CHAPTER II

Indicators for Soil and Water Conservation on Rangelands

INTRODUCTION

Soil and water provide the media 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 a soil phase 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 has been 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.

The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion, defined as a category of conditions or processes that can be assessed to determine if the current level of rangeland management will ensure 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 assess change. Indicators are quantitative or qualitative variables that are assessed in relation to a criterion. An indicator describes attributes of the criterion in an objective, verifiable, and unambiguous manner, and it is capable of being estimated periodically 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 reflect directly the conservation of soils on rangeland sites, whereas the water indicators will reflect the conservation of water as it flows through rangelands. This is an important distinction because changes of status for indicators of soil resources will be measured directly on rangeland sites and will reflect impacts made directly on rangelands, whereas changes of status for indicators of water resources would be measured on rangelands but might reflect impacts occurring on non-rangeland sites (e.g. forest, agricultural, or urban lands). These impacts can influence the availability or quality of water resources for sustaining rangeland resources (social, economic, and ecological) even though they may not be direct impacts of rangeland uses on water resources.

The indicators are the outcome of an evaluation of the conservation and maintenance of soil and water resources indicators identified in the Roundtable on Sustainable Forests (RSF), as well as pertinent indicators from The H. John Heinz III Center (2002) and our identification of new indicators that pertain specifically to rangeland sustainability. We evaluated the eight RSF soil and water indicators for their relevance to rangelands, using information from Neary et al. (2000). Based on this evaluation, we retained five of the RSF soil and water indicators (Table 2-1).

We applied a consistent set of questions to each indicator. The questions focus on: (1) what is the indicator, (2) what does the indicator measure and why it is important to rangeland sustainability, (3) geographic variation of the indicator, (4) the degree of meaning of the indicator at various spatial and temporal scales, (5) the availability and quality of data sets, and (6) how well stakeholders understand the indicator. Answers to these questions are presented, by indicator, after Table 2-1.

Table 2-1. The 10 soil and water resources indicators identified by the Soil and Water Resources Criterion Group of the Sustainable Rangelands Roundtable (SRR).

Indicators	Originated with Roundtable on Sustainable Forests and retained in SRR?	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	Yes	Soil productivity, infiltration, nutrient content, nutrient availability, nutrient cycling, carbon sequestration, resistance to erosion.
Area and Extent of Rangelands with Changes in Soil Aggregate Stability	No, a new indicator identified by SRR	Resistance to erosion by water and wind, soil water availability, root growth.
Assessment of Microbial Activity in Rangeland Soils	No, a new indicator identified by SRR	Soil productivity, decomposition, nutrient content, nutrient availability.
Area and Percent of Rangeland with a Significant Change in Extent of Bare Ground	No, a new indicator identified by SRR	Erosion potential, aboveground vascular plant productivity.
Area and Percent of Rangeland with Accelerated Soil Erosion by Water and Wind	Yes	Soil loss by water or wind, soil productivity.
Water-based		
Percent of Water Bodies in Rangeland Areas with Significant Changes in Natural Biotic Assemblage Composition	Yes	Water quality and aquatic habitat conditions.
Percent of Surface Water on Rangeland Areas with Significant Deterioration of their Chemical, Physical, and Biological Properties from Acceptable Levels	Yes	Water quality.
Changes in Groundwater Systems	No, a new indicator identified by SRR	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	Yes, but modified to focus on no-flow periods	Aquatic and terrestrial biodiversity, watershed functioning.
Percent Stream Miles in Rangeland Catchments in which Stream Channel Geometry Significantly Deviates from the Natural Channel Geometry	No, a new indicator identified by SRR	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.

CURRENT STATUS OF INDICATORS

Soil-Based Indicators

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

Importance: What does this indicator measure and why is it important to sustainability? 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 its potential for biological decomposition. Soil organic carbon provides many benefits to the soil and is associated with the productive potential of soils and soil sustainability. Soil organic carbon: (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 the 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 negative environmental effects of pesticides, heavy metals, and other pollutants by actively trapping or transforming them (USDA, Natural Resources Conservation Service, 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 are 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 and hence less nutrient cycling, whereas soils with a C:N ratio of $\leq$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 variation and scale: Is this indicator meaningful in different regions? 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, attributable 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 C_3 grass-dominated plant communities to C_4 grass-dominated plant communities, result in greater root:shoot ratios and greater C:N ratios (Schuman et al. 1999). Shifts from a C_3-dominated to a C_4-dominated plant community generally reflect an increase in soil C because C_4 species tend to transfer more energy to belowground plant parts (Coupland and Van Dyne 1979, Frank et al. 1995). Climate affects rangeland productivity, which directly influences soil organic matter levels. For example, tallgrass prairie will have greater soil organic matter levels compared with shortgrass prairie, because of the greater contributions of litter and root biomass attributable to the greater productivity. Climate also affects decomposition rates which influences soil organic matter levels.

Soil organic matter and its C:N ratio also can reflect temporal changes attributable to changes in management. Temporal changes in soil organic matter and C:N ratios can take many years to be detectible, subsequent to the changes in vegetation and litter inputs. Spatially, soil organic carbon 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 carbon; however, baseline-sampling sites can be established to assess change over time and space.

Data. Methods of assessing soil organic matter and C:N ratios are available and are adaptable to the regional and national level. 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 is generally reported as soil organic carbon, rather than vice-versa. 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 change in soil organic matter.

Methods of sampling to assess soil organic carbon generally involve collection of soil samples for laboratory evaluation and are generally used both regionally and nationally. However, 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 reflect adequately the soil organic carbon in surface soils at 0-5 cm depth because: (1) changes in soil organic carbon occur more rapidly in the 0-5 cm depth from management and management changes; and (2) 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 mass basis rather than a 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 USDA-Agricultural Research Service has recently initiated a national research program called GRACEnet (Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network) to assess the effects of management on soil organic carbon stocks on croplands, rangelands, and forestlands. Sampling protocols are being developed for soil sampling, soil carbon assessment, trace gas emissions, and data presentation through GRACEnet. Whereas 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 for determination of soil organic carbon which routinely includes nitrogen analyses. In general, soil organic carbon and nitrogen data are limited for rangelands compared with croplands.

