CHAPTER 2
Criterion I: Soil and Water Conservation on Rangelands

Michael G. "Sherm" Karl,[1] Paul T. Tueller,[2] Gerald E. Schuman,[3] Mark R. Vinson,[4] James L. Fogg,[5] Ronald W. Shafer,[6] David A. Pyke,[7] D. Terrance Booth,[8] Steven J. Borchard,[9] William G. Ypsilantis,[10] and Richard H. Barrett, Jr.[11]

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Abstract: The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion of rangeland sustainability. Within the soil/water criterion, 10 indicators – five soil-based and five water-based – were developed through the expert opinions of rangeland scientists, rangeland management agency personnel, non-governmental organization representatives, practitioners, and other interested stakeholders. These indicators are not inclusive but provide a suite of variables that, when complemented with indicators from the four other criteria, produce a viable system to monitor and assess rangeland sustainability.

Authors are [1]Inventory and Monitoring Specialist, Division of Resource Services, National Operations Center, USDI Bureau of Land Management, Lakewood, CO, 80225, USA; [2]Professor Emeritus of Range Ecology, University of Nevada, Reno, NV, 89512, USA; [3]Soil Scientist (retired), High Plains Grasslands Research Station, USDA Agricultural Research Service, Cheyenne, WY, 82001, USA; [4]Supervisory Research Fishery Biologist, Lake Superior Biological Station, Great Lakes Science Center, U.S. Geological Survey, Ashland, WI, 54806, USA; [5]Hydrologist (retired), National Training Center, USDI Bureau of Land Management, Lakewood, CO, 80225, USA; [6]Operations Research Analyst, U.S. Environmental Protection Agency, Washington, DC, 20640, USA; [7]Research Rangeland Ecologist, Forest and Rangeland Ecosystem Science Center, U.S. Geological Survey, Corvallis, OR, 97331,USA; [8]Rangeland Scientist, High Plains Grasslands Research Station, USDA Agricultural Research Service, Cheyenne, WY, 82001, USA; [9]District Manager, California Desert District, USDI Bureau of Land Management, Moreno Valley, CA, 92553, USA; [10]Deputy Division Chief, Division of Environmental Quality and Protection, USDI Bureau of Land Management, Washington, DC, 20036, USA; and [11]Rangeland Management Specialist (retired), Oregon State Office, USDI Bureau of Land Management, Portland, OR, 97204, USA.

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Correspondence: Michael G. "Sherm" Karl, Division of Resource Services, National Operations Center, USDI Bureau of Land Management, Lakewood, CO, 80225, USA, email: sherm_karl@blm.gov

Introduction

Soil and water are essential for ecosystem processes. Primary production of ecosystems requires soils in terrestrial systems and water bodies in aquatic systems to support energy capture through photosynthesis and energy flow through consumption, growth, and respiration. Terrestrial nutrient cycling generally requires soil before nutrient uptake can occur in plants, whereas aquatic nutrient cycling requires physical or temperature-induced mixing of nutrients within the water. In terrestrial systems, soil influences hydrologic processes by the capture, storage, and release of water (Whisenant 1999), but water and wind can erode soil. Soil erosion is regarded as a major contributor to declines in human civilizations over the past 7,000 years (Lowdermilk 1953). Rangelands and their associated communities rely on conservation and maintenance of soil and water resources to maintain them over time.

The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion to assess rangeland sustainability. As a criterion, conservation and maintenance of soil and water resources is too general to monitor directly, but it can be characterized by a set of indicators monitored over time to detect change.

The indicators for the conservation of soil and water resources are divided between soil-related and water-related components of this criterion (Table 2.1). Soil indicators will directly reflect the conservation of soils on rangelands, whereas water indicators will reflect the conservation of water as it flows through rangelands. This is an important distinction because changes in indicators of soil resources will be measured or monitored directly on rangelands and will reflect direct effects on rangelands, whereas changes in indicators of water resources would be measured on rangelands but might reflect changes occurring on non-rangelands (e.g., forest, agricultural, or urban lands). These changes can influence the availability or quality of water resources for sustaining rangeland resources even though they are occurring elsewhere.

Table 2.1. Indicators for soil and water conservation on rangelands, in no particular order of importance, Criterion I.

Indicator	What the Indicator Describes
Soil-based	
Area and percent of rangeland with significantly diminished soil organic matter and/or high carbon:nitrogen (C:N) ratio[1]	Soil productivity, infiltration, nutrient content, nutrient availability, nutrient cycling, carbon sequestration, resistance to erosion
Extent of rangelands with changes in soil aggregate stability[2]	Resistance to erosion by water and wind, soil water availability, root growth
Assessment of microbial activity in rangeland soils[2]	Soil productivity, decomposition, nutrient content, nutrient availability
Area and percent of rangeland with a significant change in extent of bare ground[2]	Erosion potential, aboveground vascular plant productivity
Area and percent of rangeland with accelerated soil erosion by water and wind[1]	Soil loss by water or wind, soil productivity
Water-based	
Percent of water bodies in rangeland areas with significant changes in aquatic biota assemblage composition[1]	Water quality and aquatic habitat conditions
Percent of surface water on rangeland areas with unacceptable levels of chemical, physical, and biological properties[1]	Water quality
Changes in groundwater systems[2]	Water quantity, watershed functioning, change in geographic extent of riparian and wetland ecosystems
Changes in the frequency and duration of surface no-flow periods in rangeland streams[3]	Aquatic and terrestrial biodiversity, watershed functioning
Percent of stream miles in rangeland catchments in which stream channel geometry significantly deviates from the natural channel geometry[2]	Watershed functioning, including sediment transport, sediment filtering and retention, substrate composition, flood amelioration, fish and wildlife habitat, aquifer recharge, water temperature, and season and duration of surface flow

[1] Originated with Roundtable on Sustainable Forests and was retained in SRR.
[2] A new indicator identified by SRR.
[3] Originated with Heinz (2002) and was retained in SRR.

The indicators are the outcome of an evaluation of the soil and water resource indicators identified in the Roundtable on Sustainable Forests (RSF), the soil and water resource indicators from The H. John Heinz III Center for Science, Economics, and the Environment report entitled: *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States* (Heinz 2002), plus our identification of new indicators that relate specifically to rangeland sustainability. Neary et al. (2000), in an effort not associated with the SRR, evaluated the applicability to rangeland sustainability of the eight RSF soil and water indicators. We evaluated Neary et al. (2000), and, based on this evaluation, we retained four of the RSF soil and water indicators (Table 2.1).

We applied a standard set of questions to each indicator: 1) what the indicator is, 2) what the indicator measures and why it is important to rangeland sustainability, 3) geographic applicability of the indicator, 4) the meaning of the indicator at various spatial and temporal scales, 5) the availability and quality of data sets, and 6) the degree of understanding that stakeholders have for the indicator. By indicator, answers to these questions are presented below.

Area and Percent of Rangeland with Significantly Diminished Soil Organic Matter and/or High Carbon:Nitrogen (C:N) Ratio

Description and Importance of the Indicator

This indicator measures the soil organic carbon (soil organic matter) content of the soil and the carbon:nitrogen (C:N) ratio of the soil organic matter. The C:N ratio is a relative measure of soil organic matter's potential for biological decomposition. Soil organic matter provides many benefits to the soil and is associated with the productive potential of soils and soil sustainability. Soil organic matter 1) binds soil particles together into stable aggregates, thus improving porosity, infiltration, water storage, root penetration, and reduction of runoff and erosion, 2) supplies the primary source of nitrogen in a soil system, enhancing soil fertility and plant productivity, 3) supplies the primary energy source for microbial soil organisms that are responsible for biological nutrient cycling, 4) reduces physical soil crust formation, thus reducing runoff potential, and 5) improves water quality by reducing the negative environmental effects of pesticides, heavy metals, and other pollutants by actively trapping or transforming them (USDA NRCS 2001a). Grazing management that ensures a healthy plant community can result in increased soil organic matter through increased carbon sequestration (Schuman et al. 2002).

The C:N ratio of soil organic matter provides an indication of the potential availability of the organic matter to microbial decomposition and, therefore, nutrient release for plant growth. Litter or organic amendments with a high C:N ratio will likely result in nitrogen immobilization in the system. If the C:N ratio of organic inputs is high, then the decomposition of those inputs will be slow. Soils with a high C:N ratio would indicate that the organic matter is more resistant to biological decomposition whereas soils with a C:N ratio of < 10:1 would indicate a good healthy soil and one that would have good biological decomposition of organic matter occurring. Elevated atmospheric CO_2 levels have been shown to reduce the nitrogen content of the plant community, which may influence soil C:N ratio over time (Morgan et al. 2001).

Geographic Applicability and Scale in Time and Space

Soil organic matter levels vary by soil type, plant community, and climate. Fine-textured soils with greater clay content generally exhibit greater soil organic matter levels because the productivity potential is greater. This can be attributed to the greater water holding capacity and reduced decomposition and oxidation rates in fine-textured soils (Reeder et al. 1998). Changes in vegetation and litter inputs, for example as a result of a significant shift from C3 grass-dominated plant communities to C4 grass-dominated plant communities, result in greater root:shoot ratios and greater C:N ratios (Schuman et al. 1999). Shifts from a C3-dominated to a C4-dominated plant community generally reflect an increase in soil carbon because C4 species tend to transfer more energy to belowground plant parts (Coupland and Van Dyne 1979; Frank et al. 1995). Climate and its effects on soil moisture and temperature affect rangeland productivity, which directly influences soil organic matter levels. For example, tallgrass prairie has greater soil organic matter levels than shortgrass prairie. This is because its higher productivity leads to greater contributions of litter and root biomass to the soil. Climate also affects decomposition rates, which influence soil organic matter levels. Long-term severe drought conditions have resulted in decreased soil organic matter in heavily grazed rangelands because of the shallower deposition of soil organic matter by a C4-dominated grassland community compared with a more natural complex plant community (Ingram et al. 2008). The drought conditions also result in a shift in the microbial community structure. A synthesis of soil organic matter (carbon sequestration) data across rangeland ecosystems of the Great Plains indicated that ecosystems receiving greater than 440 mm of precipitation were likely to have lower rates of carbon sequestration in the 0-10 cm soil depth than those ecosystems receiving less than 440 mm of precipitation (Derner and Schuman 2007). For the 0-30 cm soil depth, the precipitation threshold appears to be 600 mm of precipitation.

Soil organic matter and its C:N ratio also can reflect temporal changes attributable to changes in management. Although temporal changes in soil organic matter and C:N ratios lag somewhat to temporal changes in vegetation and litter, the changes can be detected in enough time to initiate management changes to prevent serious degradation of soil. Spatially, soil organic matter varies considerably, reflecting the heterogeneity of soils across short distances. The degree of heterogeneity across short distances infers difficulty in sampling rangelands adequately for a national-level assessment of soil organic matter; however, baseline-sampling sites can be established to compare and detect change over time and space.

Data Collection and Availability

Methods of assessing soil organic matter and C:N ratios are available and are adaptable to the regional and national level. Soil organic matter is generally reported as soil organic carbon, rather than vice-versa (Appendix 2-A). The laboratory methodologies available for measuring soil organic carbon are economical, repeatable, and accurate. To date, no in situ field methodology exists for assessing soil organic carbon. Some methods being developed show promise but presently do not possess the required accuracy and sensitivity necessary to assess soil organic carbon. Soil organic matter can be indirectly estimated by multiplying the soil organic carbon by 1.74, the ratio of organic matter to organic carbon commonly found in the soil. However, many studies (see Nelson and Sommers 1982) have found that 1.74 is too low for many soils, and its use underestimates soil organic matter. Conversion factors need to be developed for individual soils because of the wide range of climates and soils being assessed for soil organic carbon response to management. It is recommended that soil organic carbon be assessed to detect spatial and temporal changes in soil organic matter.

Methods of assessing soil organic carbon generally involve collection of soil samples for laboratory evaluation. Soil samples are typically collected from various sample depths and depth increments, causing problems when comparing soil carbon stocks (Schuman et al. 1999). For example, soil samples collected from the 0-30 cm depth will not adequately reflect the soil organic carbon in surface soils at 0-5 cm depth. This is because changes in soil organic carbon occur more rapidly in the 0-5 cm depth from management and management changes, and mixing the 0-5 cm depth increment with the remaining 5-30 cm depth dilutes the effect.

