Section I: Monitoring program development in six easy steps

This section describes how to design and implement a long-term ecosystem-based monitoring program at the landscape level (an area > 400 ha or 1000 acres; Fig. 0.1). It is based on the assumption that one of the primary objectives of the monitoring program will be to detect long-term changes in the status of three basic attributes of grassland, shrubland and savanna ecosystems: soil and site stability, hydrologic function and biotic integrity (Fig. Intro.1).

The six steps

Each of the first six steps illustrated in the flow chart (Fig. 0.2) and listed in the Monitoring Program Design Checklist (found at the end of this Introduction to Section I) is described in its own chapter (Chs. 1-6). The steps are listed in the order they are normally completed. Because there is no "single" way to design a monitoring program, revisiting earlier steps is often helpful. For example, the assessments completed in Step 3 often reveal issues that lead to new management and monitoring objectives (Step 1). State and transition models can be helpful here by focusing attention on areas that are at risk, or have a high potential for recovery. It is also helpful to redefine management and monitoring objectives (Step 1) for specific monitoring units identified in Step 2.

Use the Monitoring Program Design Forms I (Ch. 1) and II (Ch. 4) to organize information about your monitoring program. Use the Monitoring Program Design Checklist to ensure that you have completed each step. The system allows maximum flexibility to address objectives and long-term changes, including monitoring for adaptive management, additional objectives, short-term monitoring, and monitoring threats and drivers.

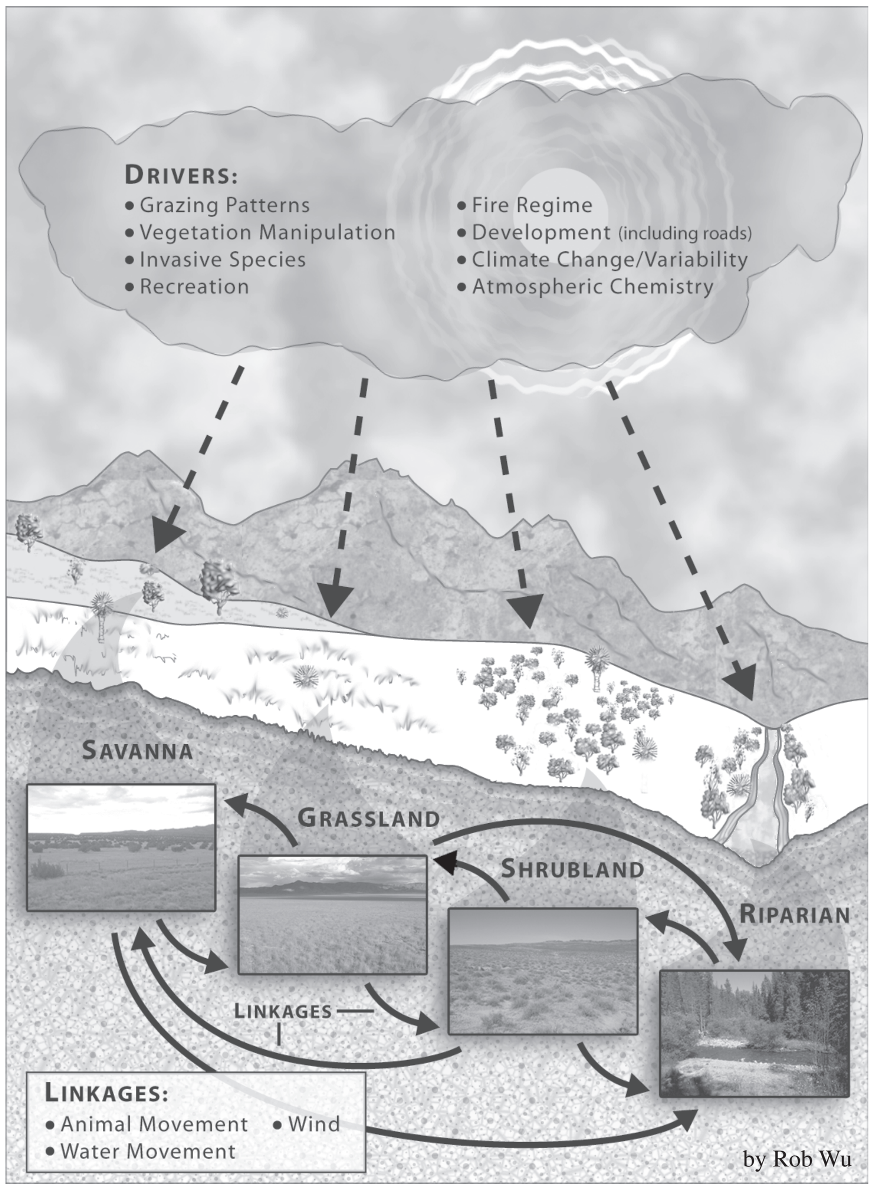

Figure 0.1. Landscape-scale monitoring programs should be responsive to the most important drivers, and sensitive to interactions among landscape units.

