Canopy gap intercept (2)**, basal gap intercept (2)	Changes in basal gaps can be related to changes in plant distributions that relate to infiltration and runoff.
11. Compaction layer	Thickness of compaction layer	Direct measurement	Thicker compaction layers are likely to have greater impacts on hydrologic function and root soil penetration.
	Ratio of penetration resistance in the upper 15 cm (6 inches) between the evaluation and reference area	Impact penetrometer (2)	Ratios of penetration resistance or bulk density above 1 can indicate the presence of a compaction layer.
	Ratio of mass-per-volume of soil in the upper 15 cm between the evaluation and reference area	Bulk density	
12. Functional/structural groups	Percent composition by functional or structural group	**Line point intercept (2)**	Composition and richness of functional or structural groups are positively related to the plant functional/structural groups qualitative indicator.

Qualitative Indicator	**Quantitative Indicator**	**Measurement (References)**	**Interpretation**
	and group richness	Annual production (1)	
13. Dead or dying plants or plant parts	Proportion of live-to-dead canopy ______________ Density of dead plants	**Line point intercept (2)** ___________________ Belt transect	The live-to-dead proportion is positively related to the plant mortality or decadence.
14. Litter cover and depth	Litter cover	**Line point intercept (2)**	The cover and depth of litter are positively related to litter amount.
	Litter depth	Direct measurement	
15. Annual production	Total annual production	Annual production (1)	Production relates directly with the qualitative indicator of annual production.
16. Invasive plants	Density of invasive species	Belt transect (1) (2)	Number of species and their densities or cover directly relate to the qualitative indicator.
	Percent foliar cover of invasive species	**Line point intercept (2)**	
17. Vigor with an emphasis on reproductive capability of perennial plants	Basal cover	**Line point intercept (2)**	Basal area of perennial bunchgrasses is positively correlated with vigor.
	Plant height	Vegetation height (2)	

1

Appendix 11. Information Sources Useful in Completing an IIRH Assessment

Aerial Photos

- Earth Explorer: 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 Earth Explorer.
- U.S. Department of Agriculture Aerial Photography: https://www.fsa.usda.gov/programs-and-services/aerial-photography/
- Google Earth: https://www.google.com/earth/resources/

Digital Orthophoto Quarter Quadrangle (DOQQ) Aerial Photos

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: http://www.ncgc.nrcs.usda.gov/products/datasets/index.html

Topographic Maps

- U.S. Geological Survey topographic maps (7.5-minute quadrangles): https://nationalmap.gov/ustopo/index.html

Digital Raster Graphic

A digital raster graphic is a U.S. Geological Survey topographic map that has been digitized and georectified and is ready for GIS applications.

- Digital Raster Graphics: http://topomaps.usgs.gov/drg/

Soil Surveys and Maps

- Visit the local Natural Resources Conservation Service office.
- NRCS website: http://soils.usda.gov/survey
- STATSGO (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.

- Visit the local U.S. Forest Service office to obtain a Terrestrial Ecosystem Survey for the area of interest. Some offices may have this data available in digital form.

- Soil survey data 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 offices (monitoring records)

- Ecological site descriptions

- North American Native Plant Society local chapter: http://nanps.org/

- Plants Database: https://plants.usda.gov/java/

Ecological Site Descriptions

- Ecosystem Dynamics Interpretive Tool: edit.jornada.nmsu.edu

- Local Natural Resources Conservation Service offices (range site handbook)

Geologic Maps

- National Geologic Map Database: http://ngmdb.usgs.gov

Invasive Species

- Introduced, Invasive, and Noxious Plants: https://plants.usda.gov/java/noxiousDriver

Land-Potential Knowledge System (LandPKS)

- https://www.landpotential.org

Landscape Toolbox

- http://www.landscapetoolbox.org

Land Treatment Information

- Land Treatment Digital Library: http://ltdl.wr.usgs.gov

Additional Information about Soil-Related Indicators

- Rangeland Soil Quality Information Sheets: https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/resource/