Clarity: Do stakeholders understand the indicator and indicator unit? 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 how they relate to litter decomposition and nutrient cycling.

Area and Extent of Rangelands With Changes in Soil Aggregate Stability

Importance. Soil aggregates are groups of soil particles that are bound to each other more strongly than to adjacent soil particles. Aggregate stability refers to the ability of aggregates to resist degradation (USDA, Natural Resources Conservation Service, 2001b). Repeated measurements of soil aggregate stability can indicate the degree to which resistance to erosion by water and wind is changing.

Stable soil aggregates are critical to erosion resistance, water availability, and root growth. 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 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 Natural Resources Conservation Service, 2001b).

This indicator may provide an early-warning indicator of erosion. We anticipate that changes in soil aggregate stability would occur before significant erosion would be detected over large areas. 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).

A field soil aggregate stability kit (Herrick et al. 2001c) now allows measurements without having to transport soil samples to the laboratory. Changes in soil aggregate stability can be caused by land management practices and by changes in plant community composition, and therefore soil aggregate stability is sensitive to changes in land management and plant community composition (Herrick et al. 2001c).

Geographic variation. Soil aggregate stability measurements appear to be meaningful across regions. Herrick et al. (2001c) have evaluated the field soil aggregate stability kit over a wide range of agricultural and natural ecosystems throughout North America, including northern Mexico, and found the method to be sensitive to differences in management 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 and extremely sandy soils in which there is little formation of aggregates larger than 1.5 mm in diameter even under good conditions. The method has been evaluated and adopted for use in agricultural soils in Illinois, in a citizen soil-quality-monitoring program.

Evaluations by Herrick et al. (2001c) provide evidence that soil aggregate stability methodology is applicable in different regions. An inference that can be made 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 in regard to rangeland sustainability as a change detected in any other region.

Scale. Soil aggregate stability is meaningful at the site (ecological site, range site, or soil series) scale. At the site scale, differences in soil properties have been detected for areas beneath shrubs and areas in shrub interspaces (Herrick and Whitford 1995), helping to explain desertification processes.

In comparison, there appears to be less certainty of the meaningfulness of this indicator at spatial scales larger in geographic extent than the site scale. Aggregate stability varies widely across a variety of scales (Pierson et al. 1994) and soil textures (Herrick et al. 2001c). Much variability in soil stability is typical for rangeland and can be attributed to spatial variability in organic matter inputs and aggregation and degradation processes (Herrick et al. 2001c). 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. Yet, Herrick and Whitford (1995) state that the spatial and temporal scale and pattern of variation in surface soil characteristics, such as soil aggregate stability, may be a good indicator of the capacity of a system to retain resources. Herrick and Whitford (1995) recommend a spatially stratified sampling approach to minimize the spatial variance associated with measuring soil properties.

Aggregate formation varies temporally, largely attributable to the timing of precipitation and the resultant soil moisture levels. The timing and amount of precipitation received affect soil moisture levels, which affect biological activity and physical processes such as frost heaving. Biological activity and physical processes like frost heaving affect aggregate formation (Herrick and Whitford 1995). Given the responsiveness of aggregate formation to weather and precipitation, soil aggregate stability measurements will vary temporally. Repeated sampling will need to be stratified, preferably during times of similar weather conditions and soil moisture levels.

Data. Standardized methods and procedures for data collecting and reporting exist at the regional-national level, but useable data set(s) do not exist at the regional-national level (see data matrix in Appendix 2-1 for more detail).

Clarity. Soil aggregate stability is not 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 indicator before significant erosion occurs. Stakeholders understand the value of reducing soil erosion.

Assessment of Microbial Activity in Rangeland Soils

Importance. Soil microbial organisms are important contributors to decomposition, nutrient cycling and a major byproduct of these components is the incorporation of organic material into soil thereby aiding soil infiltration and 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 a measure of general biological activity. Microbial respiration is a surrogate for assessment of potential nutrient cycling, and soil organic matter dynamics. 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.

Based on the above, this indicator is closely associated to the soil organic matter indicator. However, 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 moisture and carbon already in the soil, or moisture and carbon inputs.

Geographic variation. 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. However, the relationships between this indicator and standardized methods of assessing microbial activity and biomass imply that this can be used as a surrogate indicator of nutrient cycling potential and soil 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 the system is being degraded through reduced carbon inputs or severe climatic factors. Since this indicator is assessed under optimal temperature and moisture conditions, we must keep in mind that it is telling us the soil's microbial potential.

Scale. This indicator will exhibit large spatial and temporal variation. 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. This indicator is conceptually feasible for assessing microbial status of rangeland soils, but no regional-national methods or data sets currently exist. Despite the lack of regional to national level methods, methods do exist for measuring soil microbial respiration as a proxy for soil biological activity. Recent research has resulted in the evaluation of a "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).

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, which ensures a common baseline and enables 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 and condition. Data that are available likely represent small plot research and were collected using standardized methods.

Clarity. 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

Importance. Although bare ground is often defined as non-vegetated areas, bare ground as defined in this document is exposed mineral or organic soil that is susceptible to raindrop splash erosion, which is the initial form of most water-related erosion (Morgan 1986). Increases in the amount of bare ground and reductions in the fragmentation of the 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). As bare ground area increases, soil becomes increasingly susceptible to raindrop impacts that may dislodge soil particles and begin the erosion process. The distribution of the bare ground is also important, since the same area of exposed bare ground spread among a large number of small patches (high fragmentation) is less susceptible to soil movements off a site than large patches (low fragmentation) where the velocity of soil movement by water or wind may increase. Prevalence of bare ground on U.S. rangelands is detected often around watering points, fence corners, and other high-use areas such as off-road vehicle use areas. Internationally, soil erosion is a common occurrence on degraded lands and often leads to desertification (UNEP 1990).