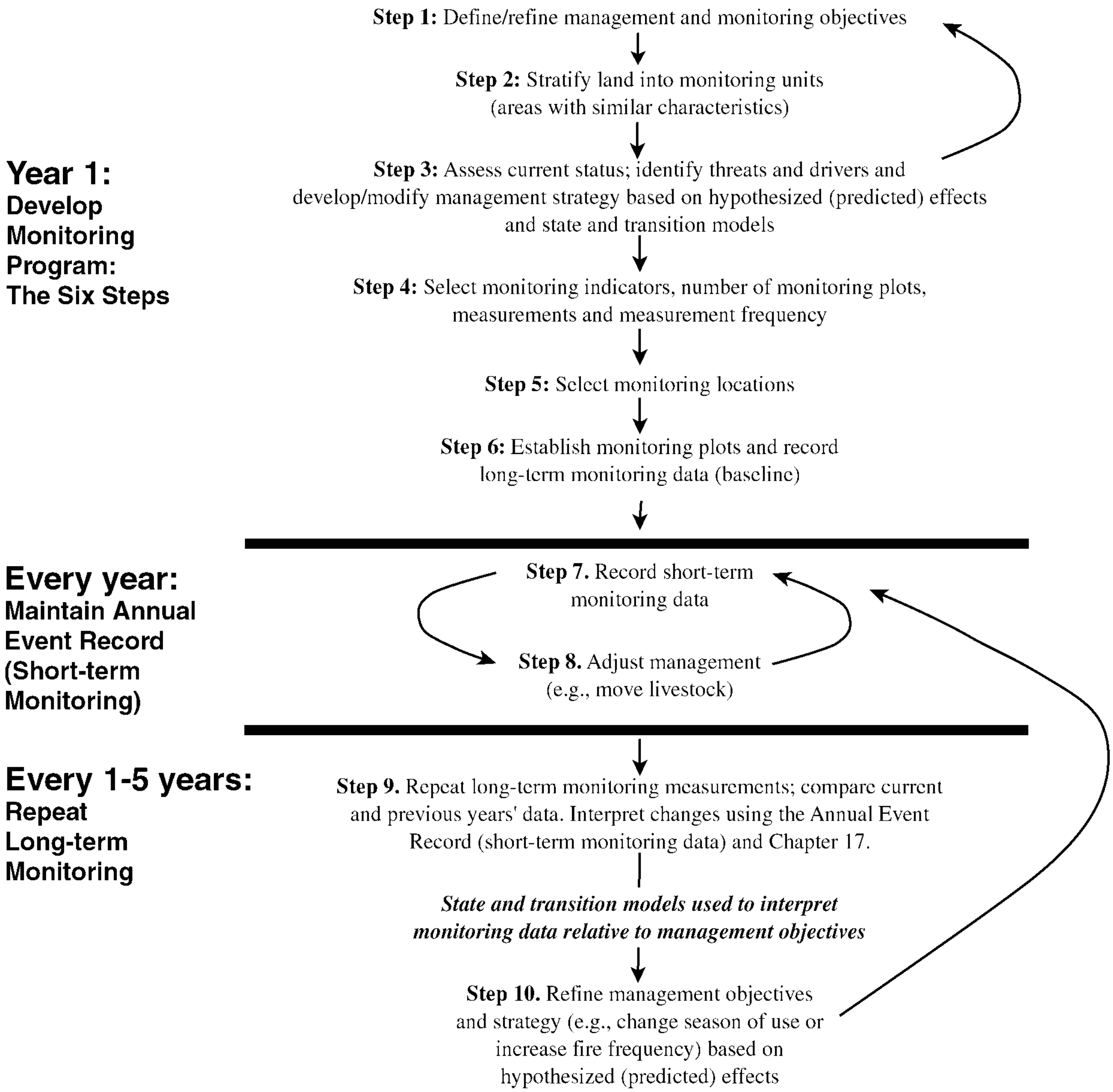

Figure 0.2. Monitoring program design and implementation (Steps 1-6) and integration with management (Steps 7-10).

Monitoring for adaptive management and management by hypothesis

In addition to long-term monitoring data, adaptive management requires three types of information: short-term monitoring data, knowledge of potential threats or drivers, and clearly defined hypotheses (predictions) of management effects (Steps 1, 3 and 7 of the checklist). State and transition models (Ch. 24) can be used to integrate assessment and monitoring data with current knowledge about potential management effects (based on management experience, scientific studies and simulation models) to generate these predictions.

Monitoring for additional objectives

Monitoring for the three basic attributes can serve as the foundation for use-specific monitoring, as illustrated in Figure Intro.1.

The basic measurements (described in Quick Start) were selected in part because they also can be used to generate indicators related to specific uses. For example, the Line-point intercept generates vegetation cover and composition indicators that are related to the quantity and quality of forage production. These indicators, together with spatial structure indicators from the Gap intercept method, can be used to assess and monitor wildlife habitat quality, as well as plant community changes in response to fire.

The value of the basic measurements can often be increased at a relatively low cost through slight modifications (see Section IV). For example, vertical vegetation structure can be measured by adding plant height measurements to the Line-point intercept protocol (Ch. 15), or by adding the Vegetation structure method (Ch. 11). In some cases, such as riparian monitoring, supplementary measurements (Section II) may be required. Section IV also provides recommendations for addressing specific monitoring objectives.

Short-term monitoring (Annual Use Records)

Short-term monitoring data (listed at the end of Quick Start) are used to make short-term management changes (Steps 7 and 8). For example, information on residual cover or biomass is often used to decide when to move livestock to a new pasture. This information is also used to interpret long-term monitoring data.

Monitoring threats and drivers

Information on potential threats and drivers, such as development of new roads or a change in fire frequency, is used to help identify areas where a change in management and/or monitoring will be required. Threats and drivers are identified in Step 3.

What if I don't have enough time?

Nearly any monitoring is better than no monitoring. Using management and monitoring objectives to guide monitoring program design can reduce monitoring costs. A few days of careful planning often can reduce monitoring costs by 50 percent or more and result in much more useful data.

- Use photo points where few changes are expected (see description of state and transition models in Ch. 24) or where you require only a qualitative record.
- Select measurements that are sensitive to changes defined in the management and monitoring objectives.
- Select measurements that generate indicators that are relevant to multiple objectives. The measurements included in Quick Start were selected in part because they are sensitive to changes in the three key attributes, while generating numerous indicators that are relevant to many other objectives.
- Match monitoring frequency to expected rates of change based on minimum detectable change. If the smallest change in basal cover you can detect is five percent (Ch. 4) and it takes at least five years for this change to occur, it's a waste of time to repeat measurements more frequently.

Using State and Transition Models for Monitoring Design

State and transition (S&T) models (Chapter 24) are conceptual models that describe the soil and vegetation dynamics for a particular type of land with similar soils and climate. Applying S&T models to monitoring program design helps a) define ecological potential, benchmarks, or reference conditions and b) specify predictions about the possible future change of different land units in a landscape. This approach allows monitoring site selection to be based on objectives and the ecological processes involved in land change. Designing a monitoring program within a state and transition model framework helps specify the ecosystem attributes to be monitored and other details that may vary among states and ecological sites.

Applying S&T conceptual models to monitoring site selection minimizes monitoring expenditures in highly degraded states where all available evidence suggests they will not change; and focuses monitoring efforts in 'at risk' states and plant communities where management has the potential to limit degradation or promote recovery. With this logic in place, monitoring can be treated as a series of tests matched to specific parts of a landscape. Key components of this test are the steps used to apply S&T models to a monitoring program design.

Steps for S&T Monitoring Design

First, stratify the landscape (Chapter 2) into ecological sites or potential-based land classes. This is done using soil surveys, landform maps, digital elevation models and knowledge of key soil gradients. Next, stratify each ecological site into states based on S&T models using aerial photography, remote sensing and/or field surveys. Finally, select monitoring methods that detect changes in focal patterns and processes within each specific ecological site and state.

Monitoring Program Design Checklist

Step*	Task	Completed?
	Develop monitoring program	
1	**Define management and monitoring objectives**	
	Define management objectives	________
	Define monitoring objectives	________
2	**Stratify land into monitoring units (areas with similar characteristics)**	
	Assemble background information (maps, photos, management history)	________
	Define stratification criteria (e.g., soils, vegetation, management units)	________
	Complete stratification and list monitoring units on Monitoring Program Design Forms I and II (Chs. 1 & 4).	________
3	**For each monitoring unit, assess current status; identify threats and drivers; refine long-term management and monitoring objectives; and develop/modify management strategy**	
	Select assessment system (e.g., Pellant et al. 2005)	________
	Verify that personnel have relevant qualifications	________
	Complete assessments	________
	Identify and record threats, drivers and opportunities	________
	Refine long-term management and monitoring objectives	________
	Develop/modify management strategy	________
4	**Select monitoring indicators, number of monitoring plots, number of measurements, and measurement frequency based on objectives and resource availability**	
	Select monitoring indicators	________
	Define number of monitoring plots	________
	Define measurement frequency	________
	Estimate time requirements	________
5	**Select monitoring plot locations**	
	Choose and apply site selection approach	________
	Select "rejection criteria" and use to eliminate unsuitable locations	________
6	**Establish and describe monitoring plots, and record long-term monitoring data (baseline)**	
	Establish and permanently mark monitoring plots	________
	Describe monitoring plots and record GPS locations, including coordinate system, datum and zone	________
	Record long-term data	________
	Error-check and copy data and keep copies in different locations	________
	Short-term monitoring (all years)	
7	**Record short-term monitoring data (at least 1x/year) (Quick Start)**	________
8	**Adjust management, if necessary (Quick Start)**	________
	Repeat long-term monitoring (every 1-5 years)	
9	**Repeat long-term monitoring measurements (Ch. 6), compare data with Year 1 and interpret changes (Ch. 17)**	
	Repeat long-term monitoring measurements	________
	Copy data and keep copies in different buildings	________
	Calculate indicators	________
	Compare with Year 1 (or previous years)	________
	Interpret changes using short-term monitoring data and Section III	________
10	**Refine management strategy, if necessary**	________

*Steps 1-6 correspond to Chapters 1-6, except where noted.