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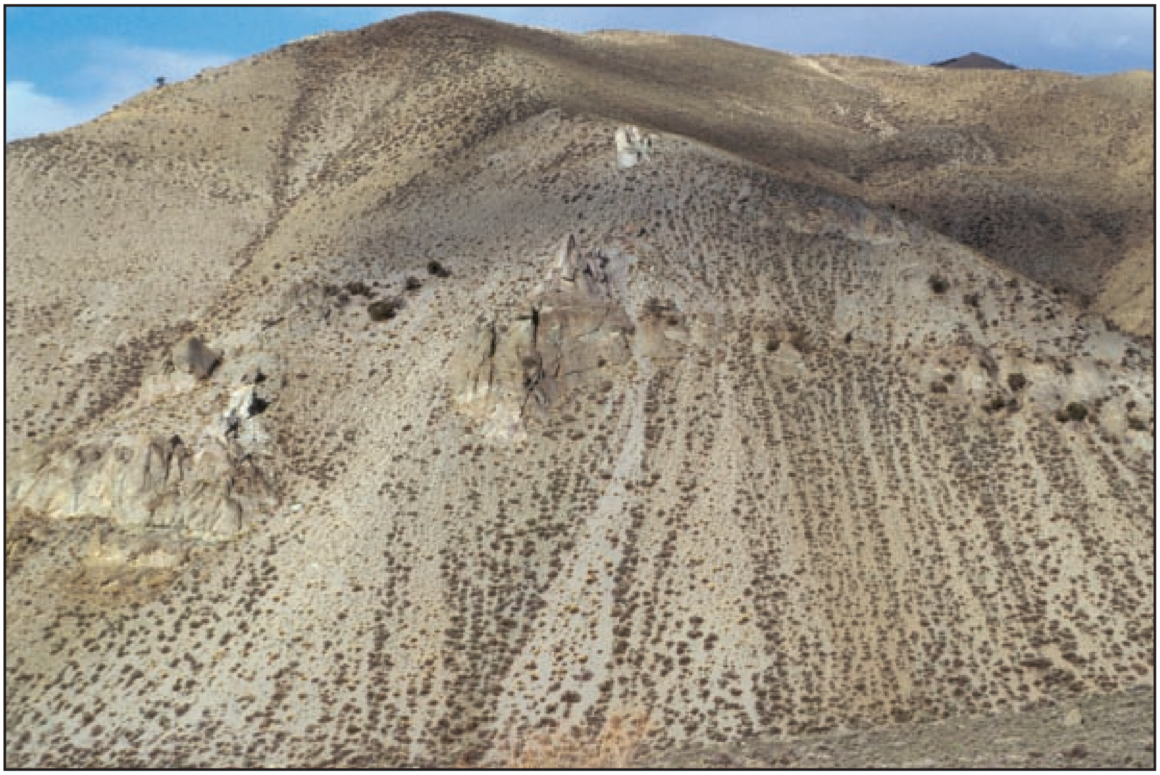
Appendix 12

Photographs of the 17 Indicators from Version 4. Photographs will be updated and included in each indicator write-up section in the final Version 5 publication.

1. Rills



1a - Rills are a natural component of this site due to erodible soils.