Soil organic carbon should be expressed on a volume basis rather than a mass or concentration basis, and to do so requires measurement of soil bulk density. In many instances, however, soil bulk density data sets do not exist for soil organic carbon data sets. If care is taken in obtaining soil samples for soil carbon assessment, soil core increment weights can estimate soil bulk density because soil core volume is known. The U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) recently initiated a national research program called Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network (GRACEnet) (Jawson and Shafer 2002) to assess the effects of management on soil organic carbon stocks in croplands, rangelands, and forest lands. Sampling protocols are being developed for soil sampling, soil carbon assessment, trace gas emissions, and data presentation through GRACEnet. While a great deal of soil organic carbon data exist that can be used to make initial assessments, C:N ratio data are not as prevalent because simultaneous nitrogen data were not always collected in earlier studies. Recently, researchers have begun to collect soil organic carbon and nitrogen because of the heightened recognition of the interrelationships of carbon and nitrogen from a microbial and nutrient cycling standpoint. Also many laboratories are now using combustion methods to determine soil organic carbon, which routinely includes nitrogen analyses. In general, soil organic carbon and nitrogen data are limited for rangelands compared with croplands.

Clarity to Stakeholders

Stakeholders generally understand the importance of organic matter as it relates to soil. However, soil organic carbon and the C:N ratio are less well understood, particularly in how they relate to litter decomposition and nutrient cycling.

Extent of Rangelands With Changes in Soil Aggregate Stability

Description and Importance of the Indicator

Soil aggregates are groups of soil particles bound to each other more strongly than to adjacent soil particles. Aggregate stability refers to the ability of aggregates to resist degradation (USDA NRCS 2001b) and erosive forces (Chaudhary et al. 2009). Soils with stable aggregates at the surface are more resistant to water erosion than other soils because soil particles are less likely to be detached and the rate of water infiltration tends to be greater on well-aggregated soils. Soils with stable aggregates are also more resistant to wind erosion because large stable aggregates are heavier and can resist degradation and removal by wind compared with smaller weak aggregates. Aggregated soils hold more water than other soils and provide pores for root growth (USDA NRCS 2001b).

This indicator may provide an early-warning indicator of erosion (Herrick et al. 2002). We anticipate that changes in soil aggregate stability would occur before significant changes in erosion would be detected over large areas. However, dramatic reductions in ground cover increase soil erosion risk regardless of soil aggregate stability. Soil erosion as a direct measure of soil conservation is a difficult measure to obtain and may need to be modeled using other data (see indicator on accelerated soil erosion below).

Detectible changes in soil aggregate stability have been noted with changes in land management practices and changes in biotic factors such as plant community composition, biological soil crust cover, and arbuscular mycorrhizal fungi (although not always, see Rillig et al. 2003). Therefore, soil aggregate stability can be sensitive to these factors (Herrick et al. 2001b; Seybold et al. 2002, 2003; Rillig et al. 2003; Beever et al. 2006; Chaudhary et al. 2009). Where soil aggregate stability has not been particularly sensitive to biotic factors, abiotic factors such as soil mineral content have been speculated to be of more influence on soil aggregate stability (Rillig et al. 2003).

Geographic Applicability

Soil aggregate stability measurements appear to be applicable across regions. Herrick et al. (2001b) and Seybold et al. (2002, 2003) have evaluated the field soil aggregate stability kit over a wide range of agricultural and natural ecosystems throughout North America and found the method to be sensitive to differences in management, land use (for example, forest versus cropland), and plant community composition. These evaluations were performed on a wide range of soil textures, from clay loams to sands. The only soils in which the method has not been useful are wetland soils and extremely sandy soils in which there is little formation of aggregates larger than 1.5 mm in diameter even under good conditions.

Evaluations by Herrick et al. (2001b) and Seybold et al. (2002, 2003) provide evidence that soil aggregate stability methodology is applicable in different regions. An inference that can be drawn from this is that a change (increase, decrease, or neutral) detected for soil aggregate stability for a given region can be interpreted the same way as a change detected in any other region in regard to a change in resistance to erosion by water or wind.

Scale in Time and Space

Soil aggregate stability has been measured most frequently at the patch scale within a site (ecological site or range site, USDA NRCS 2003). At the patch scale, differences in soil aggregate stability and other soil properties have been detected for areas: beneath shrubs, compared with areas beneath grasses, compared with areas of bare ground in shrub and grass interspaces; for areas beneath vegetation compared with bare ground; with varying levels of livestock grazing intensity; and with time since removal of grazing (Herrick and Whitford 1995; Bird et al. 2002, 2007; Bestelmeyer et al. 2006; Beever et al. 2006). Patch scale differences in soil aggregate stability between areas of bare ground and types of vegetation are indicative of fragmentation of plant-soil pattern within plant communities and are predictive of desertification processes and degradation of rangelands in the Chihuahuan desert (Herrick and Whitford 1995; Bestelmeyer et al. 2006; Bird et al. 2007).

Soil aggregate stability varies widely across a variety of scales (Pierson et al. 1994; Bird et al. 2007) and soil textures (Herrick et al. 2001b). Much variability in soil aggregate stability is typical for rangeland and can be attributed to spatial variability in organic matter inputs and aggregation and degradation processes (Herrick et al. 2001b). This sensitivity to changes in soil texture, organic matter content, and spatial scale can be viewed as limiting in regard to regional- to national-level reporting because the large variability poses sampling problems. Herrick and Whitford (1995) and Herrick et al. (2005) recommend a spatially stratified sampling approach to minimize the spatial variability associated with measuring soil properties, including soil aggregate stability (Appendix 2-B).

Aggregate formation varies temporally, largely attributable to the timing and amount of precipitation and the resultant soil moisture levels. Soil moisture levels affect biological activity and physical processes such as frost heaving, which in turn affect aggregate formation (Herrick and Whitford 1995). Given the temporal responsiveness of aggregate formation to temperature, precipitation, and soil moisture conditions, repeated sampling of soil aggregate stability needs to be stratified, preferably during times of similar temperature, precipitation, and soil moisture conditions.

Data Collection and Availability

A field soil aggregate stability kit (Herrick et al. 2001b) is a standardized method for data collection of soil aggregate stability and allows measurements without having to transport soil samples to the laboratory. Standardized methods and procedures for data collecting and reporting exist at the regional to national level, but useable data set(s) do not exist at the regional to national level (Appendix 2-B). Although useable data set(s) do not yet exist at the regional to national level, soil aggregate stability has been incorporated into the USDA Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI), which focuses on non-federal rangelands—this will likely result in a national-level data set of soil aggregate stability on non-federal rangelands.

Clarity to Stakeholders

Soil aggregate stability is not well understood by stakeholders at the present time. We believe that the best way to make soil aggregate stability understandable to stakeholders is to relate soil aggregate stability to the soil's level of resistance to soil erosion and to help them understand that this may provide an early warning signal before significant erosion occurs. Stakeholders understand the value of reducing soil erosion.

Assessment of Microbial Activity in Rangeland Soils

Description and Importance of the Indicator

Soil microbial organisms are important contributors to decomposition and nutrient cycling. They are crucial in the incorporation of organic material into soil, which aids soil infiltration and improves productivity. Productive soils provide nutrients and water to maintain primary production and biodiversity of plants and animals. This indicator will assess microbial activity in rangeland soils through the measurement of microbial respiration. Microbial respiration is correlated with nitrogen mineralization potential, soil organic carbon, and microbial biomass. These microbial parameters are useful in assessing soil sustainability on rangelands. Ingram et al. (2005) found that a modified short-term method of evaluating microbial respiration was a good indicator of organic matter and nutrient cycling in rangeland soils and reclaimed rangeland soils.

This indicator is closely associated with the soil organic matter indicator. They differ because the soil organic matter indicator provides the soil organic matter (soil organic carbon) content of the soil without disclosing the microbial activity of that soil. Microbial activity infers that there is a biological community in place that can respond to the moisture and carbon already in the soil, or to moisture and carbon inputs.

Geographic Applicability

The absolute values derived from this indicator would vary considerably among locations because of climate and climate's effects on soil development and microbial activity. This indicator will require some level of standardization for various climatic zones and soils but will be a useful tool to assess general soil microbial activity. A general decline in microbial activity over time could indicate that the system is being degraded through reduced carbon inputs or severe climatic factors. Because this indicator is assessed under optimal moisture and temperature conditions (0.5 bar moisture tension near field capacity and 25°C), we must keep in mind that it is telling us the soil's microbial potential.

Scale in Time and Space

This indicator will exhibit large spatial variation across soils because of soil texture variation and organic matter content variation. Large temporal variation is inherent in microbial activity but can be minimized somewhat by using the "3-day flush method" mentioned below. Therefore, changes in this indicator over time will best describe the potential for nutrient cycling and whether a healthy microbial population exists. This indicator will likely be evaluated against some minimal value to indicate either adequate or inadequate soil microbial activity.

Data Collection and Availability

It is conceptually feasible to assess the microbial status of rangeland soils, but no regional to national methods or data sets currently exist. Despite the lack of regional- to national-level methods, localized methods do exist for measuring soil microbial respiration as a proxy for soil biological activity. Recent research resulted in the evaluation of the "3-day flush method" compared with standard 21- to 25-day incubation methods (Franzluebbers et al. 1996; Franzluebbers 1999; Franzluebbers et al. 2000). The "3-day flush method" was highly correlated with soil biological evaluations such as nitrogen mineralization potential and microbial biomass, as well as soil organic carbon. This "flush method" has recently been evaluated in rangeland soils and reclaimed mined lands and was an excellent indicator of general microbial activity (Ingram et al. 2002, 2003, 2005).

Limited, incomplete data sets are available on rangeland soils at selected regional sites. The flush method is simple and requires no special handling of soil samples in the field. Samples should be air-dried to ensure a common baseline and enable samples to be collected and stored for short periods during transport to the laboratory. Air-drying of samples also reduces variability attributable to antecedent climatic conditions and soil moisture. The flush method assesses the potential soil microbial activity under good moisture conditions and temperature, which is more appropriately indicative of soil quality/condition. Data that are available likely represent small plot research and were collected using standardized methods.

Clarity to Stakeholders

Stakeholders will not likely understand this indicator because microbial activity of rangeland soils is not a common parameter associated with rangeland sustainability. This indicator would be new for most stakeholders, yet with some education it would be easy to understand because we can relate it to emission of CO_2 by the microbial population during organic matter decomposition.

Area and Percent of Rangeland With a Significant Change in Extent of Bare Ground

Description and Importance of the Indicator

Bare ground is exposed mineral or organic soil that is susceptible to raindrop splash erosion (Morgan 1986). Increases in bare ground and greater homogeneity of existing bare ground relate—directly—to a site's 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). The distribution of bare ground is important. Bare ground as numerous small patches (high fragmentation) is less susceptible to soil movement than a few large patches (low fragmentation) where the velocity of soil-moving wind or water accelerates. The importance of bare ground as an indicator is a function of 1) its direct relationship to erosion risk, 2) its known value as an indicator of changes in land management and watershed function (Branson et al. 1972), and 3) the ease and economy with which this indicator can be monitored over extensive areas, particularly when using remote sensing methods (Tueller and Booth 1975a; Abel and Stocking 1987; Booth and Tueller 2003). It also lends itself, more than most other natural resource indicators, to automated measurement by computer image-analysis techniques (Bennett et al. 2000; Booth et al. 2003, 2008; Booth and Cox 2008a).

Geographic Applicability

The amount and distribution of bare ground varies. On many rangelands little bare ground exists because litter, rock, gravel, and sometimes functional biological soil crusts cover the non-vegetated areas. Bare ground also varies among 1) soils of differing parent materials, texture, and age, 2) plant communities, 3) lands with differing precipitation patterns, and 4) grazing intensities—to name some of the more prominent variables. Badland soils like those in South Dakota inherently have high amounts of bare ground compared with grasslands. Areas where a high percentage of bare ground cause ecological concerns on U.S. rangelands usually occur where non-grazing uses (i.e., farming, construction, off-road vehicle disturbance, roads, mineral exploration and extraction) have disturbed soil-protecting characteristics or where animals concentrate (i.e., drainage ways and riparian areas, fence corners, trail ways, sheep bed grounds). Bare ground is common on extensive areas of over-grazed lands and often leads to desertification (UNEP 1990).

Bare ground is a meaningful indicator in all different regions when compared by site over time so that the natural range of variation is established. Soil series or ecological site descriptions (USDA NRCS 2003) might become useful for predicting bare ground; however, that use must be preceded by years of trend-analysis data collection and correlation of bare ground with relevant variables such as climate, aspect, vegetation (existing and historical), geology, and slope.