Chapter 1

Step 1: Define management and monitoring objectives

Checklist

1.1. Define management objectives .... ___________
1.2. Define monitoring objectives .... ___________

Why monitor?

Monitoring data are used to:

- evaluate the effects of past management;
- confirm effective management practices;
- identify trends that can be used to predict future changes so management can be adapted accordingly;
- learn more about how different factors (drought, fire, management) affect the land.

The most useful monitoring programs help managers achieve long-term management objectives by generating relevant data. Consequently, it is essential to clearly define both management and monitoring objectives before designing a monitoring program.

Use the Monitoring Program Design Form I (end of Ch. 1) to record your objectives as you develop them. You may find it easier to complete the stratification process (Ch. 2) before defining specific short- and long-term objectives.

Step 1.1. Define management objectives

(a) List the *general long-term management objective(s) for the area to be monitored* on the first line in Monitoring Program Design Form I. What do you want the land to look like? What goods and services do you want it to be able to provide now and 100 years from now?

(b) List *specific long-term management objectives* for each monitoring unit or type of land in the fifth column of the Monitoring Program Design Form I (see Ch. 2 for a discussion of monitoring units). The long-term monitoring program will be designed to measure progress towards meeting these objectives. For example, the specific objectives may include maintaining or increasing the production of particular products (e.g., forage for livestock) or services (e.g., filtering water before it reaches streams). State and transition models (Ch. 24) can be used to help define what types of changes are possible in different areas.

(c) List *short-term management objectives* that are necessary to achieve each of the long-term objectives for each type of monitoring unit in the same (fifth) column of the Monitoring Program Design Form I. Use of short-term monitoring indicators helps ensure the short-term objectives are being met, and helps interpret long-term monitoring data.

Examples of management objectives are listed in Table 1.1.

Step 1.2. Define monitoring objectives

Monitoring objectives follow directly from the management objectives. Additional monitoring objectives may result from plot assessments (Ch. 3). Where possible, the monitoring objectives should be quantitative. Use Appendix C to help decide if monitoring objectives are realistic.

(a) List the *general long-term monitoring objectives for the area to be monitored* in the second row of the Monitoring Program Design Form I. These should be based on the general long-term management objectives. There are three general types of monitoring objectives: (i) change in average status, (ii) change in the status of areas with a *high degradation risk*, and (iii) change in the status of areas that have a *high recovery potential*. Monitoring programs

Table 1.1. Examples of management and monitoring objectives for a mid-elevation ranch in an area dominated by sagebrush and perennial bunchgrasses. Similar objectives can be generated for areas in which recreation, mining and/or biodiversity conservation are the primary land uses.

General

Management: Maintain or increase land productivity and the number of land use options. Minimize land degradation risk.

Monitoring: Focus monitoring on areas with a high degradation risk and/or recovery potential in order to provide as much management-relevant information as possible.

Type of monitoring unit	Long-term objectives	Short-term objectives
Steep, highly erodible south-facing slopes	***Management:*** (1) Minimize soil erosion. (2) Increase habitat diversity for wildlife. ***Monitoring:*** Detect changes in ground cover, especially grass basal and shrub foliar cover. Detect the presence of invasive species, including cheatgrass.	***Management:*** (1) Control grazing to maintain sufficient ground cover and minimize erosion. (2) Time grazing to promote perennial grass reproduction and establishment while maintaining sufficient sagebrush cover for wildlife habitat. ***Monitoring:*** Detect changes in ground cover during and at the end of the grazing period. Record the beginning and end date of each grazing period.
Riparian	***Management:*** (1) Increase tree cover. (2) Increase bank stability. ***Monitoring:*** Detect changes of >10% in tree cover along the stream and throughout the riparian area. Detect changes of >5% in the cover of bank-stabilizing species along the stream.	***Management:*** (1) Limit growing-season use of trees until they are taller than browse line. (2) Limit livestock and recreational access and crossings to erosion/compaction resistant substrates, like gravel. (3) Time grazing to promote growth of bank-stabilizing species. ***Monitoring:*** Document completion date and effectiveness of new animal distribution control structures (e.g., fencing, hardened crossings). Where possible, directly document livestock distribution (e.g., with dung pat counts). Record the beginning and end of each grazing period.

designed to primarily address the first objective are usually the least cost-effective because a lot of effort is devoted to monitoring areas with a low probability of change. Selecting one or both of objective types (ii) and (iii) allows resources to be focused on areas where management is most likely to have an effect. See Chapter 5 for more information on site selection.

(b) List the *specific long-term monitoring objectives* for each type of monitoring unit in the sixth column of the Monitoring Program Design Form I. The potential for degradation and recovery varies both within and among monitoring units. State and transition models (Ch. 24) can be used to help select appropriate monitoring objectives for each type of monitoring unit.

(c) List the *short-term monitoring objectives* necessary to ensure the management plan is being followed and to document management changes. Record objectives in the same sixth column of Monitoring Program Design Form I.

Examples of monitoring objectives are listed in Table 1.1. Figures 1.1 and 1.2 show two additional examples, where arrows indicate desirable changes.

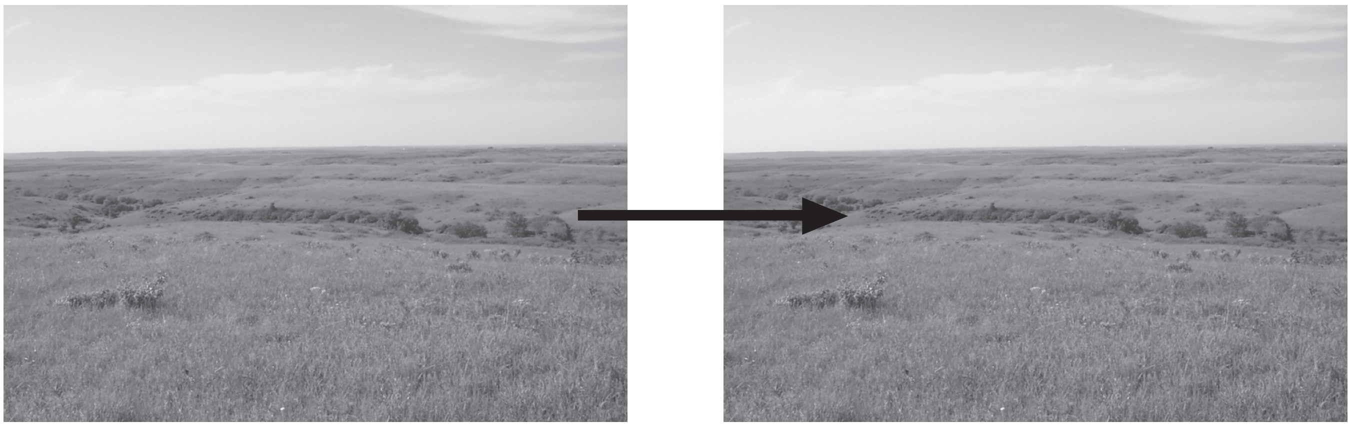

Figure 1.1. Tallgrass prairie functioning at its highest potential, Kansas, USA. Arrow reflects lack of significant change over time. *Long-term management objective(s):* Maintain biodiversity and productivity. *Long-term monitoring objective(s)*: Detect changes in plant cover and production by plant functional group; detect changes in plant species richness.