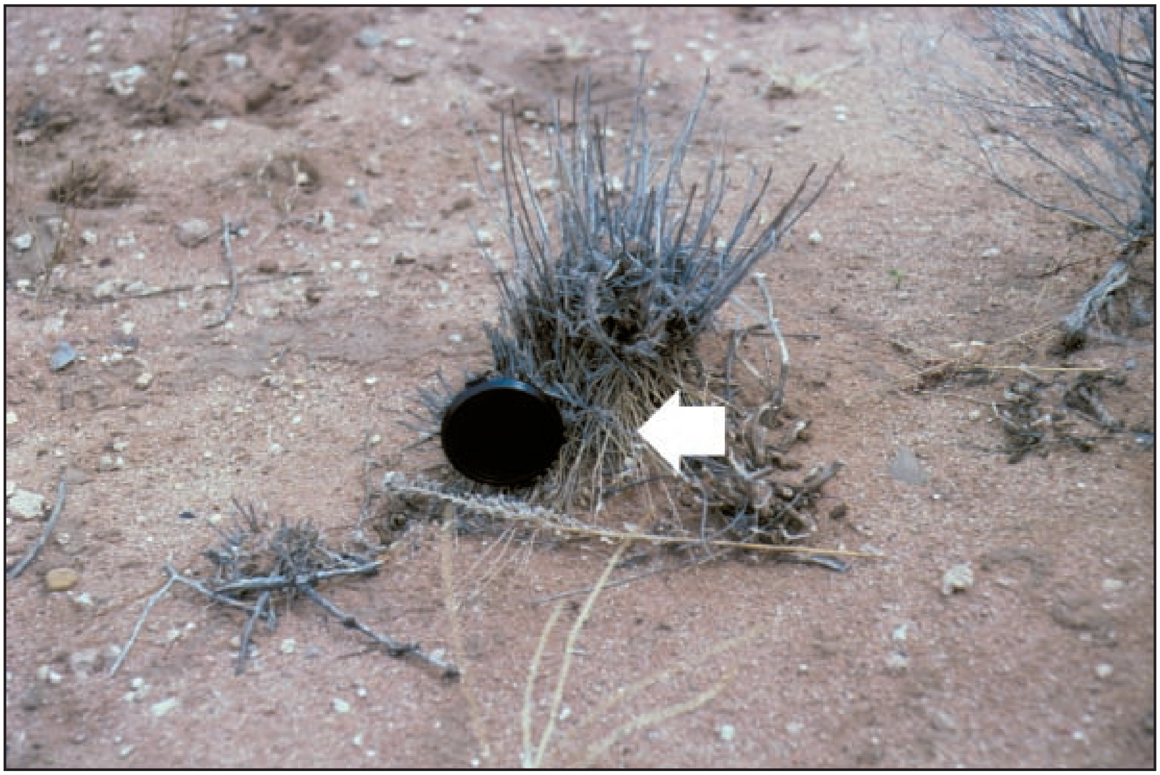
1b - Short linear rill caused by accelerated water flow.

2. Water Flow Patterns

2a - Extensive water flow pattern in plant interspace indicative of high overland water flow.

2b - Short water flow pattern (white dotted line) in plant interspaces.

3. Pedestals and/or Terracettes



3a - Plant pedestal caused by wind erosion. Note the exposed roots (arrow).

3b - Terracette (arrow) caused by litter obstruction in water flow pattern.

3. Pedestals and/or Terracettes (continued)

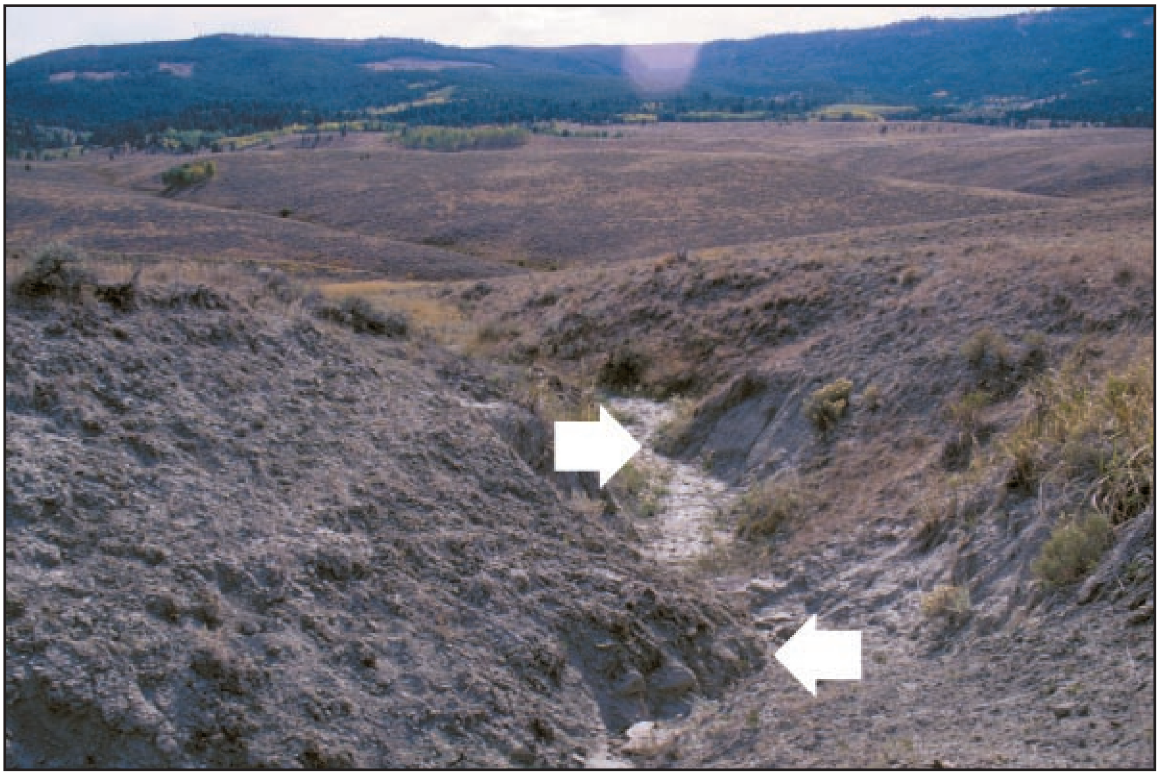
3c - Terraces formed by ungulate grazing on hillsides are not evaluated with this indicator. Other indicators that may be applicable in this situation include numbers 4, 8, 9, and 11.