Scale in Time and Space

Until the stability and range of variation of a given ecosystem or management unit is established, it seems advisable to measure bare ground frequently (1- to 5-year intervals). Where the natural range of variation is established and data indicate bare ground is relatively stable over time, a 5- to 10-year sampling interval seems appropriate unless there is a significant disturbance or change in management. Methods of measuring bare ground include point, plot (area), and linear (line intercept) methods. Point methods include the point frame (Levey 1927) and the point-step (Evans and Love 1957). A common procedure is to measure 100 points per m2 (that is, points are spaced on a 10-cm grid) using the point frame or 100 to 200 points in a paced transect using the point-step method. Plot methods include the now archaic charting (usually of a 1-m^2 plot) by means of a pantograph (Stoddart and Smith 1955) and 2-cm diameter Parker loop (Parker 1951).

Bare ground measurement by image analysis has developed considerably since Cooper (1924) described his methods for obtaining vertical photographs of vegetation from 1.8 m above ground level. Daubenmire (1968) observed that cover could be measured from an image (chart, map, or photograph) by using a planimeter, by cutting out and weighing parts of the image, or by using a dot grid. Computers greatly facilitate cover measurements from images. Where image pixel resolution is similar to the 2 mm per pixel used by Bennett et al. (2000), image analysis can be considered a direct point-sampling of ground-cover that gives greater precision than is obtained by on-the-ground methods like the point frame (Walker 1970; Wells 1971; Bennett et al. 2000). Images with less resolution give an area measurement. Point sampling (dot grid or pixel count) used with lower-resolution images measures image cover (as opposed to ground cover), and image cover converts to a ground-area measurement. The greater the ground area per pixel, the greater the inaccuracies attributable to pixels containing mixtures of bare ground and other attributes (for example, vegetation, rock, gravel, litter, and biological soil crusts). These are inaccuracies of absolute bare ground per unit area. The inaccuracies are less problematic if we consider only temporal changes by delineating the exact area and using the same method to measure change over time. Regardless of methods, season and annual variation in vegetation cover may impact the measure of bare ground and must be considered when interpreting changes (Anderson 1974; Gutierrez and Hernandez 1996).

As with all indicators, data collected at a local level are not easily extrapolated to, and reported over, larger geographic areas without a sampling design consistent with the inherent variability of the larger geographic area being monitored. It is usually impractical for extensive land areas such as public grazing allotments or watersheds to be monitored using sample numbers and a distribution adequate to something like a 95-percent confidence interval if sampling is limited to ground-based methods. Aerial sampling as used by Booth (1974), Abel and Stocking (1987), Booth et al. (2003, 2006, 2008), and Booth and Cox (2008a, 2008b) greatly enhance the practicality for adequate sampling over extensive areas.

Data Collection and Availability

Some data sets exist at the regional to national level, but methods and procedures are not standardized at the regional to national level. For most available data, bare ground was not measured using the strict definition we used above, although the NRI began using our strict definition in 2003 for rangeland surveys (Pyke et al. 2002; Spaeth et al. 2003). The data sets exist as two types: ground data collected with various methods and remotely sensed data. We list two potential data sets that currently exist: the NRI and various remote sensing formats (Appendix 2-C).

Ground data: Bare ground is included in vegetation analyses for many agencies and non-governmental organizations, including most military reservations in the United States (for example, the military's Land Condition and Trend Analysis). The data within and among these agencies and organizations have been collected using various methods and for numerous sites yet lack adequate sampling designs for regional to national aggregation. However, where sequential, comparable data exist they may provide a useful measure of the natural range of variation for the site. Another potential source for obtaining the natural range of variation for bare ground is the NRCS individual soil pedon data for recent surveys. The aggregated data for soil map units and taxonomic units are stored in NASIS (National Soil Information System) and available through the SSURGO (Soil Survey Geographic) Database for digitized surveys. A limitation here is that ground cover is probably ancillary data in most soil surveys, without stringent standards for providing estimates (Schoeneberger et al. 1998).

Remote sensing data: Data sets (United States or otherwise) with an image resolution that potentially allows an accurate measure of bare ground (Morgan 1986) are rare and largely limited to research efforts (Wells 1971; Bennett et al. 2000; Table 1 in Booth and Tueller 2003; Booth et al. 2003). No remote sensing study has measured bare ground classification accuracy using the strict definition adopted from Morgan (1986). Theoretically, bare ground can be measured using existing remote sensing databases; however, measurement inaccuracies are likely, attributable to pixels containing mixtures of factors and to variable amounts of soil moisture and organic matter that confound image analysis. Research is addressing these limitations. For example, there has been some limited success reported for remotely sensed discrimination of biological soil crust from other soil surface components (Karnieli et al. 2001). Reflectance characteristics vary considerably as soil moisture content changes. Soil textural differences can provide different spectral curves. For example, a sandy-textured soil has a relatively flat spectral curve hovering around 30-percent reflectance, while a silty-textured soil's spectral curve climbs more steeply and has a much greater reflectance particularly at mid-infrared wavelengths above 1.7 µm. A clayey-textured soil is intermediate between these two extremes. The amount of organic matter affects the spectral curve, with lesser reflectance values for soils with greater amounts of organic matter.

The brightness, or intensity, of radiation reflected from bare ground is high because there is nothing to absorb it. Conversely, a dense vegetation cover absorbs most of the incoming red radiation, so its brightness is low. The light that vegetation does not absorb well is the infrared wavelengths. Heavily vegetated areas therefore reflect a high proportion of infrared light. The combination of low red and high infrared reflectance is often referred to as "greenness." Most remote sensing studies categorize areas as bare ground in an indirect manner, by assuming that areas not reflecting infrared must be non-vegetated. This is somewhat simplistic, however, because of the confounding classification factors mentioned previously and the fact that many arid land plants exhibit little spectral greenness. However, the results of such studies do describe increases in bare ground associated with land degradation.

A number of remote sensing studies have shown a high accuracy for a bare ground category when classifying images at various scales (Tueller et al. 1988; Tueller and Oleson 1989). However, these studies do not adhere to our strict definition for bare ground nor do they partition out the confounding factors mentioned previously. For arid rangelands, areas of bare ground can be identified with high accuracy using representative fraction scales varying from 0.2 m pixel Kodak Color infrared digital air photo data, to 0.6 m Quick Bird (commercial satellite system) data, to 1 m IKONOS data (commercial satellite system provided by Space Imaging, Inc., Thornton, CO), to 5 m pixel IRS satellite data. Changes can be quantified easily where areas are classified and the bare ground category is reasonably accurate based on image processing techniques. Resolution of these confounding classification factors at various scales enhance the usefulness of remote sensing for quantifying bare ground and monitoring bare ground changes on rangelands.

Recently, remote sensing experts have been experimenting with hyperspectral data. Hyperspectral systems provide complete spectroradiometric curves of various sized polygons, representing individual plants or plant communities (vegetation types) depending on the scale. Spectroradiometric curves show discrete absorption features that can represent bare ground, individual soils, or the mineral characteristics of specific kinds of soils. The shape of spectroradiometric curves can be indicative of the amount of bare ground in a pixel. Research in this field is promising and should be encouraged. In addition, new Interferometric Syntheic Aperature Radar (IFSAR) systems may provide new data that will be useful to evaluate bare ground.

Ground vs. remote sensing: West (1999) stated the feelings of many when he wrote, "I see no hope that traditional methods of monitoring, *via point sampling on the ground* [italics added], will be able to accomplish those [monitoring] needs . . . especially when landscape and regional perspectives are required. There are simply not enough adequately trained people and that approach would not be affordable, even if the necessary professionals existed." This was demonstrated by the NRI Colorado Test (a prototype procedure) where random sampling and ground data (objective and subjective) collection was used (Pellant et al. 1999). Pellant et al. (1999) reported an average 2.5 hours travel time for 3-person teams to reach sample sites. This included the use of helicopters for sites not accessible to wheeled vehicles. Field data collection cost (with no data analysis included) was $893 per sampled site. The field crews sampled 448 locations at a total cost of $400,000 (Pellant et al. 1999).

The dilemma has been in choosing where to err. The smaller the scale (larger-sized pixels) used in remote sensing the greater the extensive information about large-sized geographic areas, but the lower the accuracy of our inference about specific details (that is, the area of land susceptible to raindrop splash). Conversely, accurate measurement of bare ground at specific sites limits the geographic area of inference and has high cost and increasingly difficult access for ground work. Hopefully the newly evolving technologies will solve the dilemma.

Clarity to Stakeholders

The public generally understands that bare ground is less desirable than soils covered by vegetation. Changes in the extent of bare ground over time, rather than how much bare ground there is at any moment in time, are more compelling in regard to rangeland sustainability. The concept of some bare ground being normal for many rangelands, rather than all bare ground being viewed as negative, is a concept that stakeholders still need to understand.

Area and Percent of Rangeland With Accelerated Soil Erosion by Water and Wind

Description and Importance of the Indicator

Soil erosion by wind or water begins with the loss of all or part of the surface horizon. Surface horizons of soils are important to maintain because they contain the majority of the organic material and are the exchange medium for transferring nutrients from the soil to plants. Losses of soil through erosion may lead to reductions in the productivity of the site (Dormaar and Willms 1998; Davenport et al. 1998). Because upper soil horizons typically contain the highest organic matter and nutrient content, this component of the soil generally controls the rate of water infiltration and plant establishment and growth (Wood et al. 1982). Excessive erosion can contribute soil sediments to waterways thereby reducing water quality.

Since 1945, the United Nations Environment Programme (UNEP 1990) estimates that 11 percent of Earth's vegetated soils (1.2 billion ha) have become degraded to the point that their original biotic functions were damaged and that reclamation would be impossible or too costly. Wind and water erosion is the process that caused most of this degradation. Accelerated erosion is arguably the number one contributor to declines in human civilizations over the last 7,000 years (Lowdermilk 1953). This points to the importance of monitoring soil erosion rates as an indicator of rangeland sustainability and the sustainability of human civilizations associated with rangelands.

This indicator will identify areas where erosion is greater than expected for the soils on a specified site. It does not identify areas with high natural erosion rates (for example, areas with an inherently low vegetative cover and with steep and dissected topography, such as the South Dakota badlands). This indicator measures soil loss by the action of water or wind.

Geographic Applicability

Soil erosion on rangelands was recognized as a serious problem at both local and national levels in the United States in the 1920s (Weltz et al. 1998). Soil erosion varies from soil to soil and from plant community to plant community but is important in any region. Local, regional, and national data on soil erosion can only be accumulated if similar soils and vegetation are affected and the data summarized for the total of the affected areas.

Scale in Time and Space

This indicator is applicable at various spatial and temporal scales. Its applicability depends on the kind of soil involved as well as the ability to measure rills and gullies, provide evidence of inter-rill erosion, and measure soil movement through the air. Rill erosion is caused by concentrated runoff water flowing over the soil, whereas inter-rill (sheet) erosion results from raindrop impact and splash. Soil aggregate size and stability, biological soil crusts, physical crusting, random and oriented roughness, and extent of vegetative cover are related to wind and water erosion. The distribution of these erosion characteristics and their changes across spatial scales from an individual plot to large geographic areas will influence changes in erosion. The temporal scale would be in terms of years but often related to individual storm events in relationship to overgrazing and other sources of rangeland degradation.

Data Collection and Availability

Accelerated erosion by water can be observed using several parameters including movement of litter downslope, evidence of sheet erosion, or an increase in the number and size of rills and gullies (Pellant et al. 2005). Soil erosion rate can be viewed as a function of site erosion potential (SEP) determined by climate, slope conditions, soil erodibility, and ground cover. In pinyon-juniper dominated areas with high SEP, the erosion rate is highly sensitive to ground cover and can cross a threshold so that erosion increases dramatically in response to a small decrease in cover (Davenport et al. 1998). After disturbance, both runoff and erosion amounts tend to increase and remain at elevated levels for a decade or more although the rate is not increased with time (Wilcox et al. 2003). As rangeland vegetation mosaics change as the result of disturbance, ecologically important changes in runoff and erosion can result (Reid et al. 1999).