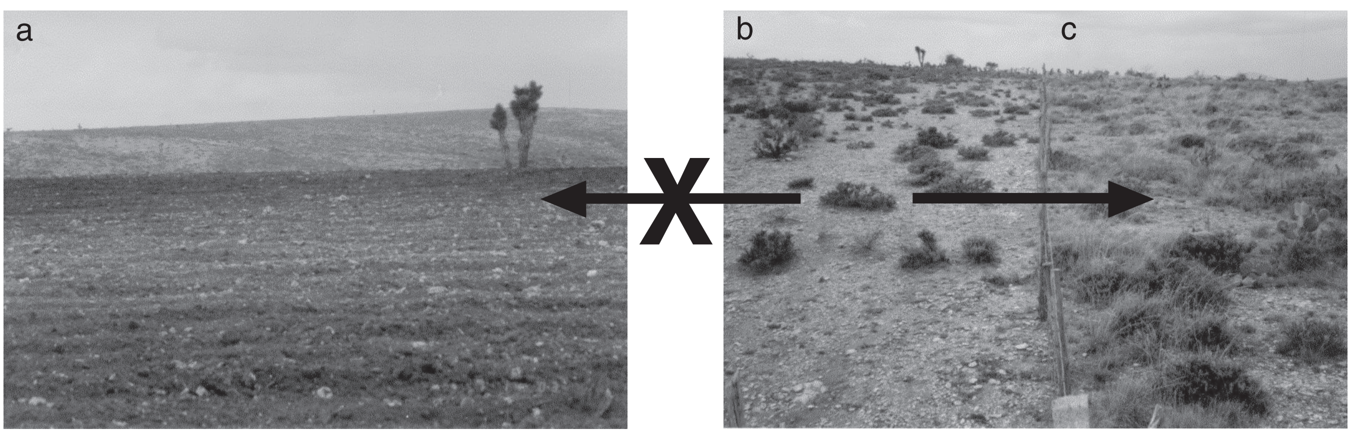

Figure 1.2. Overgrazed rangeland on left side of fence (b), and appropriately grazed rangeland on right side of fence (c), and conversion to rain fed agriculture (a), Zacatecas, Mexico. Arrows reflect desirable and undesirable changes from a long-term ecological sustainability perspective. *Long-term management objectives:* (1) Increase grass cover for livestock forage production. (2) Avoid cultivation, which leads to a relatively irreversible threshold due to increased soil degradation and erosion. *Long-term monitoring objectives*: (1) Detect changes in plant cover and production by plant functional group and vegetation spatial distribution. (2) Collect sufficient data to detect 5% change in bare ground.

Monitoring Program Design Form I. List different types of monitoring units and management and monitoring objectives for each type of unit. Record notes on the back of this form.

General management objective(s):

General monitoring objective(s):

Monitoring Unit Name* (Ch. 2)	Soil/ landscape position** (Ch. 2)	Dominant vegetation (Ch. 2)	Current status (Ch. 3)	Management objectives (Ch. 1) – Long-term – Short-term	Monitoring objectives (Ch. 1) – Long-term – Short-term	Total area (all units of this name)	Monitoring level (Ch. 4)

*Copy these to the first column of Monitoring Program Design Form II (Ch.4)
**Or ecological site or equivalent, if known.

Chapter 2

Step 2: Stratify land into monitoring units

Checklist

2.1. Assemble background information (maps, photos, management history) ___________
2.2. Define stratification criteria (e.g., soils, vegetation, management units) .. ___________
2.3. Complete Stratification .... ___________
2.4. Complete Monitoring Program Design Forms I (Ch. 1) and II (Ch. 4) ...... ___________

This chapter describes how to stratify the area into monitoring units and decide which units to monitor. Data from individual monitoring plots can be more reliably extrapolated to represent larger areas if the area of interest is stratified.

Because rangelands are among the most diverse ecosystems in the world, it is impossible to design a monitoring system that perfectly reflects changes in all landscape units. However, the accuracy and precision of any monitoring system can be improved by carefully dividing the area into relatively uniform monitoring units.

Monitoring units are areas located in a particular part of the landscape (e.g., flood basin or hill summit), within which vegetation, soil type, management and current status are relatively similar. All sections within a given monitoring unit are expected to respond similarly to changes in management and to catastrophic disturbances, such as a combination of drought and fire. Monitoring units may range in size from less than an acre to several square miles or more.

Multiple monitoring units of the same type (e.g., hill backslope in Fig. 2.1) often repeat across the landscape, geographically separated from one another by other monitoring units. Figure 2.1 shows how a landscape unit (floodplain) was divided into two types of monitoring units based on management (grazed vs. ungrazed).

Not all monitoring units will necessarily be monitored (Fig. 2.1). For example, highly stable types of monitoring units (such as bedrock) might not be included in a monitoring program if the primary objective is to monitor for degradation risk or recovery (see Ch. 1). Use Monitoring Program Design Forms I (Ch. 1) and II (Ch. 4) to keep track of potential monitoring units.

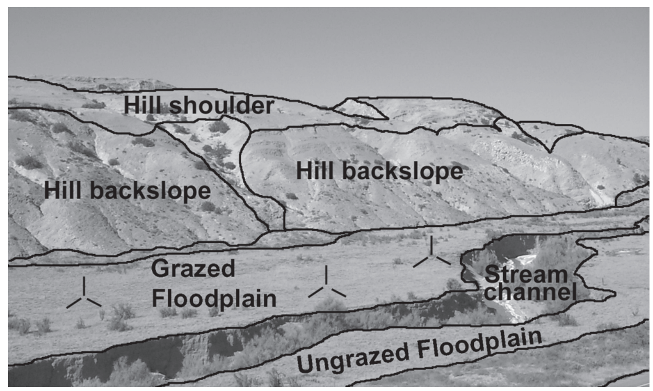

Figure 2.1. Example of how monitoring units are defined using landscape, soil, vegetation and management criteria. In this example, three monitoring plots, shown here as three sets of three transects (spokes), were located in the summer-grazed floodplain monitoring unit, which has a high potential for both degradation and recovery. No monitoring plots were located on monitoring units on the adjacent slopes because they did not meet the selection criteria, which included livestock use.

Stratification: How to do it

Landscape stratification is a three-step process:

2.1 Collect background information, maps and photographs.
2.2 Define stratification criteria.
2.3 Divide the area into monitoring units:
  (a) divide the area into soil-landscape units;
  (b) subdivide the soil-landscape units into soil-landscape-vegetation units (if necessary);
  (c) subdivide the soil-landscape-vegetation units into monitoring units based on type of management.