4. Bare Ground


4a - Amount of bare ground is slight relative to site potential and recent weather.


4b - Amount of bare ground is excessive relative to site potential and recent weather.

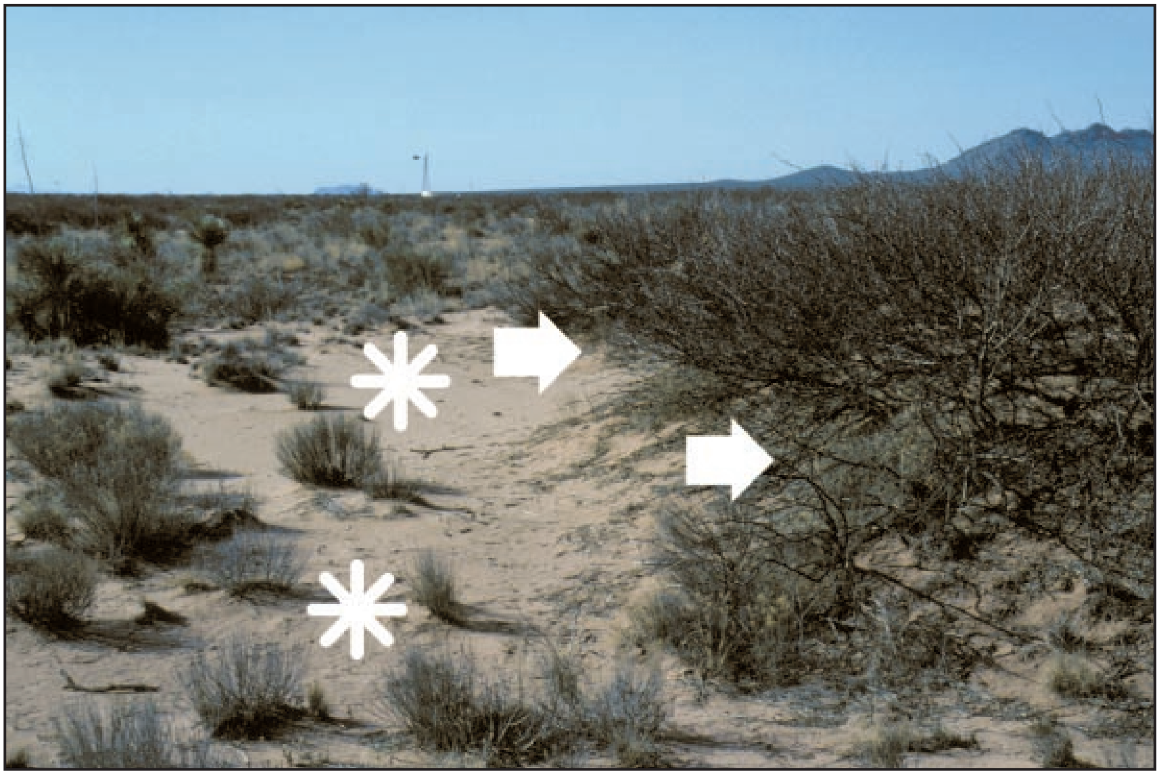
5. Gullies



5a - Gully that shows signs of active erosion (nickpoints - see arrows) and downcutting.

5b - Relatively stable gully with few signs of active erosion with good vegetation recovery occurring.

6. Wind-Scoured and/or Depositional Areas



6a - Wind-scoured areas in plant interspaces (star) with soil deposition occurring at plant bases (arrows).