On many rangelands, little true bare ground exists because litter, rock, gravel, and biological soil crusts cover the non-vegetated areas; however, the expected amount and distribution of bare ground will vary among soils of differing parent material, texture, and age. For example, badland soils of South Dakota inherently have high amounts of bare ground, whereas soils associated with black grama grasslands of New Mexico would typically have low amounts of bare ground. Thus, it is important to relate this measure to the expected amount of bare ground for each specific soil unit (for example, a soil series).

Geographic variation. This indicator is meaningful in different regions. However, for it to be meaningful the natural range of variation in the extent of bare ground must be established for a given area. The soil series might be the ideal unit for determining the expected amount and distribution of bare ground. Other units might include ecological sites or vegetation communities such as habitat types that incorporate factors such as climate, aspect, vegetation potential (for example, shrubland, shrub-steppe, grassland), geology, and slope into their descriptions.

There is no regional pattern for bare ground. Rather, there is, depending on the soil and vegetation type, a "normal" amount of bare ground for a given ecological site. Changes from this "normal" can be construed as an indication of some impact.

Scale. This indicator is useful and sensitive over most spatial and temporal scales. Depending on measurement technique, it is meaningful over linear and area measures. Bare ground data collected at local areas are not easily extrapolated to and reported over larger geographic areas without an adequate sampling design. Bare ground data collected through remote sensing techniques suffer currently from inaccuracies due to pixels containing a mixture of bare ground, vegetative cover, and other attributes such as rock, gravel, litter, and soil biological crusts that are difficult to impossible to discriminate. These inaccuracies pertain to the absolute amount of bare ground area estimated for a given area at one moment in time. These inaccuracies are less problematic if we are interested in temporal changes in vegetation cover that may relate directly to changes in bare ground area, where we delineate the exact area, use the same method over each area at each time, and subsequently compute the difference in bare ground area. Regardless of technique, 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).

Data. Some data set(s) exist at the regional-national level, but methods and procedures are not standardized at the regional-national level. Most currently available data sets do not measure bare ground using the strict definition we used above; they should be considered as an initial approximation until better techniques or measures are found. For example, the NRCS Rangeland National Resources Inventory will use our strict definition in the rangeland bare ground beginning in 2003. The data sets exist as two types: *ground data* using various methods and *remote sensing* data. We list two potential data sets that currently exist: the National Resources Inventory and various remote sensing formats (see data matrix in Appendix 2-1 for more detail).

Ground data--Many agencies and groups have collected vegetation data using various methods on numerous sites. The protocols for these data collections have often included measurements of bare ground. Unfortunately these data are widespread, are site specific, lack adequate sampling designs for regional or national aggregation, and do not have an estimated natural range of variation to serve as a standard upon which to gauge change.

A potential source for obtaining the natural range of variation for bare ground is the USDA Natural Resources Conservation Service's individual soil pedon data for recent surveys. These data are collected and stored in the NASIS (National Soil Information System). Aggregated data for soil map units and taxonomic units are stored in NASIS and available through the SSURGO (Soil Survey Geographic) database for digitized surveys. These data include soil surface features such as stones, cobbles, and gravel. The NRCS ESIS (Ecological Site Information System) database, http://plants.usda.gov/esis/index.html, contains information on vegetation cover for each ecological site description and ESIS will include in the future expected variation of bare ground for ecological sites.

Pyke et al. (2002) state that a quantitative protocol could be developed using line-point measurements. This technique is proposed for use by the NRCS in the National Resources Inventory for rangelands beginning in 2003 (Spaeth et al. 2003).

Most military reservations within the United States have Land Condition and Trend Analysis (LCTA) data. These data are site-specific, include data on bare ground, and are collected with line intercept methods. However, these data are very site-specific and do not represent a national or even a regional data set.

Remote sensing data--All techniques fail currently to measure bare ground using the definition we believe is necessary to use bare ground as an indicator for soil conservation. Theoretically, bare ground could be measured using remote sensing technology; but factors such as biological soil crusts, soil moisture content, amount of litter, and amount of organic matter reduce classification accuracy of a remote sensed bare ground category. Though additional research is needed to address this limitation, there has been some 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, whereas a silty-textured soil's spectral curve climbs more steeply and has a much greater reflectance particularly at mid-infrared wavelengths above 1.7 micrometers. 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, therefore heavily vegetated areas 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. (However, this is somewhat simplistic because of the confounding classification factors mentioned previously.) The results of such studies do describe increases in bare ground associated with land degradation.

Without partitioning these confounding classification factors, 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), but these do not adhere to our strict definition for bare ground. 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 (commercial satellite system provided by Space Imaging, Inc., Thornton, CO) data, to 5 m pixel IRS satellite data. Recent work with very large-scale (fine-grained) data also shows promise (Booth et al. 2003). 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 will 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 IFSAR (Interferometric Synthetic Aperture Radar) systems may provide new data that will be useful to evaluate bare ground. To provide accurate data on bare ground extent with hyperspectral data and other remote sensing data, one must obtain reliable and adequate ground data upon which to base classification accuracy.

<u>Clarity</u>. 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

<u>Importance</u>. 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). Upper soil horizons typically contain the highest organic matter and nutrient content therefore this component of the soil generally controls the rate of water infiltration, plant establishment, and growth (Wood et al. 1997). Excessive erosion can contribute soil sediments to waterways thereby reducing the quality of water for animal consumption or for aquatic organism survival.