Record each type of monitoring unit from 2.3 in Monitoring Program Design Forms I and II.

Step 2.1. Collect background information

The following resources are helpful in stratifying the landscape into monitoring units and selecting the units to monitor. See Table 2.1 for sources of background information (regularly check http://usda-ars.nmsu.edu for the most up-to-date list). In some instances, there is a fee for these resources, but many of them can be downloaded free from the Internet. New sources are constantly becoming available.

Aerial photographs. One of the easiest ways to organize information is on a map or recent aerial photograph of the area, or through a Geographic Information System (GIS). Ideally, use one or more aerial photographs with fences and roads marked on them.

If you want to be able to locate yourself on the aerial photo using GIS and a GPS (Global Positioning System) unit, you will need a digital image that has been modified so that the distances on the photo correspond directly to distances on the ground (orthorectified). The most widely available photographs of this type are the USGS Digitial Orthophoto Quarter Quadrangles, or DOQQs. Each of these images covers one quarter of a 7.5 minute USGS topographic map.

Satellite imagery. High resolution satellite imagery can be used for stratification. See Chapter 25 for more information on the use of remote sensing in monitoring.

Written and oral histories. Information on historic changes can help predict which parts of the landscape are most likely to change in the future. Sources of information on historic changes include old monitoring records (often stored in the local Bureau of Land Management [BLM] or United States Forest Service [USFS] offices), old aerial photographs and survey records. Interviews with current and previous land managers are among the most valuable sources of information.

Property maps. Conservation plan maps (available from NRCS offices) locating current and historic homesteads, fence lines, corrals, roads, watering holes, supplemental feeding locations, and areas seeded, herbicided or where vegetation was removed are valuable when stratifying the landscape into monitoring units. All of these have the potential to affect the way land will respond to future management.

Species lists. Lists of plant species commonly found in the area are helpful. Vegetation measurements are usually recorded to the species level. At a minimum, lists of potential invasives and exotics should be acquired for all monitoring programs.

Ecological Sites and Site Descriptions (ESDs). Each ecological site includes several similar soils. Each ESD includes partial species lists and basic soils information and state and transition models that can be used to help plan and interpret monitoring (see end of Introduction).

Soil maps. Soil maps are commonly available in the form of county soil surveys. Soil maps are often drawn on aerial photos. In addition to maps, soil surveys have a wealth of information on soil properties and the suitability of soils for different uses. GIS layers of soil surveys can be obtained for most counties from the local NRCS office.

Soil maps of pastures and rangelands rarely include map units named with a single soil series due to the complexity of most rangeland landscapes (a soil series is like a plant species). Instead, individual areas are mapped as “complexes” or “associations” of two or more soil map unit components. Soil map unit components are phases of soil series. Phases of soil series are usually identified based on features important for management, such as slope, soil surface texture, surface rockiness and salinity. A soil map unit component is like a plant subspecies. The soil survey (or a professional soil scientist) can help you decide if the components in a particular map unit are sufficiently similar to be treated uniformly for monitoring purposes.

Soil series are distinguished based on soil profile characteristics. These characteristics are usually, but not always, directly related to soil function. Soil series allow us to access reference information included in Ecological Site Descriptions and other databases.

Table 2.1. Landscape stratification resources. Internet links often change. These are valid as of September 19, 2008.

Resources	Sources
Aerial photos*	• USGS at http://edcsns17.cr.usgs.gov/EarthExplorer • Companies selling USGS photos at http://nationalmap.gov/gio/viewonline.html • http://ask.usgs.gov/sils_index.html, http://ask.usgs.gov/sources.html, or call 1-888-ASK-USGS. Images newer than 1996 can be obtained from the National Aerial Photography Program (NAPP) and National High Altitude Photography (NHAP), and are searchable on Earth Explorer at http://edcsns17.cr.usgs.gov/EarthExplorer • USDA Sales Branch, USDA FSA APFO, 2222 West 2300 South, Salt Lake City, UT, 84119-2020, or (801) 844-2900, or http:www.fsa.usda.gov/FSA/apfoapp?area=apfohome&subject=landing&topic=landing
Aerial photos: Digital Orthophoto Quarter Quadrangle (DOQQ)*	• An aerial photograph that has been digitized (scanned into a computer) and georectified, giving it all the properties of a map. DOQQs are helpful when using GIS technology to stratify landscapes. • USGS or its business partners at http://eros.usgs.gov/index.html • USDA NRCS at http://www.ncgc.nrcs.usda.gov/products/datasets/index.html
Topographic maps	• 7.5 minute USGS topographic maps http://topomaps.usgs.gov • Other topographic maps can be purchased via hard copy or CD from USGS or its business partners at http://eros.usgs.gov/index.html
Digital Raster Graphic (DRG)	• A scanned USGS topographic map that has been digitized (scanned into a computer) and georectified, ready for GIS applications. • USGS or its business partners at: http://topomaps.usgs.gov/drg
Soil surveys and maps*	• Visit the local NRCS office (look under United States Government, Department of Agriculture, USDA Natural Resources Conservation Service in the blue pages of the phone book), or check the NRCS website (http://soils.usda.gov/survey) to obtain a copy of a soil survey for the county of interest. • STATSGO (State Soil Geographic Database) map coverage (1:250,000) is available for most areas. SSURGO (1:24,000) maps are in the process of being digitized. Hard copies are available through local NRCS offices. • Visit the local USFS office to obtain a Terrestrial Ecosystem Survey for the area of interest. Some offices may have this data available in digital form.
Vegetation Inventory Data*	• BLM land: Soil Vegetation Inventory Method (SVIM) maps. These are maps of field-collected vegetation inventory data. Some offices may have this data available in GIS form. • Private land: NRCS status maps and Natural Resource Inventory data are found at: www.nrcs.usda.gov/technical/dataresources
General maps	• BLM land status maps (look under United States Government, Dept. of Interior, Bureau of Land Management in the blue pages in the phone book).
Species lists	• USFS, BLM and NRCS offices (especially old monitoring records). • NRCS lists of plants: www.nrcs.usda.gov/technical/dataresources • See Ecological Site Descriptions (NRCS) below. • Look up your local chapter of the Native Plant Society at (www.nanps.org) • PLANTS national database (http://plants.usda.gov)
Ecological (Range) Site Descriptions*	• Local NRCS office (ask for descriptions as listed in the Field Office Technical Guide, or go to http://esis.sc.egov.usda.gov) • Some revised descriptions may not yet be on the web.
Geologic Maps	• USGS Geologic Maps at http://ngmdb.usgs.gov
Invasive Species Lists	• NRCS http://plants.usda.gov/java/noxiousDriver

* Landowners can also refer to their own Conservation Plan developed through the local conservation district and NRCS.

Step 2.2. Define stratification criteria

There is virtually an infinite number of strategies for stratifying the landscape into functionally similar monitoring units. Three criteria useful for a wide variety of ecosystems are: soil-landscape, current vegetation and management.

Soil-landscape criteria include topography, landscape position and soils. These criteria determine the potential of the unit to support different plant communities. Incorporating soil-landscape criteria is a very important step, especially in areas where the same plant community currently dominates much of the land. In these areas, knowledge of the underlying soils can help identify locations where there is a high recovery potential.