Wind erosion and transport of surface materials depend on the strength of the wind, the soil surface texture, and the surface protection materials including rocks, biological soil crusts, and vegetation. Surface soil texture is an important key to wind erosion hazard potential. Loamy sand and sand, characterized by particles ranging between 50 and 2,000 µm in size, are the most vulnerable soil textures to wind erosion. Clayey soil, because of the ultrafine particle size with highly reactive surfaces, has better structure and is thus more resistant to wind erosion. Coarse sand and gravelly or rocky soils also are more resistant to wind erosion because the particles are too heavy to be removed. Wind erosion can lessen soil productivity because it physically removes soil particles and organic matter near and at the soil surface and because soil fertility (for example, nitrogen and phosphorus) decreases with diminished organic matter content (Foth 1984). Soil particles transported by wind erosion can enter suspension and become part of the atmospheric dust load. Dust obscures visibility, pollutes air, and fills road ditches, potentially resulting in decreased water quality, automobile accidents, fouling of machinery, and imperilment of animal and human health (Skidmore and Layton 1988). Accelerated erosion constitutes a very strong indicator of rangeland degradation.

Standardized methods and procedures for data collection and reporting have been studied for use at the regional to national level, but useable data set(s) do not exist at the regional to national level (Appendix 2-D). However, the Universal Soil Loss Equation (USLE), Revised USLE (RUSLE), RUSLE2 and Water Erosion Prediction Project (WEPP) have been or are being evaluated for rangeland use. Early models (USLE and RUSLE) were developed for cropland and failed as useful predictors of erosion on rangelands. NRCS soil survey data can potentially provide a national-level soil erodibility and soil erosion data set on rangelands, but erosion was a visual estimate of an observer at an NRI point while erodibility was calculated using the inaccurate USLE or RUSLE models.

Remote-sensing techniques provide a promising technology to obtain information on soil erosion, but limited testing has been done. We encourage additional research to refine and test various methods for obtaining accurate data over larger areas. Recent publications using large scale imagery may be useful for measuring erosion features (Booth et al. 2006; Booth and Cox 2008a).

Clarity to Stakeholders

Erosion is understood by stakeholders. When interested individuals see active or past erosion, the reaction is often a concern for the health of the land. More subtle signs of erosion and the concept of wind-caused dust and the relationship of these to good land stewardship is obscure, requiring further stakeholder education over time.

Percent of Water Bodies in Rangeland Areas With Significant Changes in Aquatic Biota Assemblage Composition

Description and Importance of the Indicator

Measurements of biological assemblages have a long history of use as indicators of change in resource condition. On rangelands, these indicators have traditionally been based on vegetation assemblages. To estimate rangeland condition and trend in condition, plant composition existing at a given moment in time is compared with the plant composition that the given area is capable of supporting at its potential (Stoddart et al. 1975). Downward trends in rangeland condition can also be associated with declines in water quality, aquatic and riparian habitats, and the ability of aquatic habitats to support native biota. These changes can cause aquatic native biota assemblages to shift away from that which would be expected to occur under natural, unimpaired hydrologic conditions (Karr 1991; Hawkins et al. 2000).

The importance of this indicator lies in its relation to watershed conditions and natural biological diversity. Expanding human populations and technology have resulted in a myriad of impacts to our nation's watersheds and water resources (Karr 1991) and a subsequent decline in the biodiversity of aquatic systems (Allan and Flecker 1993), changes in taxonomic composition (Hawkins et al. 2000), and an increase in invasive nuisance exotic species to the detriment of native species. These impacts can be observed in rangeland aquatic systems throughout the western United States. The recognition that multiple stresses are occurring within watersheds has led to the development of ecosystem assessment techniques that evaluate ecosystem attributes that integrate and reflect these multiple impacts. In aquatic habitats, biological assemblages are thought to integrate multiple stressors. Algal, macroinvertebrate, and fish assemblages have all been used as indicators of ecosystem health, with aquatic macroinvertebrates being most often used because of the ease in collection and identification and the relatively high degree of ecological understanding that exists for this group of organisms (Rosenberg and Resh 1993). Monitoring programs based on changes in aquatic macroinvertebrate assemblages are relatively easy to implement, and the data appear to be ecologically meaningful and relevant to the public and decision makers (Karr 1991; Karr and Chu 1999; Norris and Hawkins 2001).

Geographic Applicability

Aquatic systems are dynamic in the number and kinds of species they support within a local habitat and at broader spatial scales (Vinson and Hawkins 1998, 2003). An intuitive and easily understood measure of determining if human activity has affected the biological health or integrity of a place is to compare the fauna observed (O) at that place to that predicted or expected (E) to exist at that place in the absence of human-caused stresses. This comparison between observed and expected (O/E) ecological conditions has proven to be a powerful tool for assessing biological integrity (e.g., Wright et al. 1994; Wright 1995; Hawkins et al. 2000; Hawkins and Carlisle 2001). The units of this comparison can be taxonomic composition, species richness, or functional ecosystem properties such as production or mineral cycling. But in practice, a measure of community composition has proven to be most effective and widely applied (Wright et al. 1994; Wright 1995; Hawkins et al. 2000; Hawkins and Carlisle 2001).

The basis for this comparison is being able to accurately and precisely predict taxa occurrences in the absence of human disturbances. We thus need to identify and then determine the biotic composition at a wide range of undisturbed sites that exist throughout a region. These reference sites need not be pristine, yet they need to be representative of the environmental and biological potential of unaltered or minimally altered places in the region of interest. An additional assumption is that spatial variation in the overall biotic composition among similar sites is similar to the range of variation that an individual site might exhibit over time scales relevant for monitoring objectives.

Scale in Time and Space

Comparisons of observed to predicted species occurrences can provide a meaningful measurement of the degree of impairment at local and regional scales (Wright et al. 1994). Regional scale inferences can be made by aggregating local data across broader geographic areas to evaluate the degree of change occurring within a basin or ecoregion, for example. A hypothetical example would be that at 50 percent of the local sites, 80 percent or more of the species predicted to occur at these sites were observed (O/E = 0.8), whereas at the basin scale, only 60 percent of the species predicted to occur were observed. This would suggest that cumulative impacts are likely occurring within the basin. The cause of the measured effect (the lack of species occurrence) can also be evaluated by correlating trends in assemblage changes with local and regional human-altered environmental factors or known contaminants—for example, by evaluating the strength of the relationship between O/E and nitrate values.

At the temporal scale, variability in aquatic macroinvertebrate assemblage data is typically greater across sites than that observed at the same site over time in the absence of human impairment (Wright et al. 1994). This suggests that natural changes in assemblage composition over time will be less than that observed after human-caused impairment. Thus, data from reference sites do not need to be collected at the same time as data from managed sites, and these data can be used for extended periods of time.

Data Collection and Availability

Standardized methods and procedures for data collecting and reporting for aquatic macroinvertebrate assemblages exist at the regional to national level, and useable data set(s) exist at the local and regional levels (Appendix 2-E).

Clarity to Stakeholders

Comparing the number of aquatic macroinvertebrate taxa that are found at a site to what was expected should be an easily understood concept for stakeholders. A ratio of 0.5 indicates that 50 percent of the species predicted to occur at a site were not found. Thus, the site may have lost its ability to support 50 percent of the species that should occur there. Similarly, these results could be communicated to stakeholders as a 50-percent loss in the natural biodiversity at the site.

Percent of Surface Water on Rangeland Areas with Unacceptable Levels of Chemical, Physical, and Biological Properties

Description and Importance of the Indicator

This indicator measures the percent of surface water with impaired water quality. Surface water includes the length of small, medium, and large streams and rivers, and the area of lakes and reservoirs. Under the Clean Water Act, states and authorized tribes develop water quality standards for their individual stream and river segments, often including their lakes and reservoirs (EPA 1994). A water body segment is a bounded part of a stream, river, lake, or reservoir that is regulated by a set of water quality standards. To establish these standards, states and tribes identify designated beneficial uses (for example, drinking water, recreational, agricultural) for each of their water segments, and then they set water quality criteria to ensure protection of its chemical, physical, and biological integrity (EPA 1994). A water quality criterion is an ambient concentration of an important parameter such as dissolved oxygen, pH, temperature, or heavy metals. An LD_{50} or other metric of these parameters is used to ensure that the designated use or uses for a given water segment are not impaired. Impaired water quality means that one or more of the criteria adopted to protect the designated use or uses of an individual water body segment are not being met. Leading causes of water quality impairment in our nation are excess nutrients (nitrogen and phosphorus), sediment/siltation, pathogens, and metals (USGS 1999). The U.S. Environmental Protection Agency (EPA) National Water Quality Inventory 2000 report states that approximately 40 percent of the nation's assessed streams are impaired (EPA 2006). This water quality indicator is an important measure of water resource sustainability and is an important factor for meeting rangeland sustainability objectives. Water resources must be of adequate quality to support a variety of uses such as human and livestock consumption, wildlife habitat, agricultural and industrial supply, and recreation (Heinz 2002). Water quality is important to rangeland sustainability because wildlife, livestock, downstream water users, recreationists, and others depend on clean water, particularly in arid and semiarid rangelands.

Geographic Applicability

Water quality standards vary geographically. For a particular water body, the water quality parameters that are deemed important, as well as the appropriate criteria or thresholds, depend on the designated uses. Also, states and tribes consider natural ranges of variation when designating uses and developing water quality standards. Water quality impairment assessments are local decisions because our nation's waters do not naturally exhibit the same characteristics. However, states and tribes regularly monitor and assess water quality and identify their water bodies that do not meet their standards. These impaired water bodies are reported on a Clean Water Act Section 303(d) list that is updated biennially (EPA 2003).

Scale in Time and Space

States and tribes have flexibility in how they determine designated uses, which water quality parameters to monitor, which monitoring methods to use, and which methods are used to assess water quality. Also, to meet management and compliance objectives, most water quality monitoring is conducted at "fixed" stations, and the resultant data are not necessarily representative of the whole water body or watershed. National reports on water quality do not yet provide an assessment of all the watersheds in the United States. For these reasons, scaling water quality parameter data up to a regional or national reporting level would be very difficult. Assessing comprehensive regional or national trends of important water quality parameters would present similar challenges. However, the Section 303(d) impairment lists, updated by states and tribes using local water quality data, provide national information on deteriorated water quality and its causes (EPA 2003). Reporting of Section 303(d) lists began in 1998, and states are required to update their lists every two years. As part of their Section 305(b) requirements, states have for the last 30 years been monitoring and reporting water quality information into EPA's national data repository, STORET (Storage and Retrieval).

Data Collection and Availability

Under Section 305(b) of the Clean Water Act, the EPA, other federal agencies, states, and tribes are required to monitor their waters for water quality and report that information into EPA's national water quality database, STORET. Additionally, a National Water Quality Inventory is required biennially, which summarizes water quality reports submitted by states, territories, interstate commissions, and tribes. For reasons stated above, this report cannot be used as a regional or national assessment or to measure national trends in water quality. Also required is a biennial Section 303(d) list of impaired waters (EPA 2003). These impaired waters are required to develop a total maximum daily load (TMDL). TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and it allocates components of that total to the various polluters. The biennial Section 303(d) list of impaired waters is probably the best information we have on impaired water quality and should initially be the data sources for this water quality indicator.

Another potentially useful data source is U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. To help support local decision makers in developing TMDLs and to provide long-term, nationwide information on water quality, the USGS NAWQA Program is starting its second decade of intensive water quality assessments. These assessments will cover 42 large hydrologic systems representing about 60 percent of the nation's waters used for drinking and irrigation. These assessments include a broad list of physical, chemical, and biological measures including 1) streamflow and stream habitat, 2) water, 3) sediment and tissue chemistry, and 4) characterization of algae, invertebrate, and fish communities. However, NAWQA data coverage on rangelands is limited because at least half of the 40-percent non-coverage area is rangeland. (Appendix 2-F).

Clarity to Stakeholders

The concept of a water body meeting or not meeting a water quality standard is an easily understood concept to stakeholders.

Changes in Groundwater Systems

Description and Importance of the Indicator

Because groundwater is a crucial source of fresh water (Alley et al. 2002), supplying the major source of drinking water for more than 50 percent of the U.S. population and 96 percent of the rural domestic supply of water (Solley et al. 1998), a case could be made that groundwater has a direct connection with social, economic, and ecological sustainability of rangelands. Groundwater is used for irrigated pastures that supply winter forage for livestock in many regions of the country. Many of the streams, rivers, and wet meadows in rangeland depend on groundwater and the connection between groundwater and shallow water tables (Taylor and Alley 2001). Drops in groundwater levels may eventually influence stream flows in two common ways: through water moving from the stream into the groundwater system, which recharges removals made elsewhere in the system, or through input reductions at seeps, springs, and wetlands (Alley et al. 1999). Streamflow is expected to decline as a result of woody plant encroachment in landscapes dominated by subsurface flow regimes. Similarly, encroachment of woody plants can be expected to produce an increase in the fractional contribution of bare soil evaporation to evapotranspiration in semiarid ecosystems, whereas such shifts may be small or negligible in both subhumid and arid ecosystems (Huxman et al. 2005).