Since 1945, UNEP (1990) estimates that 11 percent (1.2 billion ha) of Earth's vegetated soils 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 #1 contributor to declines in human civilizations over the last 7,000 years (Lowdermilk 1953), which points to the importance of monitoring soil erosion rates as an indicator of rangeland sustainability and the sustainability of human civilizations associated with rangelands.

The intent of this indicator is to identify areas where erosion is greater than expected for the soils on a specified site. It is not to 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 variation. 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 and 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. This indicator is applicable at various spatial and temporal scales. Its applicability depends on the kind of soil involved and the ability to measure rills and gullies, provide evidence of interrill erosion, and measure soil movement through the air. Rill erosion is caused by concentrated runoff water flowing over the soil, whereas interrill (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 extent landscapes 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. 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. 2000). 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 resulting from disturbance, ecologically important changes in runoff and erosion can result (Reid et al. 1999).

Wind erosion and transport of surface materials depends on the strength of the wind, the soil surface texture, and the surface protection materials including rocks, biological soil crusts, and vegetation. Surface texture is an important key to wind erosion hazard potential. Loamy sand and sand, characterized by particles ranging between 50 and 2,000 microns 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 hence 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. Because wind erosion physically removes soil particles and organic matter near and at the soil surface, and because soil fertility (for example, nitrogen and phosphorus) decreases with decreases in organic matter content (Foth 1984), wind erosion can lessen soil productivity. Soil particles can enter suspension and become part of the atmospheric dust load. Dust obscures visibility, pollutes air, and fills road ditches and the result can be 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-national level, but useable data set(s) do not exist at the regional-national level (see data matrix in Appendix 2-1 for more detail). However, on natural rangelands 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 potentially can 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.

Clarity. 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 tutoring over time.

Water-Based Indicators

Percent of Water Bodies in Rangeland Areas With Significant Changes in Natural Biotic Assemblage Composition

Importance. Measurements of vegetation assemblages (plant composition) have a long history of use as indicators of rangeland condition and trend in condition (Stoddart et al. 1975). These indicators have traditionally been based on the comparison of a given area's plant composition at a given moment in time to the plant composition that the area is capable of supporting at its potential. Downward trends in rangeland condition, or rangeland health if other attributes besides vegetation are considered (National Research Council 1994), can be associated with declines in water quality, aquatic and riparian habitats, and the ability of aquatic habitats to support native biota. Aquatic native biota assemblages can shift away from that which would be expected to occur under natural, unimpaired hydrologic conditions (Karr 1991, Hawkins et al. 2000), leading to changes in aquatic system balance, such as predator-prey dynamics, nutrient cycling, and exotic species invasions. Species that are sensitive to a particular pollutant or habitat change will decline in numbers or disappear completely, whereas other species might benefit from these habitat changes and their populations will increase.

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), a change 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, identification, and the relatively high degree of ecological understanding that exists for this group of organisms. A monitoring program built on changes in aquatic macroinvertebrate assemblages is 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 variation. 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). To effectively measure impairment to aquatic systems, we need a way of expressing the degree to which observed species composition differs from expected species composition at individual sites and across larger geographic regions. Local site comparisons are needed to assess local management actions whereas regional comparisons are important for understanding the overall effect local management actions are having across a much larger area, for example throughout the Great Basin.

The basis for making these comparisons is an accurate measure of habitat conditions and biotic assemblage composition at minimally disturbed sites that represent the range of natural habitat conditions that occur throughout a region, that is, an extensive network of reference sites. 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. Comparisons of observed to predicted species occurrences can provide a meaningful measurement of the degree of impairment at local and regional scales. Site-specific measures can be aggregated to 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, 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 with these data by correlating trends in assemblage changes with local and regional human-altered environmental factors or known contaminants.

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. 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 does 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. Standardized methods and procedures for data collecting and reporting for aquatic macroinvertebrate assemblages exist at the regional-national level, and useable data set(s) exist at the local and regional levels (see data matrix in Appendix 2-1 for more detail).

Clarity. One objective for resource monitoring is to determine the health or degree of impairment of a site or region relative to unimpaired sites. The ratio of the aquatic macroinvertebrate taxa collected at a site to that expected is a direct measurement of this relationship and an easily understood concept. A ratio of 0.5 indicates that 50 percent of the species predicted to occur at a site were not found, thus this site has lost its ability to support 50 percent of the species that should occur there. Similarly these data could be reported as a 50 percent loss in natural biodiversity at this site. These data also lend themselves to good, fair, or poor class categorization based on statistical properties of the data distribution within a region or a priori decisions as to the percentage of taxonomic change that is considered acceptable. This ratio also provides a benchmark by which restoration goals can be set and evaluated over time.

Percent of Surface Water on Rangeland Areas With Significant Deterioration of Their Chemical, Physical, and Biological Properties From Acceptable Levels

Importance. 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, including their lakes and reservoirs. A water body segment is a bounded part of a stream, river, lake or reservoir that is regulated by a common set of water quality standards. To establish these standards, states and tribes identify designated uses (for example, drinking water, recreational, agricultural) for each of their water segments, and then set water quality criteria to ensure protection of its chemical, physical, and biological integrity. A water quality criterion is represented by a deterioration threshold, established for an important water quality parameter (for example, dissolved oxygen, or pH, or temperature, or heavy metals) for an individual water segment. 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 of our nation’s waters are excess nutrients (nitrogen and phosphorus), sediment/siltation, pathogens, and metals. EPA’s National Water Quality Inventory 2000 Report states that approximately 40 percent of the nation’s assessed streams are impaired, http://www.epa.gov/305b/, 03-22-2003). 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. Water quality is important to rangeland sustainability because wildlife, recreation, livestock, downstream water users, and others depend on clean water, particularly in arid and semi-arid rangelands.