In most systems, historic differences in management and disturbance have generated variability in *current vegetation* within soil-landscape units. Historic management and disturbance can be used as stratification criteria, as can current and planned future *management*.

While stratification may sound complex, in reality it is relatively simple.

Step 2.3. Complete stratification: divide the area into monitoring units

This step is often broken into separate parts, based on the number of stratification criteria. In the following example, three criteria were used. Remember that a single type of monitoring unit may include many individual units scattered across a landscape.

Step 2.3(a) Divide the area into soil-landscape units (NRCS ecological sites or functionally similar units such as the unit used in the USFS Terrestrial Ecosystem Survey). Landscape units are areas that are relatively homogeneous with respect to slope, aspect and parent material (material from which the soil was formed). As a result, they generally have similar soil series, or similar soil components. Where soil series or soil components in a landscape unit are functionally similar, they are included in the same soil-landscape unit. Functionally similar soils have relatively equivalent potentials to produce a particular type and amount of vegetation under the same climate.

Soil-landscape units generally correspond to NRCS “ecological sites” (previously referred to as “range sites”). These are also similar to the units used in the USFS Terrestrial Ecosystem Survey system and to soil-landscape-based land classification systems developed in New Zealand, Australia and other countries, although some of these systems also use current vegetation (see Step 2.3b). The grouping of functionally similar soils into ecological sites has already been completed in most areas of the United States, although the specific criteria used to create unique ecological sites varies somewhat among different states.

Soil-landscape units repeat across the landscape (Fig. 2.2). For example, multiple areas on south-facing 10-15% slopes, with 30-50 cm (12-20 in) of soil over granitic bedrock, would be classified as the same soil-landscape unit.

Step 2.3(b) Subdivide the soil-landscape units into soil-landscape-vegetation units (if necessary). Vegetation is generally correlated with landscape position and soil type, but historic differences in land use can lead to the development of different plant communities on the same soil-landscape unit (Fig. 2.3; see also Ch. 24). Vegetation subdivisions are normally based on the current dominant plant species that define the community. They can also be based on the presence of critical species, such as exotic or invasive plants, or by habitat type for a particular animal. Keep in mind that while soil-landscape units are relatively persistent and use-independent, soil-landscape-vegetation units can and do change rapidly.

Step 2.3(c) Subdivide the soil-landscape-vegetation units into monitoring units based on management (soil-landscape-vegetation-management units). A monitoring unit is the largest contiguous area with the same soil type and plant community that is expected to respond similarly to management changes. Pasture borders, distance from water, prescribed fire, woody vegetation removal and recreational use can be used to delineate monitoring units. Similar monitoring units (same type) often repeat across the landscape (Figs. 2.1 and 2.4). Figure 2.4 shows four types of monitoring units.

Step 2.4. Record each type of monitoring unit in the Monitoring Program Design Forms I and II (Chs. 1 and 4)

Each type of monitoring unit is recorded only once, even if it repeats across the landscape. Leave extra rows on Monitoring Program Design Form II below monitoring units in which you expect to include more than one monitoring plot.

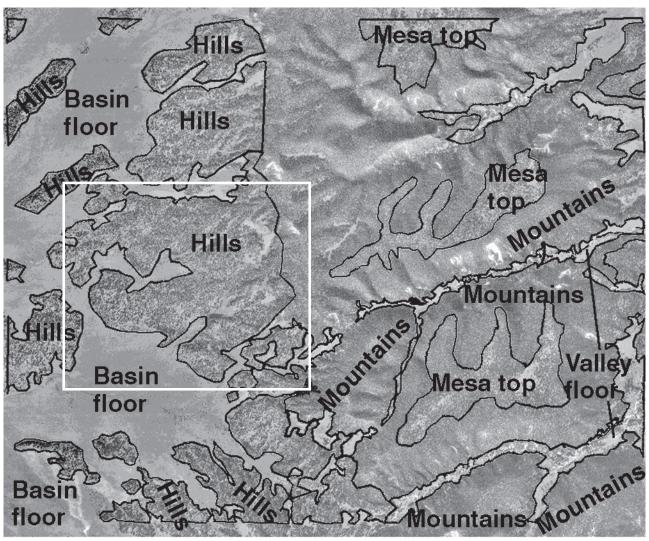

Figure 2.2. Example of landscape unit stratification. This type of stratification can only be done with aerial photos. Subdivision into soil-landscape units was not possible due to lack of soil survey information. The use of Soil Survey Maps can make this process easier and more accurate.

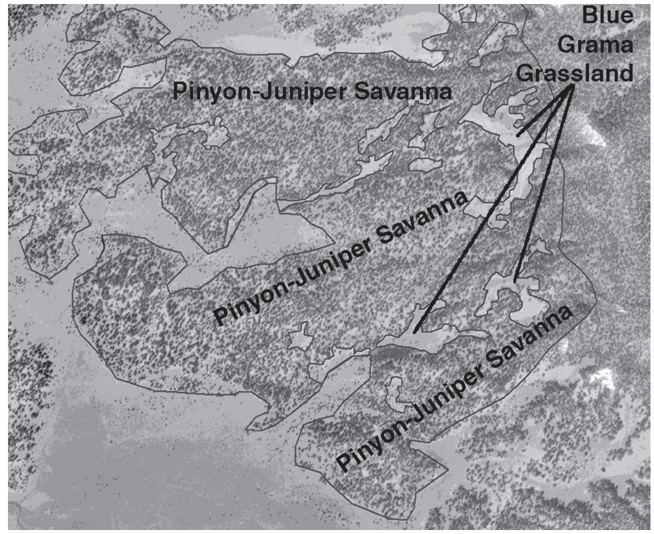

Figure 2.3. Example of the subdivision of landscape units (box in Fig. 2.2) into landscape-vegetation units. Here one of the Hills landscape units was subdivided into landscape-vegetation units.

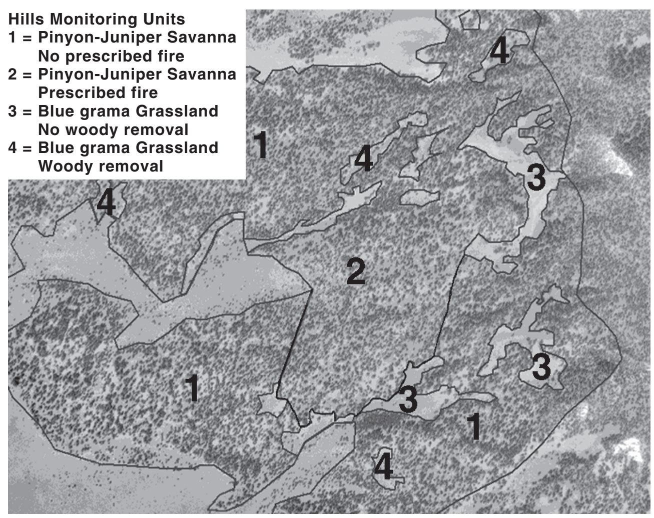

Figure 2.4. Example of the subdivision of landscape-vegetation units into different types of monitoring units (1-4) based on management. In this case, one of the Hills-Pinyon-Juniper Savanna units was subdivided based on the presence or absence of prescribed fire; and the Hills-Blue grama Grassland unit was subdivided based on whether or not woodcutting is planned.