Water-level monitoring of wells remains the best method for detecting fluctuations in groundwater levels (Taylor and Alley 2001). These measurements may relate to changes in land use and water use, but these relationships require a large array of monitoring stations. Unfortunately, only a limited portion of this array exists (Alley et al. 2002).

The appearance of increased groundwater discharge can be related to a reduction of net primary productivity (NPP) on some ecological sites. Changes in rangeland vegetation can be measured (Vogelmann et al. 1998a, 1998b) and in some cases related to changes in stream base flow. Changes in the distribution of phreatophytic vegetation can be measured using remote sensing techniques, and these changes can be related to changes in streamflow, spring discharge, and increased salinization in lowland areas. Downcutting of mountain meadows can lower water tables and cause the replacement of water-loving vegetation with upland species.

Water-level data will also show areas where surface-water and groundwater interactions may play an important role in sustaining riparian habitat. Changes in water depth in wells over regional areas can be related to phreatophyte control but much less clearly to removal of general amounts of upland range vegetation. The groundwater eventually discharges from aquifers to springs, streams, wetlands, playas, plants, and adjacent basins. All this can influence the natural rangeland vegetation associated with these features. Clearing of native vegetation has led to an order of magnitude increase in recharge rates in areas such as the Niger Basin in Africa (Favreau et al. 2002).

When drawdown exceeds recharge, the result is a loss of available groundwater supply, land subsidence, degradation of water quality, and a loss of riparian habitat. Lowering of the water table (mining of the groundwater) and reduction in groundwater flows and storage are continually changing in response to human and climatic stress. Emphasis must be given to the relationship between groundwater and surface water, so this indicator would mostly be influential near springs and seeps and in the drainages and floodplains.

Geographic Applicability

This indicator integrates groundwater levels over relatively large land areas as defined by the size and structure of the aquifers. This indicator is potentially of importance on almost any rangeland area. The USGS annually monitors groundwater levels in thousands of wells in the United States.

Scale in Time and Space

About 9,000 locations in the United States have gauging stations. The rangelands in the western U.S. have limited coverage. Enhanced coverage is needed for this indicator to become a useful early-warning indicator (Alley et al. 2002).

Data Collection and Availability

The USGS Groundwater database contains groundwater site inventory and groundwater level data (Appendix 2G). The USGS annually monitors groundwater levels in thousands of wells in the United States and conducts a groundwater site inventory of more than 850,000 wells, springs, test holes, tunnels, drains, and excavations. These data are compiled into the USGS Groundwater database. Available site descriptive information includes well location information (latitude and longitude), well depth, site use, water use, and aquifer. Groundwater level data are collected and stored as either discrete groundwater measurements or as a continuous record. Water-level data for groundwater monitoring sites in the study area have been compiled from USGS databases and other sources. Hydrographs that illustrate the water-level changes in most aquifer systems have been plotted. Geographic Information System data sets that represent predevelopment or recent groundwater levels are being created, where possible.

Clarity to Stakeholders

The public understands water levels as they relate to wells for drinking water, but the connection between groundwater and surface water is not well understood. Also, the possible influence of groundwater on vegetation characteristics is not easily comprehended by the public.

Changes in the Frequency and Duration of Surface No-Flow Periods in Rangeland Streams

Description and Importance of the Indicator

This indicator originated in Heinz (2002, 2008) and was retained by the SRR. This indicator annually measures the percentage of rangeland streams with at least one day of no-flow (also referred to as zero-flow) in a year, and, of those, the percentage that have a duration of zero-flow for a given period that is substantially longer or shorter compared with a long-term average. Together, these two variables describe the frequency and duration of surface no-flow periods.

Streamflow is critical in sustaining the habitat necessary for many rangeland plants and animals. Increasing no-flow periods can lead to loss of streamside vegetation and wildlife habitat for many rangeland species. No-flow periods can lead to loss of fish and aquatic animals. Conversely, decreasing no-flow periods can also lead to shifts in rangeland plants and animals and their habitats.

Surface no-flow periods can occur naturally. Surface no-flow periods can also occur because of increased water use for domestic, irrigation, or other purposes. Other causes of no-flow periods are changes in land use (for example, a transition from rangeland to urban development or a transition from no livestock grazing to livestock grazing) and changes in vegetation that modify the flow of surface water and the recharge of groundwater (for example, expansion of deep-rooted vegetation such as pinyon or juniper, which can draw down surface aquifers). Changes in surface no-flow periods also can be attributable to changes in weather and/or climate, such as periods of drought and wet periods.

Geographic Applicability

This indicator has been reported for ecoregions (Heinz 2002, 2008) using the ecoregion approach of Bailey (1995), specifically for the desert shrub, grassland/steppe, and California/Mediterranean ecoregions, which represent the majority of rangelands in the lower 48 United States. Trends in the frequency and duration of surface no-flow periods are discernible over time at the division level of Bailey's ecoregions, and spatially between divisions.

Scale in Time and Space

The USGS has collected flow rate data since the end of the 19th century on stream gauges across the United States (USGS stream gauge data, http://waterdata.usgs.gov/nwis/sw. Accessed 15 January 2009).

Data Collection and Availability

Methods and procedures exist for data collecting and reporting of this indicator at a regional to national level. Data sets of useable quality exist (Appendix 2-H). Data sets are maintained by the USGS and are available at http://waterdata.usgs.gov/nwis/sw. Accessed 15 January 2009.

Clarity to Stakeholders

Stakeholders can understand that streams that are changing from perennial to ephemeral or intermittent, with decreasing streamflow, will affect habitat of wildlife and plant species and will affect availability of water for agricultural, municipal, energy production, and other uses.

Percent of Stream Miles in Rangeland Catchments in Which Stream Channel Geometry Significantly Deviates From the Natural Channel Geometry

Description and Importance of the Indicator

This indicator tracks changes in stream channel geometry (that is, in cross section, in profile, and in channel bed materials) from a baseline condition. Changes in cross section are defined by the width/depth ratio at "bankfull" stage. Changes in profile are defined by sinuosity and channel slope. Changes in bed material are defined by the particle-size distribution of materials comprising the streambed. Measurements of these attributes of stream channel geometry comprise the indicator. Baseline conditions can be defined by natural, historic, or reference channels located in the same hydro-physiographic position on the landscape.

Changes in width, depth, width/depth ratio, slope, sinuosity, meander characteristics, and substrate materials are indicative of changing conditions of water and sediment yield in a watershed. Changes in channel pattern (for example, straight, meandering, braided, riffle-pool, step-pool, or cascade) are also good indicators. Where such changes are observed over time and space, the cause of channel adjustment should be explored to determine if management practices are contributing to channel degradation and if the stream system is presently out of balance with the water and sediment being supplied by the watershed.

Stream channels are constantly adjusting to the water and sediment load supplied by the watershed. Changes in channel conditions in a rangeland watershed correspond to changes in streamflow and sediment supply in the basin, as well as human manipulation of the channels, and therefore are a good indicator of sustainable rangeland management.

Geographic Applicability

This indicator should be meaningful in virtually all regions provided the baseline condition is adequately and correctly defined. Regional differences will exist in what is considered natural and baseline. Primary influencing factors will be climate and its associated influence on vegetation composition along the channel, as well as parent materials of watershed sediments available for transport and deposition along the channel.

Scale in Time and Space

Temporally, channel adjustments may be identified for a particular stream reach by evaluating a sequence of aerial photos covering several years or decades. Alternatively, upstream and downstream reaches may provide a descriptive history of channel adjustments using a "space for time" substitution. Because most channel evolution occurs in an upstream direction (that is, channel features like nickpoints, gullying, and widening tend to work upstream rather than downstream), earlier conditions for a stream reach likely resembled present conditions upstream of the reach. Similarly, channel evolution at a site would be expected to produce a future condition similar to that presently observed in downstream reaches. Thus, channel geometry measurements should be evaluated with respect to both temporal and spatial considerations.

The indicator is most useful and meaningful at the reach scale; however, it likely is amenable to aggregation on a watershed or sub-basin scale. Spatial scale also must be considered when assessing whether changes in channel geometry are local or system-wide in nature. Local site-specific changes in channel geometry result from erosion and deposition processes that are not symptomatic of a disequilibrium condition in the watershed. Common displays of local channel adjustment include instability along the concave bank of a meander bend as part of natural channel meandering or in isolated locations as a result of channel constrictions or flow obstructions (for example, ice, debris, and structures). In contrast, system-wide changes in channel geometry and substrate often reflect changes in runoff and sediment yield from the watershed or changes in resistance to flow and erosion in the channel corridor. Both could be indicative of non-sustainability of management practices. However, even system-wide adjustments can result from natural channel evolution, and care must be used when interpreting the measurements associated with this indicator.

The greatest utility of the channel geometry indicator would result from repeated measurements over a period of time. Time trends of channel narrowing, widening, flattening, steepening, fining, or coarsening would be less susceptible to misinterpretation than single measurements at a moment in time. Repeated measurements over several spatial scales (that is, both reaches and sub-basins) would also allow consideration of natural channel evolution processes versus rapid channel response to non-sustainable watershed practices. Single measurements of channel geometry at a single location in a basin would be most susceptible to misinterpretation and misunderstanding of channel processes.

Data Collection and Availability

The data for evaluating this indicator exist for some areas; however, data likely occur in a variety of formats. No national data sets exist, and any regional data sets likely include information only for a single state or federal agency. However, standardized procedures for sampling and analyzing these data do exist.

Clarity to Stakeholders

Detailed understanding of this indicator probably is not intuitive for all stakeholders; however, it might be possible to make it that way. Accurate interpretation of channel geometry and substrate measurements requires an understanding of fluvial geomorphology. Communication of this indicator will require a skilled presentation to achieve understanding by a broad cross-section of stakeholders.

A Look Ahead

Several of the indicators pose challenges regarding their applicability over broad geographic areas. Sampling schemes have not yet been designed for some of the indicators to achieve an objective of regional- to national-level reporting of change over time. Some indicators represent “outside the box” thinking and would require more understanding among stakeholders before they would widely accept the indicators as credible.

We are discovering that regional- and national-level data sets are not available for most of the indicators. More data sets are often available for smaller geographic areas, with various methods used for measurement. Elaborating on the quality of data sets has been challenging because quality-control information is scant in the literature.

Of the 10 indicators, some of the five water-based indicators might also be identified by the Sustainable Water Resources Roundtable, which is ongoing. Within SRR, there has been some overlap in indicator identification between the Soil and Water Resources Criterion Group and the Plant and Animal Resources Criterion Group. Integration, both within the SRR and between the various Roundtables, is critical to minimize overlap. In some cases, more than one indicator appears to be indexing similar rangeland components. For example, organic matter, aggregate stability of the soil surface, bare ground, and soil erosion each affect or influence assessment of soil erosion. Therefore, an obvious question is: do we require all of these soil indicators to adequately assess the role of soils and soil change in the reporting of rangeland sustainability?

Soil and water are natural capital and, as such, represent an accumulated wealth that if squandered will cause decline in rangeland sustainability. The identification and eventual quantification of rangeland indicators related to soil and water can provide an approximation of rangeland sustainability for our nation and a blueprint for evaluating rangeland sustainability worldwide.

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Appendices. Information on data sets associated with soil and water indicators. Information is not available for the microbial activity soil indicator and the stream channel geometry water indicator.

Appendix 2-A. Area and percent of rangeland with significantly diminished soil organic matter and/or high carbon:nitrogen (C:N) ratio.