Geographic variation. Water quality standards will vary geographically. For a particular water body, the water quality parameters which are deemed important, and the appropriate criteria or thresholds, will depend on a number of factors such as climate and weather, physical, chemical, and biological properties, as well as designated uses. Also, states and tribes consider natural ranges of variation when designating uses and developing water quality criteria. Water quality impairment assessments are local decisions because our nation’s waters do not naturally exhibit the same characteristics, for example the ability to support a cold-water fishery. 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.

Scale. States and tribes have flexibility on how they determine designated uses, what water quality parameters to monitor, what monitoring methods to use, and what methods are used to assess water quality impairment. Also, to meet management and compliance objectives, most water quality monitoring is conducted at “fixed” stations, and the resultant data is not necessarily representative of the whole water body or watershed. Consequently, scaling water quality parameter data up to a regional or national reporting level would be very difficult, as would be assessing regional or national trends of important water quality parameters. However, the Section 303(d) impairment lists, updated by the states and tribes using the local water quality data, provide information nationally of deteriorated water quality and its causes. Reporting of Section 303(d) lists began in 1998, and the 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 system, STORET (not a true acronym; stands for Water Quality Storage and Retrieval System).

Data. Under Section 305(b) of the Clean Water Act, EPA, other federal agencies, states and tribes are to monitor the Nation's waters for important water quality parameters and are to report that information into EPA's national water quality database—STORET. Additionally, a National Water Quality Inventory is required biennially, which is a report that summarizes water quality reports submitted by states, territories, interstate commissions, and tribes. For reasons stated above in the Scale section, this report cannot be used as a regional or national assessment or for national trends in water quality. Also required is a biennial Section 303(d) list of impaired waters. These impaired waters are required to develop a TMDL (total maximum daily load). TMDL is a calculation of (1) the maximum amount of a pollutant that a water body can receive and still meet water quality standards and (2) an allocation of that amount to the pollutant's sources. This is probably the best information we have on impaired water quality, so initially it should be the data source for this water quality indicator.

Another potentially useful data source is the USGS (United States Geological Survey) National Water Quality Assessment (NAWQA) program. To help support local decision makers in developing TMDL's and to provide long-term, nationwide information on water quality, the USGS's 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, and include a broad list of physical, chemical, and biological measures including stream flow and stream habitat, water, sediment, and tissue chemistry, and 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. For all data sets discussed here, see more detail in the data matrix in the Appendix 2-1.

Clarity. The concept of a water body achieving or failing a water quality standard is an easily understood concept to stakeholders.

Changes in Groundwater Systems

Importance. Groundwater has a direct connection with social, economic and ecological sustainability of rangelands (Alley et al. 2002). Solley et al. (1998) estimates that 96 percent of the rural domestic supply of water comes from groundwater systems. 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 deep groundwater and shallow water tables (Taylor and Alley 2001). Drops in groundwater levels may eventually impact stream flows in two common ways: (1) through water moving from the stream into the groundwater system to compensate for removals made elsewhere in the system and (2) through input reductions at seeps, springs, and wetlands (Alley et al. 1999).

Water-level monitoring of wells remains the best method for assessing fluctuations in groundwater levels (Taylor and Alley 2001). These measurements may relate to changes in land use, and water use, but these relationships will 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,b) 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). Concerns are with drawdown exceeding recharge that includes the loss of available groundwater supply, land subsidence, degradation of water quality, and loss of riparian habitat. Lowering of the water table (mining of the groundwater), reduction in groundwater flows, and storage are continually changing in response to human and climatic stress. So what influence does rangeland degradation have on the groundwater systems or vice versa? 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 variation. 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. Groundwater level data are collected and stored as either discrete groundwater level measurements or as continuous record.

Scale. Only a limited number of locations in the United States have gauging stations. The rangelands in the western United States have limited coverage. Enhanced coverage is needed for this indicator to become a useful early-warning indicator (Alley et al. 2002).

Data. The USGS Groundwater database contains groundwater site inventory and groundwater level data (see data matrix in Appendix 2-1 for more detail). The USGS annually monitors groundwater levels in thousands of wells in the United States. The USGS groundwater site inventory consists of more than 850,000 records of wells, springs, test holes, tunnels, drains, and excavations. 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 U.S. Geological Survey databases and other sources. Hydrographs that illustrate the water-level changes in most aquifer systems have been plotted. GIS data sets that represent pre-development or recent groundwater levels are being created, where possible.

The water-level data are used to evaluate the impact of changes in land use and water use on the aquifer systems. Changes in groundwater levels may also represent aquifer system response to climate variability. Water-level data will also show areas where surface-water and groundwater interactions may play an important role in sustaining riparian habitat.

Clarity. The public understands water levels as they relate to wells for drinking water, but the connection between groundwater and surface water is not understood by many people.

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

Importance. This indicator is patterned on an indicator developed by The H. John Heinz III Center for Science, Economics, and the Environment in its publication *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States*. This indicator annually measures: (1) the percentage of rangeland streams with at least one day of no flow (also referred to as zero flow) in a year; and (2) for stream gauging stations showing at least one day of zero flow, the duration of zero flow events compared with a long-term average. Together, these two variables describe the frequency and duration of surface no-flow periods. There are innumerable reasons for why streamflow is important in sustaining environmental, biological, social, and economic systems, not the least of which are: (1) the maintenance and recharge of ground water and the retention and productivity of streambank-stabilizing vegetation; (2) the continuity and quality of fish habitats; and (3) the availability of water for agricultural and municipal use and recreation.

Surface no-flow periods can occur naturally. Surface no-flow periods also can occur because of increased water use for domestic, irrigation, or other purposes, or because of changes in land use (for example, transition from rangeland to urban; transition from no livestock grazing to livestock grazing), or because of changes in vegetation which 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.

Geographic variation. This indicator has been reported at the division level of Bailey's ecoregions (for example, 320—tropical/subtropical desert division; 250—prairie division; 260—Mediterranean division [Bailey 1995, in The H. John Heinz III Center (2002)]), and in the temporal range from 1949-1999 based on USGS stream gauge data, http://water.usgs.gov/nwis/discharge, in The H. John Heinz III Center (2002). Differences are discernible over time at the division level of Bailey's ecoregions, and spatially between divisions.