Chapter 3

Step 3: Assess current status

Checklist

3.1. Select assessment system .... _________
3.2. Verify that personnel have relevant qualifications .... _________
3.3. Complete assessments .... _________
3.4. Identify and record drivers, threats and opportunities .... _________
3.5. Refine long-term management and monitoring objectives .... _________
3.6. Develop/modify management strategy .... _________

Where possible, the status of each area of each monitoring unit (or at least each type of monitoring unit) should be evaluated and recorded in the Monitoring Program Design Form I (Ch. 1). This evaluation helps determine the relative usefulness of establishing transects in each monitoring unit based on the objectives identified in Step 1.

Assessments can be qualitative or quantitative. Assessments can use current status, apparent trend, or trend based on existing monitoring data. All assessments require some kind of reference. Where trend is used, the reference is the status at some previous time. The reference for the current status is generally the site potential, which is defined based on soil and climate (e.g., in NRCS Ecological Site Descriptions as discussed in Ch. 2).

Step 3.1. Select assessment system

There are a number of protocols currently available for assessing rangelands. We have included brief descriptions of two we consider useful: *Interpreting Indicators of Rangeland Health* (IIRH) for uplands (Pellant et al. 2005; see also Pyke et al. 2002) and *Process for Assessing Proper Functioning Condition* (PFC) for riparian areas (Prichard et al. 1998a, b). These protocols were selected because they emphasize the capacity of the system to *function* relative to its potential. In other words, they reflect the current status of the same fundamental ecosystem attributes that this monitoring protocol is designed to address. They are both at present (2004) widely applied by governmental and non-governmental organizations in the United States. IIRH has been translated into Spanish and applied in Mexico.

Both of these protocols, like all qualitative systems, should be applied by a team of trained personnel with a working knowledge of the local ecosystem. Links to PDF (portable document format: documents in a format easily downloaded, viewed and printed from the World Wide Web) files of these protocols and training information are available on the Internet (http://usda-ars.nmsu.edu).

Upland areas. *Interpreting Indicators of Rangeland Health* (Pellant et al. 2005) (Fig. 3.1). This publication describes a process for using 17 qualitative indicators to generate assessments of the same three attributes addressed by this monitoring manual: soil and site stability, hydrologic function and biotic integrity. A standard or reference is established for each ecological site (type of soil-landscape unit). Reference information for each of the 17 indicators is summarized in a "Reference Sheet." Each indicator is placed into one of five categories based on its relative departure from its reference status (none to slight, slight to moderate, etc…). Specific combinations of the 17 indicators are then used to evaluate each of the three attributes.

Reference Sheets for some ecological sites have already been developed in the United States and Mexico. In the U.S., they are included in the updated NRCS Ecological Site Descriptions. Instructions for developing Reference Sheets where they do not already exist are included in the latest version of IIRH (version 4.0). This method is included *only* to assist in the identification and selection of potential monitoring sites (Ch. 5). The indicators described should *not* be used to replace the quantitative monitoring indicators described in this manual. For additional information on how to apply this method, please refer to the IIRH publication.

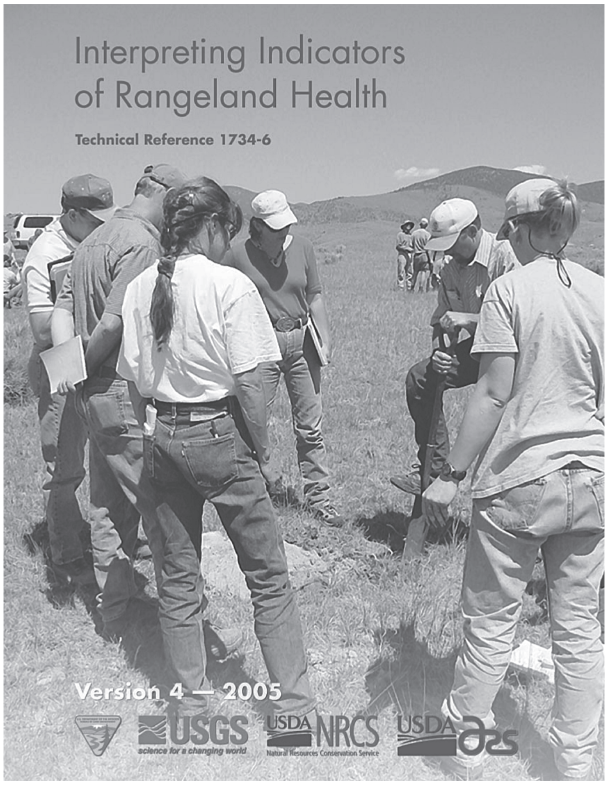

Figure 3.1. Cover of *Interpreting Indicators of Rangeland Health* (Pellant et al. 2005).

Riparian areas. *Process for Assessing Proper Functioning Condition* (Prichard et al. 1998a, b) (Fig. 3.2). This publication describes a process for developing riparian qualitative assessments. It is also based on 17 indicators. There are two primary differences, though, to the upland areas assessment protocol (IIRH). The first is that, instead of generating a "degree of departure" from that expected for the ecological site, the evaluation is designed to rate a stream reach as functional, at risk or non-functional. The second difference is that there is no standard reference. The team completing the evaluation must develop a unique standard for each area to be evaluated. For this reason it is essential that a diverse team of trained, knowledgeable and experienced individuals complete the evaluations for riparian areas.

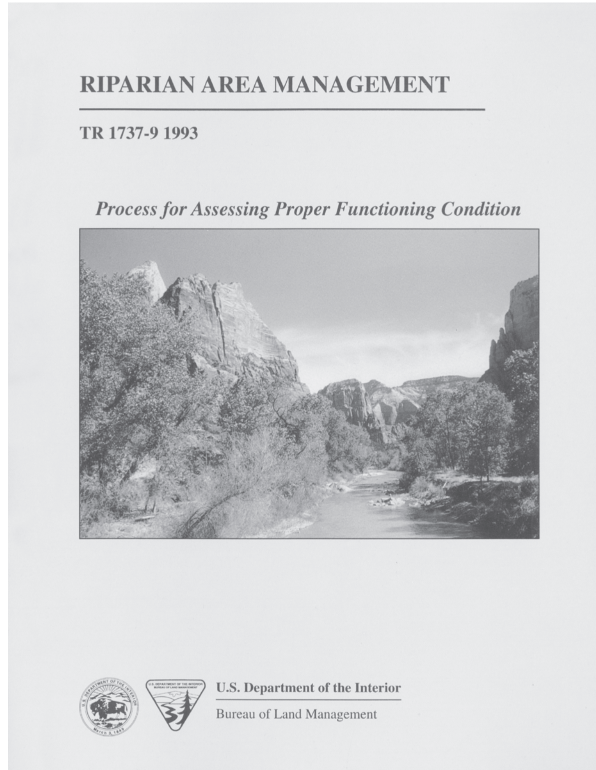

Figure 3.2. Cover of *Process for Assessing Proper Functioning Condition* (Prichard et al. 1998a, b).

Step 3.2. Verify that personnel have relevant qualifications

Relevant evaluator qualifications are listed in each document. It is important to recognize that experience and long-term knowledge of the ecosystem is often as important as academic qualifications. Academically trained individuals with little field experience will find it difficult to accurately and consistently apply assessment protocols.