	Data Set #1
Brief Title for Data Set	Organic Matter from NRI (using Statsgo).
Contact Person/Agency/Group	
Citation (if published)	
Website (if available)	
Additional information on data set	
For what years are data available, and how often are data collected?	1982 to 1992 in 5-year intervals.
In what format is the data set available?	Data points.
Are data nominal, ordinal, or interval?	Continuous.
What will be the approximate cost of collecting data?	$1,000/point (estimate for all NRI, not just soil organic carbon).
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	None.
What is the spatial grain of these data?	3 random plots per 160 acres (65 ha) per Primary Sampling Unit.
What is the spatial extent of these data?	Non-federal rangeland nationwide.
At what spatial scales can these data be aggregated and reported?	County?, Major Land Resource Area (MLRA), state, or nation.
What is the temporal grain of these data?	Every 5 years.
What is the temporal extent of these data?	1982 to 1992.
At what temporal scales can these data be aggregated and reported?	Every 5 years.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, published in NRI protocol.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Given standard protocol, should be very repeatable (no p-values available).
Quality: how biased are the sampling methods?	Limited bias; adequate statistical sampling design applied.
Quality: how precise are existing data? (Give standard error, if available)	Given protocol, should be very precise (no standard error available).
Quality: how valid are existing data?	Measures soil organic matter. Must use 58% conversion to get soil organic carbon.
Quality: how responsive are existing data?	A lag would likely occur before this measurement would show change attributable to human impacts.
Quality: how much statistical power to detect change does this data set have?	Unknown.
Quality: how well does this data set meet the data needs for this indicator?	It measures soil organic matter, thus requires a 58% correction factor to obtain soil organic carbon.
Other comments: (Include any other relevant aspects of the data set that should be included)	

Appendix 2-B. Extent of rangelands with changes in soil aggregate stability.

	Data Set #1
Brief Title for Data Set	Soil Aggregate Stability
Contact Person/Agency/Group	
Citation (if published)	
Website (if available)	
Additional information on data set	This data set does not yet exist at the national or regional level.
For what years are data available, and how often are data collected?	
In what format is the data set available?	
Are data nominal, ordinal, or interval?	Nominal. Observations of 6 to 8 mm diameter soil surface fragments during immersion and subsequent wet-sieving are compared with criteria, which results in the assignment of the soil surface fragment to 1 of 6 stability classes (stability classes 1 through 6; 1 being slakes immediately, and 6 being 75% remains on a 1.5 mm screen after sieving) (Herrick et al. 2001b; Herrick et al. 2002).
What will be the approximate cost of collecting data?	
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	
What is the spatial grain of these data?	No specific spatial grain has apparently been established for soil aggregate stability data. Most data that have been collected and reported in the literature have been collected at a patch scale, within sites (for example, ecological site).
What is the spatial extent of these data?	
At what spatial scales can these data be aggregated and reported?	Herrick et al. (2005) recommends aggregation of spatial data collected within functionally similar landscape units. They recommend a hierarchy of landscape geographic areas be used to guide the identification of monitoring units. An ecological site (USDA NRCS 2003), which represents a soil-landscape unit, would represent the largest geographic landscape area recommended for use as a monitoring unit. Ecological sites can be further subdivided into vegetation-similar landscape areas, representing soil-landscape-vegetation units (typically areas with dominant plant species that define the plant community), and these soil-landscape-vegetation units can serve as monitoring units. Vegetation-similar landscape areas within ecological sites can be further subdivided into landscape areas within which current management is similar, or soil-landscape-vegetation-management units. These soil-landscape-vegetation-management units would be expected to respond similarly to management changes. Spatial data could be aggregated to large areas by using these monitoring units.
What is the temporal grain of these data?	Herrick et al. (2005) recommend a temporal grain of 1 to 5 years.
What is the temporal extent of these data?	At the regional or national level, there is no temporal extent because soil aggregate stability data have not been aggregated to the regional or national level yet.
At what temporal scales can these data be aggregated and reported?	

Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, if the field soil aggregate stability kit (Herrick et al. 2001b) is used repeatedly over time, data can be reported in a consistent form over time.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	
Quality: how biased are the sampling methods?	
Quality: how precise are existing data? (Give standard error, if available)	Herrick et al. (2001a) present coefficient of variation statistics for soil aggregate stability measurements, but standard errors of means were not presented. Coefficients of variation increased dramatically when data collected from different vegetation types were combined. In addition, coefficients of variation were greater in shrub-dominated sites compared with grass-dominated sites, with the shrub-dominated sites being comparatively more degraded. Herrick et al. (2002) recommend that soil aggregate stability be calculated separately for plant canopy versus intercanopy spaces to help decrease variation.
Quality: how valid are existing data?	Using the field soil aggregate stability kit (Herrick et al. 2001b), this indicator measures what is intended with a high degree of accuracy. Herrick et al. (2001b) report that there is high correlation between the qualitative evaluation of soil stability class using the field soil aggregate stability kit and the quantitative measurement of soil aggregate stability done in the laboratory. The qualitative and quantitative comparisons were performed on the same soils. Aggregate stability percentage obtained from the quantitative lab procedure was within the range associated with the stability class (from the qualitative soil stability test) about ¾ of the time, and all of the aggregate stability percentages were always within 1 class of each other. Although the field soil aggregate stability kit method cannot replace careful laboratory-based measurements of soil aggregate stability, it can provide valuable information when these more intensive procedures are not possible.
Quality: how responsive are existing data?	Existing data are responsive to differences in management, disturbance levels, plant community composition, biological soil crust cover, sometimes arbuscular mycorrhizal fungi, most soil textures, and sometimes organic matter content (Herrick et al. 2001b; Rillig et al. 2003; Chaudhary et al. 2009). Soil aggregate stability apparently is not responsive in wetland and extremely coarse-textured (coarse sand to fine gravel surfaces) soils because soil aggregates do not readily form in these soils (Herrick et al. 2001b). Soil aggregate stability is relatively insensitive to intensive short-term disturbances such as trampling by horses, humans, and vehicles but is more sensitive to longer-term changes in soil structure (Herrick et al. 2002). This relative insensitivity to intensive short-term disturbances is critical to ensure that repeated measurement (monitoring) of soil aggregate stability can pick up or track actual changes, rather than being simply reflective of normal variability in the system (Herrick et al. 2002). The 1.5 mm sieve size of the field soil aggregate stability kit method increases the probability of detecting change at an early stage because aggregation at this size is generally controlled by rapidly cycling organic matter (Tisdall and Oades 1982; Herrick et al. 2002; Bird et al. 2007), and degradation of this size is likely to occur before smaller aggregates are destabilized (Bird et al. 2007).

Quality: how much statistical power to detect change does this data set have?	The answer depends on what sample size is used and what the alpha level is set at. Across 3 different sites in southern New Mexico, at an alpha level of 0.05, sample sizes ranging between 9 and 54 were necessary to achieve a power of 0.8, whereas to achieve of power of 0.9, at an alpha level of 0.05, greater sample sizes were required, ranging between 12 and 74. In this context, the power was applied to the ability to detect a difference in soil aggregate stability of 1 class. At an alpha level of 0.2, sample sizes ranging between 4 and 25 were necessary to achieve a power of 0.8, whereas to achieve a power of 0.9, at alpha level of 0.2, sample sizes ranged between 7 and 39 (Herrick et al. 2001a).
Quality: how well does this data set meet the data needs for this indicator?	
Other comments: (Include any other relevant aspects of the data set that should be included)	As reported in Bird et al. (2007), approximately 5,000 locations between 2003 and 2006 were sampled for soil aggregate stability in the western United States with the field soil aggregate stability kit, as part of the Natural Resources Conservation Service's National Resources Inventory program.

Appendix 2-C. Area and percent of rangeland with a significant change in extent of bare ground.

	Data Set #1	**Data Set #2**
Brief Title for Data Set	NRI administered by NRCS	Indian Remote Sensing (IRS); also a consideration of SPOT, IKONOS, QuickBird, Radar Satellite Data, and other fine-grained imagery of various kinds including very-large scale aerial (VLSA) (Booth et al. 2003).
Contact Person/Agency/ Group	NRCS State Offices	Satellite data: EOSAT Corporation, Thornton, CO. For protocol, Paul T. Tueller, University of Nevada, Reno, ptt@unr.edu. VLSA: Terry Booth, ARS, Cheyenne, WY, terry.booth@ars.usda.gov.
Citation (if published)		1. Booth, D.T., D. Glenn, B. Keating, J. Nance, S.E. Cox, and J.P. Barriere. 2003. Monitoring rangeland watersheds with very-large scale aerial imagery. Proceedings of the First Interagency Conference on Research in the Watersheds. 28-30 October 2003, Benson, AZ. 2. Tueller, P.T., P.C. Lent, R.D. Stager, E.A. Jacobse, and K. Platou. 1988. Rangeland vegetation changes measured from helicopter-borne 35mm aerial photography. Photogrammetric Engineering and Remote Sensing 54:609-614.
Website (if available)	http://www.nrcs.usda.gov/technical/NRI/. Accessed 28 September 2004.	http://www.geoeye.com/CorpSite. Accessed 6 April 2009 http://www.digitalglobe.com/product/index.shtml. Accessed 6 April 2009 http://rrru.ars.usda.gov/. Accessed 6 April 2009
Additional information on data set	NRCS has been working with other agencies, including ARS, BLM, USGS, and USDA Forest Service, to develop an interagency list of data elements that could be used for national-level inventories.	Considerable imagery at various scales and types available throughout the United States. Analysis and interpretation is required to use these data and accumulate bare ground estimates over large areas of rangeland.
For what years are data available, and how often are data collected?	1982 to 1992; every 5 years.	Satellite data: Numerous dates from 1972 onward. IRS has been available since 1983, and the other satellites are more recent. VLSA: Data collected since 2002 and are collected as needed for specific research projects.
In what format is the data set available?	Data points. Primary sampling units (PSUs).	Satellite data: Multispectral and panchromatic digital image data from satellite and large-scale video and digital multispectral images. VLSA: 70 mm color film and 11.1 megapixel color digital images.
Are data nominal, ordinal, or interval?	Nominal.	Satellite data: Interval—spectral brightness values. VLSA: Images are spectral; subsequent bare ground measurements are nominal.
What will be the approximate cost of collecting data?	$1,000 per PSU.	Satellite data: Variable; imagery now available for $400 per image for the digital data/date. VLSA: Costs averaged $0.07 per ha ($0.03 per acre) for a 2003 survey of Cottonwood Creek watershed (Casper Field Office of BLM) that included 559 aerial and ground photographic samples (unpublished report to BLM Wyoming State Office).

What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	Summarized reporting only.	Satellite data: Biggest problem is the classification and interpretation of the data. VLSA: The method is new and data sets are few in number.
What is the spatial grain of these data?	Plot size, 160 acres (65 ha) in a primary sampling unit (PSU) with 3 random plots per PSU.	Satellite data: Variable; 5 m multispectral and 5 m panchromatic pixels for the IRS data. VLSA: A resolution as fine as 2.2 mm per pixel from 100 m above ground level.
What is the spatial extent of these data?	A number of random PSUs on non-federal rangelands.	Satellite data: Available for numerous cloud-free dates over large areas since the early 1970s; for example, each Landsat TM scene covers an area about 115 miles (185 km) on a side. VLSA: Limited to selected research sites in Wyoming, Colorado, Idaho, Nevada, and New Mexico.
At what spatial scales can these data be aggregated and reported?	MLRA, state, or national.	For any area in which the cost of the data can be provided.
What is the temporal grain of these data?	5 years.	Satellite data: Multiple dates annually. VLSA: Can be acquired as desired.
What is the temporal extent of these data?	Every 5 years from 1982 to 1992.	Satellite data: Since 1972. VLSA: Since 2002.
At what temporal scales can these data be aggregated and reported?	5 years.	Satellite data: Seasonally and annually over the years since 1972.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes.	Satellite data: Yes, a recent protocol has been developed to calibrate older with more recent satellite data. VLSA: Yes, image acquisition and analysis methods lend themselves to consistency.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Repeatable but some dependency on different data collectors.	Satellite data: The repeatability is good because image data are available for numerous cloud-free dates. -VLSA: To be determined. Bennett et al. (2000) reported a standard deviation of 1.3 for cover estimates in a test designed to measure precision of their image-analysis method.
Quality: how biased are the sampling methods?	Somewhat biased because they are estimates.	Satellite data: The data quality is excellent because of the georeferencing along with radiometric and geometric corrections. VLSA: Systematic aerial sampling avoids human bias in sample acquisition and inadvertent bias attributable to site inaccessibility. Human bias in the measurement of bare ground is reduced by using a calibration procedure for image analysis and by using computers to make automated measurements.