Scale. The indicator does not identify cause of increases or reductions in the frequency or duration of zero flow events, but is meaningful at the division level of Bailey's ecoregions and at decadal scales (The H. John Heinz III Center 2002).

Data. Methods and procedures for data collecting and reporting, and data sets of useable quality, exist at the regional-national level and are maintained by USGS and are available at http://water.usgs.gov/nwis/discharge.

Clarity. Stakeholders can understand that changing streams from perennial to ephemeral or intermittent will impact the aquatic organisms that cannot tolerate periods without flowing water, but we anticipate they do not understand the relationships between periods of no-flow and groundwater levels.

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

Importance. 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 hydrophysiographic position on the landscape.

Changes in width, depth, width/depth ratio, slope, sinuosity, and meander characteristics are indicative of changing conditions of water and sediment yield in the 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 variation. 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 and parent materials of watershed sediments available for transport and deposition along the channel.

Scale. 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 subbasin scale. Spatial scale also must be considered when assessing whether changes in channel geometry are local or systemwide 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, structures, etc.). In contrast, systemwide changes in channel geometry 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 systemwide 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 compared with single measurements at a moment in time. Repeated measurements over several spatial scales (that is, both reaches and subbasins) also would 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. The data for evaluating this indicator exists 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. 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 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.

CHALLENGES AND OPPORTUNITIES

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.

We are discovering that regional and national level data sets are not available for most indicators; data sets often are more 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.

CONCLUSION AND FUTURE WORK

The 10 indicators identified to date might be reduced to a fewer number before this effort is completed. A Sustainable Water Resources Roundtable has recently been initiated and there is a potential that the water-based indicators we have identified, or indicators quite similar, might be identified by the Sustainable Water Resources Roundtable. The SRR has initiated discussion internally on the ramifications of potential overlap of indicators between the two Roundtables, and when the Sustainable Water Resources Roundtable becomes fully operational, plans are to formally integrate our two Roundtables with face-to-face meetings. Within SRR, there has been some overlap in indicator identification between the Soil and Water Resources Criterion Group and the Conservation and Maintenance of Plant and Animal Resources Criterion Group. Integration, both within the SRR and between the various Roundtables, is critical to minimize overlap. SRR leadership is networking with other Roundtables and at the SRR meeting in late March 2002 we began inter-criterion group discussion of indicator overlap. In some cases, more than one indicator appears to be indexing similar rangeland components. For example, organic matter and nutrient content, aggregate stability of the soil surface, bare ground, and soil erosion each affect or influence assessment of soil erosion. Therefore, the 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 the basic resources of rangeland sustainability. The identification and eventual quantification of rangeland indicators related to soil and water might provide an approximation of rangeland sustainability for our nation and provide a blueprint for evaluating rangeland sustainability worldwide.

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APPENDIX 2-1. Data matrices for soil and water indicators.

Soil Aggregate Stability indicator

	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 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 the soil sample during immersion and subsequent wet-sieving are compared with criteria which results in the assignment of the soil sample to one of 7 stability classes (stability classes zero through 6) (Herrick et al. 2001c).
Approximately what will it cost to collect 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. Herrick et al. (2001b) recommend a hierarchy of landscape geographic areas be used to guide the identification of monitoring units. An ecological site 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 (areas with dominant plant species which define the plant community), and these vegetation-similar landscape areas can serve as monitoring units. Finally, these vegetation-similar landscape areas can be further subdivided into landscape areas within which current management is similar. Monitoring units based on current management would be expected to respond similarly to management changes.
What is the spatial extent of these data?	
At what spatial scales can these data be aggregated and reported?	
What is the temporal grain of these data?	Herrick et al. (2001b) recommend a temporal grain of 1 to 5 years for soil aggregate stability data collection.
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 collected at 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. 2001c) 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.
Quality: how valid are existing data?	Using the field soil aggregate stability kit (Herrick et al. 2001c), this indicator measures what is intended with a high degree of accuracy. Herrick et al. (2001c) reports 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 100 percent of the aggregate stability percentages were within one class. 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, plant community composition, most soil textures, and organic matter content. Existing data apparently are not responsive to changes in soil aggregate stability in wetland and extremely sandy soils because soil aggregates do not readily form in these soils (Herrick et al. 2001c).
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)	

Bare Ground indicator

	Data set #1	Data set #2
Brief Title for Data Set	National Resource Inventory (NRI), Natural Resources Conservation Service, and Ecological Site Descriptions	Indian Remote Sensing (IRS); also a consideration of SPOT, IKONOS, QuickBird, Radar Satellite Data, and other fine-grained imagery of various kinds.
Contact Person/Agency/Group	NRCS State Offices	EOSAT Corporation, Thornton, Colorado. For protocol, Paul T. Tueller, University of Nevada, Reno, 775-784-4053, ptt@cabnr.unr.edu
Citation (if published)		1. Booth, D.T., D. Glenn, B. Keating, J. Nance, J.P. Barriere, and S.E. Cox. 2003. Monitoring rangelands with very large scale aerial imagery. Submitted to VII International Rangeland Congress, Durban, South Africa, July 26 to August 1, 2003. 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. 3. Website Remote Sensing Tutorial, University of Nevada, Reno, www.ag.unr.edu/serdp
Website (if available)	http://www.nrcs.usda.gov/technical/NRI/	www.spaceimaging.com www.ag.unr.edu/serdp http://www.space.gc.ca/csa_sectors/earth_environment/radarsat/default.asp http://www.spot.com/ http://www.digitalglobe.com/products/index.shtml
Additional information on data set	NRCS has been working with other agencies, including ARS, BLM, USGS, and USFS, 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 five years.	Numerous dates from 1972 onward. IRS has been available since 1983 and the other satellites are more recent.
In what format is the data set available?	Data points. Primary sampling units (PSU's).	Multispectral and panchromatic digital image data from satellite and large-scale video and digital multispectral images.
Are data nominal, ordinal, or interval?	Nominal.	Interval—spectral brightness values.
What will be the	$1,000/PSU	Variable; imagery now available for