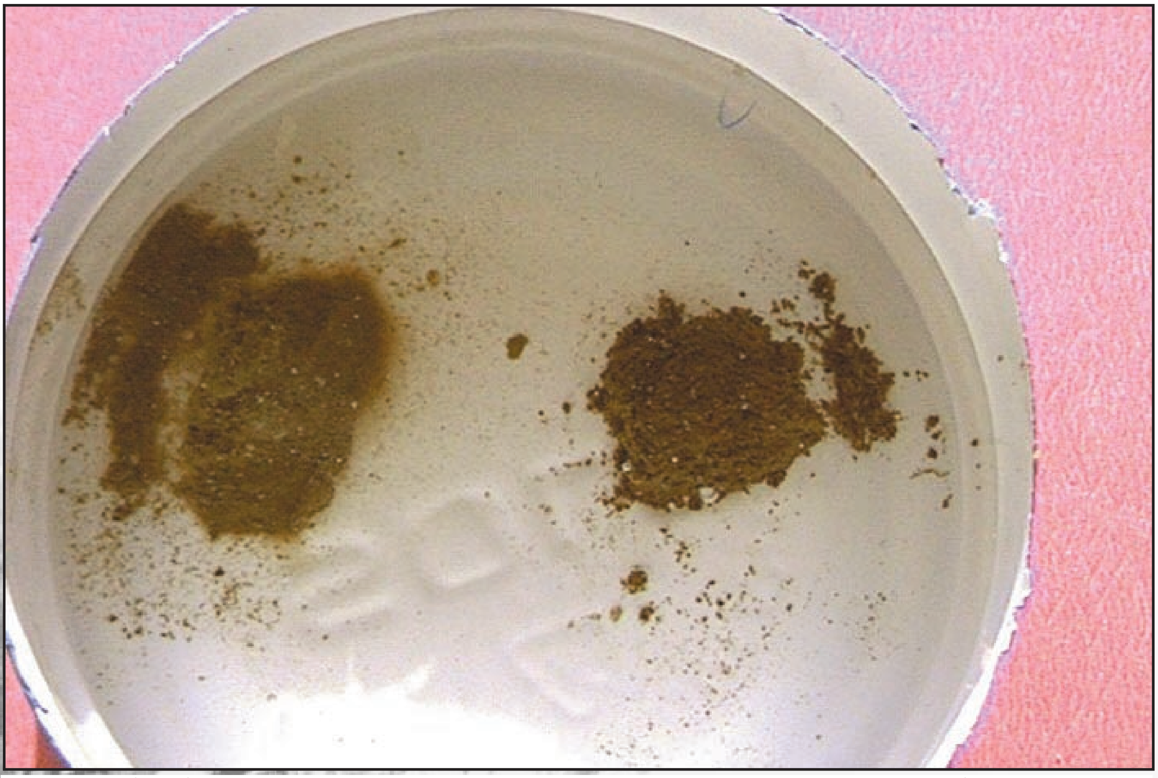
7. Litter Movement

7a - Litter movement and accumulation in a water flow pattern.

7b - Litter redistributed by wind under shrub canopy and around obstructions in the interspaces.