Quality: how precise are existing data? (Give standard error, if available)	Somewhat precise, yet the level of precision is based on the experience of the estimators; in practice and with training the estimates are quite repeatable.	VLSA: Bennett et al. (2000) reported a standard deviation of 1.3 for cover estimates in a test designed to measure precision of their image-analysis method.
Quality: how valid are existing data?	Validity is high, but the data set is sparse.	Validity can be determined based on image processing classification accuracy. Images are storable data that allow the validity of image interpretations to be reassessed as needed.
Quality: how responsive are existing data?	The data are reasonable based on the experience of those who are doing the interpretation.	These data can measure differences in bare ground on an annual basis.
Quality: how much statistical power to detect change does this data set have?	The statistical power is not high since much of the data consist of estimated values.	Satellite data: These data can have high statistical power because, based on the number of pixels, a very large sample size can be quickly obtained for any site. VLSA: See discussion in Booth and Cox (2008a). This method exceeds other rangeland-survey methods as a tool to detect change. This is attributable to the high resolution that is possible in the images and to a capability for greatly increased sampling intensity with minimal increases in image-acquisition costs. The cost to get 10 digital images per km of flight line is almost equal to the cost of getting 1 image per km as long as capacities for frame-rate capture and on-board image storage are not exceeded.
Quality: how well does this data set meet the data needs for this indicator?	The data set has the potential to meet the needs and can be summarized by MLRA.	Satellite data: The development of a bare ground category can serve as a surrogate for bare ground although it may not be possible to spectrally separate out such features as biological soil crusts or other cover features. VLSA: Bennett et al. (2000) reported most of their images showed excellent discrimination between soil and plant material. The more expensive point sampling on the ground, by a single person, at 1 point in time over a small area, is likely to best meet the data needs for this indicator. On large areas, over time, and where multiple technicians are involved, imaging methods are likely to give more satisfactory results than conventional on-the-ground sampling.
Other comments: (Include any other relevant aspects of the data set that should be included)	Such data sets often are dependent on level of annual funding appropriations available to do these inventories.	Remote sensing data are strongly dependent on the protocol to extract a bare ground category, the accuracy of the category, and its interpretation.

Appendix 2-D. Area and percent of rangeland with accelerated soil erosion by water and wind.

	Data Set #1	**Data Set #2**
Brief Title for Data Set	NRI administered by NRCS.	Fine-scale (small geographic extent) color photography for erosion evaluations.
Contact Person/Agency/Group		Terry Booth, High Plains Grasslands Research Station, ARS, Cheyenne, WY, terry.booth@ars.usda.gov; Paul Tueller, Professor Emeritus of Range Ecology, University of Nevada, Reno, ptt@unr.edu.
Citation (if published)		Tueller, P.T. and D.T. Booth. 1975b. Large scale color photographs for erosion evaluations on rangeland watersheds in the Great Basin, p. 708-752. *In*: Proceedings of the American Society of Photogrammetry, 28-31 October.
Website (if available)	http://www.nrcs.usda.gov/technical/NRI/	http://www.r-s-c-c.org/rscc/Volume4/tueller/mod4.html. Accessed 6 April 2009. There are examples here of large-scale imagery and the use of imagery for rangeland applications.
Additional information on data set	NRCS is now working with other agencies, including ARS, BLM, USGS, and USDA Forest Service, to develop an interagency list of data elements that could be used for national-level inventories.	Data sampled on 8 sites in the Great Basin. Numerous additional sites have been sampled on rangelands around the world using fine-grained aerial imagery but in no systematic manner.
For what years are data available, and how often are data collected?	1982 to 1992; every 5 years.	Two years; sampling of this kind can be done quickly and efficiently from a light aircraft or helicopter with sampling done at random locations and at sites with difficult on-the-ground access, far from roads.
In what format is the data set available?	Data points. Primary sampling units (PSUs).	Images upon which measurements can be made are usually expressed as a percent of the scene in a given erosion class or, in the case of this study, a range and mean rating for soil surface factors. These factors are flow patterns, gullies and rills, litter movement, and bare ground. Categories are stable, slight, moderate, critical, and severe with interval values for each.
Are data nominal, ordinal, or interval?	Nominal.	Ordinal and interval.
What will be the approximate cost of collecting data?	$1,000 per PSU.	Highly variable; fine-scale (small geographic extent) flight transects cost between $200 to $1,200 depending on the number of transects per flight and the distance between transect locations.
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	There is only summarized reporting of estimated erosion.	Primarily a cost consideration to acquire the imagery and a sampling problem to obtain imagery that represents the rangeland areas to be inventoried.

What is the spatial grain of these data?	Plot size is 160 acres (65 ha) in a PSU with 3 random plots per PSU; commonly 3 PSUs are sampled per township stratum.	Variable with scales ranging from 1:600 to 1:5,000 (1:1,000 in this case). Pixel sizes vary from millimeters to about 5 m.
What is the spatial extent of these data?	A number of random PSUs on non-federal rangelands. At last sample in 1992 there were 14,368 NRI points that represented 4 million acres (1.62 million ha) on rangelands nationwide, excluding Alaska.	Very narrow with sampled flight transects. New high-resolution satellite data potentially will be useful over all rangelands in the United States now that 0.6 m pixels are available with the new QuickBird satellite. See: http://www.digitalglobe.com/product/index.shtml. Accessed 6 April 2009.
At what spatial scales can these data be aggregated and reported?	MLRA, state, or national.	Variable from the plant community level to the MLRA or nationwide.
What is the temporal grain of these data?	5 years.	Variable from daily, to seasonally, to annually.
What is the temporal extent of these data?	Every 5 years from 1982 to 1992.	Can be any extent depending on the sampling scheme. Most existing data are not temporally extensive.
At what temporal scales can these data be aggregated and reported?	5 years.	At any temporal scale for which images can be obtained; this is dependent on data acquisition protocols.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Subjective; an estimated level of erosion varying from none-slight, to moderate, to severe, or gullies, concentrated flow, etc.	Very consistent spectral and spatial attributes.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Depends on the experience and training of the estimator.	High quality and excellent repeatability based on geometric and radiometric corrections of the data sets.
Quality: how biased are the sampling methods?	Somewhat biased because they are estimates.	Very objective although some subjectivity is used during interpretation. Image processing of digital data can be highly objective.
Quality: how precise are existing data? (Give standard error, if available)	Somewhat precise, yet the level of precision is based on the experience of the estimators; in practice and with training the estimates are quite repeatable.	Very precise; comparisons of photo interpretations with ground data produced regression coefficients varying from 0.83 to 0.99.
Quality: how valid are existing data?	Valid as reported; in the 1992 sample, it was reported that 30.5% of the non-federal acreage had wind or water erosion that exceeded soil loss tolerances.	Very valid but once again based on the level of interpretation; image-processing techniques will provide greater validity to the data sets.
Quality: how responsive are existing data?	Since the NRI data are somewhat subjective, the value of the data is dependent to a large extent on the experience of trained individuals.	Highly responsive based on careful interpretation and analysis of the photos.
Quality: how much statistical power to detect change does this data set have?	Has not been tested, but the number of samples is sufficient for reasonable statistical power.	High statistical power. With satellite images the statistical power may not be relevant because complete samples can be obtained.

Quality: how well does this data set meet the data needs for this indicator?	Potentially very useful since the data are to be continuously obtained on a 5-year basis.	Quite well depending on the interpretation of the aerial images.
Other comments: (Include any other relevant aspects of the data set that should be included)	Such data sets often are dependent on level of annual funding appropriations available to do these inventories.	This and other remote sensing procedures have very high potential for measuring changes in erosion features on rangelands, but cost would be great for complete sampling of all rangelands in the United States.

Appendix 2-E. Percent of water bodies in rangeland areas with significant changes in aquatic biota assemblage composition.

	Data Set #1
Brief Title for Data Set	Aquatic Invertebrate Assemblage
Contact Person/Agency/Group	BLM National Aquatic Monitoring Center, Utah State University, Logan, UT.
Citation (if published)	Hawkins, C.P., R.H. Norris, J.N. Hogue, and J.W. Feminella. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecological Applications 10:1456-1477.
Website (if available)	http://www.usu.edu/buglab/. Accessed 16 January 2009.
Additional information on data set	Aquatic invertebrate assemblage data for >30,000 samples collected at more than 12,000 sites in the western U.S. More than 80% of the sites are geographically referenced.
For what years are data available, and how often are data collected?	1992 to present.
In what format is the data set available?	Electronic database.
Are data nominal, ordinal, or interval?	The raw data are interval. Data are species composition reported for a sample at a site or for a group of sites across a user-defined region, for example, a county, watershed, state, or ecoregion. Raw interval data can be manipulated and reported as ordinal (e.g., good, fair, poor classes), and nominal (e.g., presence or absence of a particular taxa).
What will be the approximate cost of collecting data?	$800 to $1,200 per site, depending on travel.
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	None; data are public and easily accessible. EPA's national water quality database—STORET, is an example of a public database with this information.
What is the spatial grain of these data?	Individual site data are for a stream reach, typically 100 m in length that characterizes the upstream and upslope watershed. Data can be aggregated to evaluate larger hydrologic units, ecoregions, or political regions. Monitoring units based within similar environmental areas (e.g., similar in elevation, latitude, ground cover, stream size) and under similar management would be expected to respond similarly to management changes.
What is the spatial extent of these data?	Western U.S. predominantly.
At what spatial scales can these data be aggregated and reported?	Subbasin and larger, e.g., ecoregions or physiographic regions (e.g., Great Basin or Colorado Plateau), or political geographic areas such as counties or states.
What is the temporal grain of these data?	Wide variation from seasonal, annual, to single-moment-in-time sampling events. The data appear to have good temporal stability.
What is the temporal extent of these data?	Primarily 1992 to present. Some pre-1992 data are available, but these data were collected using different protocols and these data are often not in electronic format.
At what temporal scales can these data be aggregated and reported?	Most commonly annual, but it depends on the sampling frequency; an analysis of temporal trends across broad landscapes is certainly possible.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, most of the samples were collected and treated similar in the laboratory.

Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Should be high because temporal variability is low for aquatic macro-invertebrate assemblages sampled in areas with absence of human impairment.
Quality: how biased are the sampling methods?	Likely low if sampling methods are consistent. Several studies have shown low variability (error associated with methodology) among different data collectors.
Quality: how precise are existing data? (Give standard error, if available)	Good; quality assurance and quality control studies have shown high precision.
Quality: how valid are existing data?	Data are valid for evaluating impairment of rangeland aquatic habitats across much of the western U.S.
Quality: how responsive are existing data?	Aquatic invertebrate assemblages have been shown to be responsive to many management actions occurring on rangelands.
Quality: how much statistical power to detect change does this data set have?	Very high statistical power based on the size and geographic coverage of the data set.
Quality: how well does this data set meet the data needs for this indicator?	The data set provides a straightforward measurement of the difference between the species expected to occur at a site and those collected.
Other comments: (Include any other relevant aspects of the data set that should be included)	

Appendix 2-F. Percent of surface water on rangeland areas with unacceptable levels of chemical, physical, and biological properties.

	Data Set #1	**Data Set #2**	**Data Set #3**
Brief Title for Data Set	CWA 303(d) list of Impaired Water Bodies	STORET—Storage and Retrieval System for Water and Biological Monitoring Data	National Water-Quality Assessment (NAWQA)
Contact Person/Agency/ Group	EPA Office of Water	EPA Office of Water	USGS National Headquarters, Reston, VA.
Citation (if published)			
Website (if available)		http://www.epa.gov/storet/. Accessed 28 September 2004.	http://water.usgs.gov/nawqa/. Accessed 28 September 2004.
Additional information on data set		STORET is EPA's main repository of water quality monitoring data. It contains water quality information from a variety of organizations, from volunteer watershed groups to state and federal environmental agencies.	
For what years are data available, and how often are data collected?	1998. Lists are updated biennially. States submit lists to EPA on April 1 in even-numbered years.	"Legacy STORET" is the original STORET Water Quality File and has data from 1965 to 1998, but it requires a mainframe user ID and specialized training. STORET Data Warehouse was created to replace Legacy STORET and has data from 1999 to present. The system is refreshed with new data at the end of each month. Data are submitted to STORET from the monitoring groups at varied rates (that is, monthly, quarterly, etc.).	1991 to present. Data are typically collected monthly. The rest of the data are synoptic.
In what format is the data set available?	State lists designate water bodies that fail 1 or more standard(s) and list the water quality parameter(s) that fail to achieve standards. States are directed to identify the location of impaired waters. EPA's Reach File Version 3.0 is a database that identifies and provides a unique address for 3.2 million stream segments.	STORET Data Warehouse uses a UNIX/Oracle database server, and its contents may be browsed or downloaded by the public using a standard web browser such as Netscape.	Computer databases generally employing the Oracle format.