approximate cost of collecting data?		$400/image (????) for the digital data/date.
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.	Biggest problem is the classification and interpretation of the data.
What is the spatial grain of these data?	Plot size, 160 acres in a primary sampling unit (PSU) with three random plots per PSU.	Variable; 5 meter multispectral and 5 meter panchromatic pixels for the IRS data.
What is the spatial extent of these data?	A number of random PSU's on non-federal rangelands.	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 on a side.
At what spatial scales can these data be aggregated and reported?	Major Land Resource Area (MLRA), State, or national.	For any area for which you can provide the cost of the data.
What is the temporal grain of these data?	5-year	Multiple dates annually.
What is the temporal extent of these data?	Every five years from 1982 to 1992.	Since 1972.
At what temporal scales can these data be aggregated and reported?	5 years.	Seasonally and annually over the years since 1972.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes.	Yes, a recent protocol has been developed to calibrate older with more recent satellite data.
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.	The repeatability is good because image data are available for numerous cloud free dates.
Quality: how biased are the sampling methods?	Somewhat biased because they are estimates.	The data quality is excellent because of the georeferencing along with radiometric and geometric corrections.
Quality: how precise are existing data? (Give standard error, if available)	Somewhat precise but once again based on the experience of the estimators; in practice and with training the estimates are quite repeatable.	A bare ground category can have accuracies which exceed 80 percent.
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.

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.	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.
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.	The development of a bare ground category can serve as a surrogate for bare ground even though it may not be possible to spectrally separate out such features as soil biological crusts or other cover features.
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 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.

Accelerated Erosion by Water and Wind indicator

	Data set #1	**Data set #2**
Brief Title for Data Set	National Resource Inventory (NRI), Natural Resources Conservation Service	Fine-scale (small geographic extent) color photography for erosion evaluations
Contact Person/Agency/Group		Terry Booth, High Plains Grasslands Research Station, Agricultural Research Service, USDA, Cheyenne, WY, 307-772-2433, ext. 110, tbooth@lamar.colostate.edu; Paul Tueller, Professor of Range Ecology, University of Nevada, Reno, NV, 775-784-4053, ptt@unr.edu.
Citation (if published)		Tueller, P.T., and D.T. Booth. 1975. Large scale color photographs for erosion evaluations on rangeland watersheds in the Great Basin. Proc. of the American Society of Photogrammetry, October 28-31, pp. 708-752.
Website (if available)	http://www.nrcs.usda.gov/technical/NRI/	http://www.ag.unr.edu/serdp/tutorial/tutorial.htm. There are examples here of fine-grained imagery obtained with a Kodak Digital color infrared camera.
Additional information on data set	NRCS is now working with other agencies, including ARS, BLM, USGS, and USFS, to develop an interagency list of data elements that could be used for national level inventories.	Data sampled on eight 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	1982 to 1992, every five years.	Two years; sampling of this kind can be done quickly and efficiently from a light aircraft or helicopter with sampling done at

collected?		random locations with difficult access, far from roads.
In what format is the data set available?	Data points. Primary sampling units (PSU's).	Images upon which measurements can be made 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/PSU	Highly variable; fine-scale (small geographic extent) flight transects will 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 in a PSU with three random plots per PSU; commonly three PSU's are sampled per township stratum.	Variable with scales ranging from 1:600 to 1:5,000 (1:1,000 in this case). Pixel sizes will vary from millimeters to about 5 m.
What is the spatial extent of these data?	A number of random PSU's on non-federal rangelands. At last sample in 1992 there were 14,368 NRI points that represented 4 million acres or 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 meter pixels are available with the new QuickBird satellite. See: http://www.digitalglobe.com/index.shtml
At what spatial scales can these data be aggregated/reported?	Major Land Resource Area (MLRA), State, or national.	Variable from the plant community level to the MLRA or nationwide.
What is the temporal grain of these data?	5-year	Daily, seasonally, and annually variable.
What is the temporal extent of these data?	Every five 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?	Subjective, an estimate of level of erosion; none-slight, moderate, severe, gullies, concentrated flow, etc.	Very consistent spectral and spatial attributes.

(Consistent methodology)		
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, 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 but once again 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 percent of the nonfederal 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 is somewhat subjective the value of the data is dependent 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 since complete samples can be obtained.
Quality: how well does this data set meet this indicator's needs?	Potentially very useful since the data is to be continuously obtained on the 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 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 U.S.

Aquatic Assemblage indicator

	Data set #1
Brief Title for Data Set	Aquatic Assemblage
Contact Person/Agency/Group	Dr. Mark Vinson, BLM Western Bioassessment Center, Utah State University, Logan, Utah
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/
Additional information on data set	Aquatic invertebrate assemblage data for about 20,000 samples collected at more than 7,000 sites in the western

	United States (see Fig. 1). More than 80 percent 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 as percents, for a sample at a site, or species composition for a group of sites across a user-defined region, e.g., a county, watershed, state, or ecoregion. Raw interval data can be manipulated and reported as ordinal also (for example, good, fair, poor classes), and nominal (e.g., presence or absence of a particular taxa).
How much will it cost to collect data?	$800 to $1,000 per site.
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 meters 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 (for example, 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 United States predominantly (see Fig. 1).
At what spatial scales can these data be aggregated and reported?	Subbasin and larger, or ecoregion, or physiographic region (for example, Great Basin, 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. Data 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 and 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 macroinvertebrate 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, we have done some quality assurance and quality control. A publication is being prepared.
Quality: how valid are existing data?	Data are valid for evaluating impairment of rangeland aquatic habitats across much of the western United States.
Quality: how responsive are existing data?	Aquatic invertebrate assemblages are responsive to many management actions occurring on rangelands.
Quality: how much statistical power to detect	Very high statistical power based on the size and

change does this data set have?	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)	