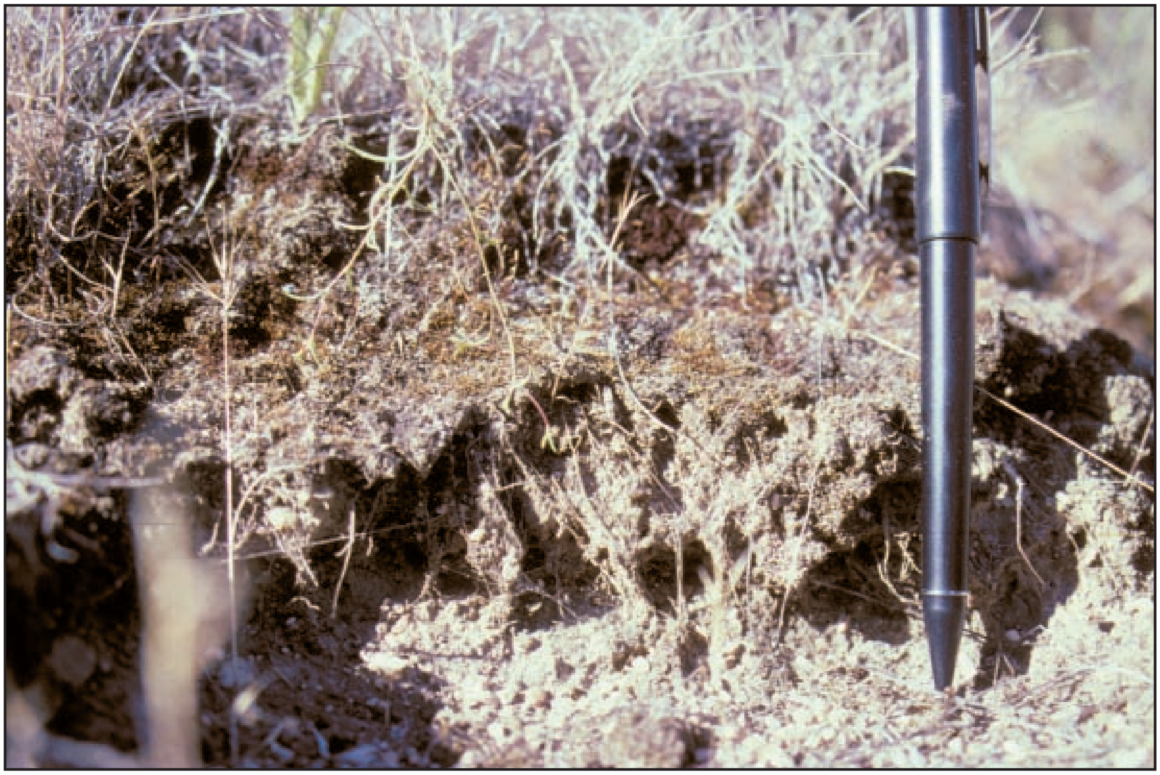
8. Soil Surface Resistance to Erosion

8a - Surface physical crusts in plant interspaces can increase overland flow of water.



8b - Soil surface fragment on right is resistant to breakdown in water indicating presence of soil-binding organic matter. Soil surface fragment on left is "melting" indicating less organic matter and stability.

9. Soil Surface Loss or Degradation



9a - Evidence of soil surface loss (foreground) is evident when compared to the cover of the plant and biological crust in the background.

10. Effects of **Plant Community Composition and Distribution** on **Infiltration and Runoff**

10a - Desert grassland site where grasses promote infiltration and minimize runoff.

10b - Degraded desert grassland site where infiltration has declined and runoff has dramatically increased due to conversion from grass to shrubs.

11. Compaction Layer

11a - An example of a restrictive compaction layer that reduces root penetration and water percolation.

12. Functional/Structural Groups

12a - Nitrogen-fixing forb (*Astragalus* spp.) that is included in a different functional group than non-nitrogen-fixing forbs.

12b - Biological crusts (foreground) are an important functional/structural component in many plant communities.

12. Functional/Structural Groups (continued)

12c - Sagebrush-perennial bunchgrass site near potential. Native annual grasses are a minor component of the vegetation mix.

12d - Perennial bunchgrasses have been replaced with cheatgrass, an exotic annual grass.

13. Dead or Dying Plants or Plant Parts

13a - Dead and decadent sagebrush (*Artemisia* spp.) plants.

13b - Decadent shrub with dead branches.

14. Litter Cover and Depth

14a - Amount of litter is in balance with site potential and recent weather.

14b - Litter is uncommon compared to what is expected given the site potential and recent weather.

14. Litter Amount (continued)

14c - Amount of litter and standing dead vegetation is well above what is expected due to the presence of an exotic annual grass.

15. Annual Production

15a - Production of current year's aboveground biomass is consistent with site potential and recent weather.

15b - Production of current year's aboveground biomass is well below site potential relative to recent weather.

16. Invasive Plants

16a - Cheatgrass (*Bromus tectorum*) is an exotic invasive annual grass that can dominate the understory in disturbed shrublands.

16b - State-listed noxious weeds, such as this knapweed in Idaho, are another category of invasive plants.

16. Invasive Plants (continued)

16c - Juniper, a native tree, is invasive when it invades and increases on rangeland sites where the potential is for shrubs and herbaceous plants.

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

17a - Perennial forbs and grasses show good potential for reproduction as evidenced by flowers and seed-stalk production.

17b - Reproduction potential of this shrub is low due to lack of seed production.