Are data nominal, ordinal, or interval?	Nominal—water bodies that fail to meet standard(s).	Mostly interval data with some ordinal data—monitoring site location data, water quality parameter data, and biological data and index results.	Mostly interval data, that is, continuous random variables.
What will be the approximate cost of collecting data?	Unknown.	A multi-million dollar federal, state, local, tribal, and private water quality monitoring program.	$63 million annual appropriation, and approximately $700 million over the life of the USGS NAWQA Program. $7.2 million is spent on each study unit over their 10 year life (in total).
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	Available for public use.	Data from 1999 to present are available on EPA's website. Older data require mainframe ID and special training.	Access to Internet.
What is the spatial grain of these data?	Water bodies, first order streams.	All national water bodies from first order streams to rivers including lakes, reservoirs, wetlands, and estuaries.	Water bodies down to the 10 digit Hydrologic Unit Code (that is, watersheds) of the USGS.
What is the spatial extent of these data?	National; however, agencies have great latitude in deciding what water bodies are impaired.	National; however, agencies and organizations inputting into the system have a great deal of flexibility on what parameters they monitor and how they conduct the monitoring, making aggregation to the national level difficult if not impossible.	Limited to 59 major river basins in 1991, 52 basins in 1997, and 42 basins in 2001. In 2001, 13 study units were eliminated. Study areas were selected to focus on the nation's most important river basins, that is, those supplying drinking water and irrigation, under a 10-year study cycle. So coverage is limited for rangelands.
At what spatial scales can these data be aggregated and reported?	National; however, there is no explicit assessment protocol for determining water quality impairment.	Most of the parameter data are collected for regulatory or compliance objectives, and use for local assessment is appropriate. Aggregating to watershed, regional or national level will be difficult and possibly not appropriate.	National.
What is the temporal grain of these data?	Two years.	Daily, monthly, and quarterly monitoring depending on the monitoring station and type of water quality parameter.	Continuous, daily, and monthly depending on the parameter or constituent.
What is the temporal extent of these data?	1998 to present.	Realistically, 1999 to present.	The period of record for NAWQA data is 1991-present; however, the period of continuous record for select water quality data is in 3-year intervals.

At what temporal scales can these data be aggregated and reported?	Two years.	Monitoring design is for regulatory objectives, not for developing time series. Reporting over time will be difficult if not impossible.	Annually.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Jurisdictional variation in methodology used to determine impairment and listing. Individual jurisdictions have latitude in interpretation of data, types of data used, threshold selection, and monitoring methods.	Not at the present time.	Yes. Whereas each basin study includes core water quality parameter data, each basin study is tailored to water quality issues within the study unit. Data are collected and analyzed using consistent methodology.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	NA	Parameter data that go into the STORET Data Warehouse must meet EPA QA/QC guidelines; repeatability is 1 of those requirements.	Yes, they are repeatable and they are also verifiable.
Quality: how biased are the sampling methods?	NA	NA	They are basically unbiased. That is a key objective of the design and implementation of NAWQA study units.
Quality: how precise are existing data? (Give standard error, if available)	NA	NA	Very difficult to answer. Consider that in Fiscal Year 2004 alone there were 155 sampling stations, which involved the measurement of tens of thousands of water quality constituents. The question is only meaningful in terms of a specific constituent record.
Quality: how valid are existing data?	Some water bodies on state lists were placed there without the benefit of adequate water quality standards or data.	Parameter data in the STORET Data Warehouse are valid.	Very difficult to answer. Consider that in Fiscal Year 2004 alone there were 155 sampling stations, which involved the measurement of tens of thousands of water quality constituents. The question is only meaningful in terms of a specific constituent record.
Quality: how responsive are existing data?	Not very responsive. Lists reported biennially.	Water quality parameter data are responsive at local assessment areas.	Not very responsive except where the data are being measured on a continuous temporal scale.
Quality: how much statistical power to detect change does this data set have?	NA	NA	NA

Quality: how well does this data set meet the data needs for this indicator?	As a gross indicator that water quality problems exist it has value. As an indicator of rangeland sustainability in a region it is not specific or responsive enough.	It is unlikely that STORET will provide timely and consistent reporting of the key water quality parameters applicable to rangelands.	Very well. These data are collected so that use attainability analyses can be determined for waters in the involved study unit.
Other comments: (Include any other relevant aspects of the data set that should be included)			The closest parallel database in USGS to STORET is the National Water Information System (NWIS), which is 1 of several data sets used within the NAWQA Program. It may be that the name of the data set here should be NWIS rather than NAWQA because NAWQA is a bit broader than just a data set. NAWQA data address both surface and groundwater quality.

Appendix 2-G. Changes in groundwater systems.

	Data Set # 1
Brief Title for Data Set:	Changes in Groundwater Systems
Contact Person/Agency/Group (email, phone, address):	The project chief for the Southwest groundwater study is Stanley A. Leake, saleake@usgs.gov, at the Tucson office of the Arizona District, USGS. The study area includes aquifer systems in the arid to semiarid basins in the southwestern states of California, Nevada, Utah, Arizona, and New Mexico; USGS (see website below).
Citation (if published):	Alley, W.M., R. W. Healy, J.W. LaBaugh, and T. E. Reilly. 2002. Flow and storage in groundwater systems. Science 296:1985-1990.
Website (if available):	http://waterdata.usgs.gov/nwis/gw. Accessed 6 April 2009.
Additional information on data set:	Measurements of changes in well depth, spring discharge, and other variables can be done very accurately although not a lot of data are available for many watersheds on western rangelands.
For what years are data available, and how often are data collected?	Variable, but many wells are measured every year, often more than once per year.
In what format is the data set available?	Depth of well above mean sea level and depth of water in the well in feet.
Are data nominal, ordinal, or interval?	Interval.
What will be the approximate cost of collecting data?	For well depth data from 850,000 sites in the United States the data are free; developing relationships with range vegetation parameters may be costly.
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	The cost of relating groundwater data or spring discharge data to changes in the rangeland vegetation may be somewhat difficult and take a number of years. Some of the well data are 30 to 40 years old or more.
What is the spatial grain of the data?	The groundwater site inventory of the USGS consists of more than 850,000 records of wells, springs, test holes, tunnels, drains, and excavations in the United States. Available site descriptive information includes well location information (latitude and longitude, well depth, site use, water use, and aquifer). See http://waterdata.usgs.gov/nwis/gw. Accessed 6 April 2009.
What is the spatial extent of the data?	Numerous wells in each state and hydrological region.
At what spatial scales can these data be aggregated and reported?	Primarily by hydrological region and/or drainage basin.
What is the temporal grain of the data?	Once or twice per year or more often.
What is the temporal extent of the data?	Variable; some wells have long term records while others are quite limited with only 1 or 2 years of data.
At what temporal scales can these data be aggregated and reported?	Annually or semiannually. Under natural conditions, the travel time of water from areas of recharge to areas of discharge can range from less than a day to more than 1 million years (Bentley et al. 1986).
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, all measurements of well depth are in feet.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Repeatable. Meaningful trends are best provided over relatively long time periods, probably decades of measurement.
Quality: how biased are the sampling methods?	Unbiased.

Quality: how precise are existing data? (Give standard error, if available)	Precise.
Quality: how valid are existing data?	Quite valid.
Quality: how responsive are existing data?	Responsive in certain hydrologic units.
Quality: how much statistical power to detect change does this data set have?	Reasonable especially where there may be several wells representing an area of rangeland and/or floodplain with forage.
Quality: how well does this data set meet the data needs for this indicator?	Only partly; the fluctuations in well data must eventually be related to phreatophytic or other vegetation on rangelands.
Other comments: (Include any other relevant aspects of the data set that should be included.)	Data are scarce on springs and their discharge; such data would be important as rangeland vegetation and management changes. This is likely a very important potential indicator over the long term and is of intense interest in the west on rangelands. Much of the concern is at the urban fringe where many new wells are being drilled for culinary water causing a mining or potential mining of the water table.

Appendix 2-H. Changes in the frequency and duration of surface no-flow periods in rangeland streams.

	Data Set #1
Brief Title for Data Set:	USGS Surface-Water Data for USA
Contact Person/Agency/Group (email, phone, address):	USDI USGS, http://waterdata.usgs.gov/nwis/feedback. Accessed 15 January 2009
Citation (if published):	Slack, J.R. and J.M. Landwehr. 1992. Hydro-climatic data network (HCDN): a U.S. Geological Survey streamflow data set for the United States for the study of climate variations. U.S. Geological Survey, Open-File Report 92-129.
Website (if available):	http://waterdata.usgs.gov/nwis/sw, Accessed 15 January 2009
Additional information on data set:	Data are retrieved by category, such as surface water, groundwater, or water quality; and by geographic area. Of the 1.5 million sites with data, 80% are wells; 350,000 are water quality sites; and 19,000 are streamflow sites, of which more than 5,000 are real-time.
For what years are data available, and how often are data collected?	Years of data availability depend on the site (stream gauge). The earliest data were collected in 1857. Real-time data on streamflow in ft^3/sec typically are recorded at 15-60 min intervals, stored onsite, and then transmitted to USGS offices every 4 hours. Recording and transmission times may be more frequent during critical events. Data from real-time sites are relayed to USGS offices via satellite, telephone, and/or radio and are available for viewing within minutes of arrival.
In what format is the data set available?	Data can be presented in graph or table form. Streamflow data for the United States and Puerto Rico are presented in map form also, for these objectives: 1) showing real-time streamflow comparisons to historical on a daily basis using point data (individual stream gauges); 2) showing monthly-average streamflow comparisons to historical, on a hydrologic unit basis.
Are data nominal, ordinal, or interval?	Streamflow is a continuous variable, can be measured, and can be analyzed and reported in various ways. Streamflow measurements can be reported as interval data in graphs or tables. Map data are reported as percentile classes, which are then converted to nominal categories (dry, normal, and wet).
What will be the approximate cost of collecting data?	
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	Information presented on the website is considered public information and may be distributed or copied. USGS strongly recommends that data be acquired directly from a USGS server and not through other sources that may change the data in some way.
What is the spatial grain of the data?	Stream gauge, point data.
What is the spatial extent of the data?	The streamflow data are collected across all 50 states and Puerto Rico. Within state, spatial extent varies, with some states having few stream gauges and none in certain sections of the state, and other states having numerous stream gauges well dispersed.
At what spatial scales can these data be aggregated and reported?	Heinz (2002, 2008) performed data analyses of streamflow data at stream gauges by subbasin, with subsequent aggregation and reporting of the data at 3 divisions of Bailey's ecoregions. Reporting by aggregation of streamflow data by hydrologic units, to the national level, can be seen online. Streamflow data can be reported as point data, too.

What is the temporal grain of the data?	As short as 15 min.
What is the temporal extent of the data?	Temporal extent of the data varies by individual stream gauge.
At what temporal scales can these data be aggregated and reported?	Users of the website can view daily streamflow data by stream gauge in graph or table form, daily streamflow statistics, monthly streamflow statistics, and annual streamflow statistics. Heinz (2002, 2008) opted for different approaches and analyzed data and reported daily streamflow data by averaging to decadal increments (Heinz 2002) and 5-year increments (Heinz 2008) to show trend.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	
Quality: how biased are the sampling methods?	
Quality: how precise are existing data? (Give standard error, if available)	All real-time data are provisional and subject to revision. Recent data provided by the USGS in the United States—including stream discharge, water levels, precipitation, and components from water quality monitors—are preliminary and have not received final approval. Most data relayed by satellite or other telemetry have received little or no review. Inaccuracies in the data may be present because of instrument malfunctions or physical changes at the measurement site. Subsequent review may result in significant revisions to the data.
Quality: how valid are existing data?	
Quality: how responsive are existing data?	Because the temporal grain of streamflow data can be as short as 15 min, data can rapidly show a response. However, this only explains the responsiveness attributable to temporal grain. Therefore, although streamflow response can be detected from a visual perusal of data (for example, from a graph of trend), the responsiveness of streamflow data to management changes or climate or weather is not interpretable in the data set.
Quality: how much statistical power to detect change does this data set have?	
Quality: how well does this data set meet the data needs for this indicator?	The data set meets the data needs for this indicator very well if data are continually collected with no interruption. However, data collection at stream gauges is dependent on sustained funding, which is not a certainty for all stream gauging stations.
Other comments: (Include any other relevant aspects of the data set that should be included.)	