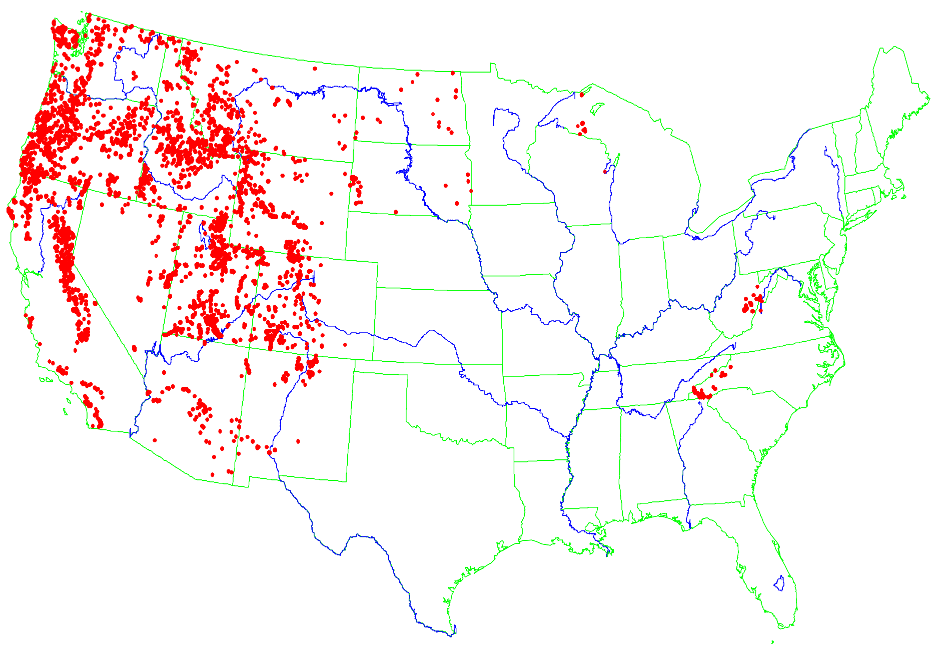

Figure 1 (App. 2-1). Red dots indicate aquatic macroinvertebrate sample data locations within the Western Bioassessment database, Utah State University. Considerable overlap of points exists.

Water Quality indicator

	Data set #1	Data set #2	Data set #3
Brief Title for Data Set	CWA 303(d) list of Impaired Water Bodies	STORET	NAWQA
Contact Person/Agency/Group	U.S. EPA Office of Water	U.S. EPA Office of Water	USGS
Citation (if published)			
Website (if available)			
Additional information on data set			
For what years are data available and how often are data collected?	1998. Lists are updated biennially. States submit lists to EPA on April 1st in even numbered years.	1972 to present, water quality data are monitored and collected on a regular basis.	
In what format is the data set available?	State lists designate water bodies that fail one 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.		
Are data nominal, ordinal, or interval?	Nominal—water bodies that fail to meet standard(s).		
What will be the approximate cost of collecting data?	Unknown.		
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.		
What is the spatial grain of these data?	Water bodies, first order streams.		
What is the spatial extent of these data?	National		
At what spatial scales can these data be aggregated and reported?	National		
What is the temporal grain of these data?	Two years.		

What is the temporal extent of these data?	1998 to present		
At what temporal scales can these data be aggregated and reported?	Two years.		
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.		
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	NA		
Quality: how biased are the sampling methods?	NA		
Quality: how precise are existing data? (Give standard error, if available)	NA		
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.		
Quality: how responsive are existing data?	Not very responsive. Lists reported biennially.		
Quality: how much statistical power to detect change does this data set have?	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.		
Other comments: (Include any other relevant aspects of the data set that should be included)			

Groundwater indicator

	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, Tucson office of the Arizona District, U.S. Geological Survey. The study area includes aquifer systems in the arid to semiarid basins in *southwestern states* of California, Nevada, Utah, Arizona, New Mexico; USGS (see web site 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
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 is available for may watershed 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/year.
In what format is the data set available? (map only, data point, …)	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 ground water 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 goes back 30 to 40 years or more.
What is the spatial grain of the data?	The *ground-water 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). http://waterdata.usgs.gov/nwis/gw.
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 other 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; Yes but the time frames can be rather lengthy although important. 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 a 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. Relatively long time periods, probably decades of measurement before meaningful results may be provided.
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.)	*There is very little data 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.*

Rangeland Stream, Surface No-Flow indicator

	Data set # 1
Brief Title for Data Set:	Daily Streamflow for the Nation
Contact Person/Agency/Group (email, phone, address):	Department of the Interior, United States Geological Survey, h2oteam@usgs.gov.
Citation (if published):	
Website (if available):	http://waterdata.usgs.gov/nwis/discharge.
Additional information on data set:	Data are retrieved by category of data, such as surface water, ground water, or water quality; and by geographic area. Of the 1.5 million sites with data, 80 percent are wells; 350,000 are water quality sites; and 19,000 are streamflow sites, of which over 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 minute 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 3 minutes of arrival.
In what format is the data set available? (map only, data point, …)	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?	The H. John Heinz III Center (2002) performed a data analysis 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 on-line. Streamflow data can be reported as point data too.
What is the temporal grain of the data?	As short as 15 minutes.

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. The H. John Heinz III Center (2002) analyzed data and reported streamflow data at decadal increments 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 USA--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 occur from instrument malfunctions or physical changes at the measurement site. Subsequent review may result in significant data revisions.
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 minutes, 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.)	