Step 3.3. Complete assessments

Paper and electronic forms are available for completing the assessments.

Where? It is more important to complete assessments in areas where the value of monitoring and/or a change in management is uncertain. If you already know that an area is in a relatively stable state, it's usually not worth completing an assessment. Be sure to justify all assessments with comments and observations.

Both the upland and riparian assessment systems are designed to evaluate individual locations. Record additional notes of off-site effects and impacts to describe relationships among monitoring units. For example, excessive runoff in one monitoring unit may reflect problems in an upslope monitoring unit, or the presence of invasive species on one monitoring unit may pose a risk to adjacent monitoring units.

Step 3.4. Identify and record drivers, threats and opportunities

A critically important part of the assessment process is identifying drivers, and current and future threats and opportunities. Both of the assessment protocols are limited to current status only. Areas likely to be threatened by future activities, or where future activities present new opportunities, should be considered for monitoring because of their potential for change.

Drivers. Drivers include all factors that can contribute to changes in the properties and processes to be monitored. Typical drivers in rangeland ecosystems are listed in Figure 0.1. Drivers may or may not be threats.

Threats. Threats are drivers that might *negatively* impact the land in the future. Future threats might include increased off-road vehicle activity, invasive plants that have been identified in the area, cultivation (see Fig. 1.2), overgrazing by wildlife/ livestock associated with a change in management, or drought and insect damage. The level of each threat usually varies among monitoring units. For example, off-road vehicle activity is less likely to be a threat on isolated mesas, and the threat of insect damage is frequently greater in grass-dominated ecological sites. Gully formation is more likely to occur in monitoring units located downslope of areas where an increase in runoff (e.g., associated with road construction) is anticipated.

Invasive species sometimes pose a high threat in particular soil types. Disturbance can favor the establishment of invasive species. For example, road graders can disperse African rue (*Peganum harmala*) rhizomes. Additionally, cheatgrass (*Bromus tectorum*) seeds are often dispersed by grazing animals. Thus it pays to consider all potential threats and drivers when designing a monitoring program.

Opportunities. New opportunities are often more difficult to predict than threats, but are at least as important to address in a monitoring program. Opportunities might include grants for restoration that can only be applied to particular areas (e.g., riparian). A new neighbor or the development of a grass bank in the region might bring new opportunities for cooperative livestock management. Climate change and even short-term weather patterns can be viewed as both threats and opportunities.

Identifying known or potential future opportunities for a monitoring unit may influence your decision to monitor. Knowledge of such opportunities can allow flexible management to use them. If monitoring data are collected prior to and following a management change, the effects of the new management can be quantitatively evaluated.

3.5. Refine long-term management and monitoring objectives

New information can be provided by on-site assessments and the development of a list of threats and opportunities for each monitoring unit. This information can be used to refine management and monitoring objectives. These changes should be recorded in the Monitoring Program Design Form I (Ch. 1).

3.6. Develop/modify management strategy

The management plan should be finalized (to the extent possible) before beginning site and indicator selection. At the risk of redundancy, we repeat that *in order for monitoring to be cost-effective, it must focus on those areas, properties and processes that are likely to change in response to management (including lack of active management).*

Chapter 4

Step 4: Select indicators and number of measurements

Checklist

4.1. Select monitoring indicators .... ________
4.2. Define number of monitoring plots .... ________
4.3. Define measurement frequency .... ________
4.4. Estimate time requirements .... ________

Indicator selection should be based on the objectives defined in Step 1 (see Ch. 1). It is important to think carefully about what you need to learn from your monitoring program, and how precise the data need to be.

Types of indicators

Two basic types of monitoring indicators are addressed in this manual: short-term and long-term. Some (like plant cover) can serve as short- and long-term indicators. The difference between short- and long-term indicators is discussed in Quick Start and in Step 4.1.

In addition to the short- and long-term indicators described in this manual, you may want to include indicators of potential threats and new opportunities. These are briefly described in Chapter 3. Information on threats and opportunities can be used to anticipate future changes and adapt monitoring and management accordingly.

Reducing monitoring costs

The most effective way to reduce monitoring costs is to minimize the number of measurements. Selecting measurements that generate indicators addressing multiple objectives can minimize costs. For example, the Line-point intercept method described in Quick Start can be used to generate ground cover indicators that are important (1) for erosion prediction; (2) for plant cover and species composition; and (3) as an indicator of wildlife habitat structure. Habitat structure requires the addition of height measurements to the Line-point intercept method (Ch. 15).

The measurements described in Quick Start are sufficient to generate all of the indicators required for most monitoring objectives. In many cases, indicators generated from the Quick Start measurements can substitute for the more time-consuming measurements described in the following chapters. For example, the Single-ring infiltrometer (Ch. 8) is a direct measurement of how quickly water will soak into the soil (infiltration capacity), but it is very time consuming. The Soil stability test (Quick Start) is less time consuming and, together with indicators calculated from the Line-point and Gap intercept measurements, can generate information relevant to the infiltration capacity of the soil (see Section III). Another option is to make the more time-consuming measurements (generally Level 4 in Table 4.1) at a few high-priority locations.

Monitoring Intensity (Table 4.1). Where only qualitative documentation of change is required, photographs (Level I) are often sufficient. Level II monitoring intensity (semi-quantitative) is

Note: Steps 4 and 5 (Chs. 4 and 5) are often completed simultaneously. The number of transects that can be monitored often depends on where they are and how many different types of measurements are to be made on each transect. Different types of monitoring units sometimes require different measurements. We suggest reading through Chapter 5 before actually beginning the tasks listed in Chapter 4.

Table 4.1. Levels of monitoring intensity.

Level	Objective	Measurements
I	Qualitative documentation of large changes in vegetation structure.	Photographs at standard photo points.
II	Semi-quantitative documentation of changes in vegetation composition, structure and soil stability (less repeatable than Level III).	Semi-quantitative alternatives to basic measurements (described in Quick Start).
III	Quantitative documentation of changes in vegetation composition, structure and soil stability.	One or more of four basic quantitative measurements described in Quick Start: Line-point intercept, Gap intercept, Soil stability test and Belt transect.
IV	Quantitative documentation of changes in the status of specific issues (e.g., compaction, water infiltration, vegetative production or streambank stability).	Various. See Chapters 7-15.

appropriate where only the core indicators included in Quick Start are required, and where the data will always be collected by the same person. Level III monitoring intensity is the same as Level II (i.e., Quick Start methods), except that the measurements are more precise and repeatable.

In many cases, only a subset of Level II or III measurements is necessary. For example, where the primary concern is a change in woody shrub cover, Line-point intercept (Level III) or step-point (Level II) alone is often sufficient if woody species comprise at least five percent of the foliar cover. The Belt transect (Level II or III) is appropriate where the only concern is early detection of undesirable plant establishment, or when the species/ functional group you wish to monitor is very sparse (less than five percent cover).

Level IV measurements are usually included to address specific concerns or objectives that cannot be addressed using the basic measurements.

Step 4.1. Select monitoring indicators

The monitoring indicators selected will determine which measurements are needed. Selecting measurements that generate multiple indicators, or that generate indicators that address multiple objectives, can often reduce costs.

Table 4.2 lists the measurements described in both volumes of this manual and briefly describes the relevant monitoring objectives for each. It also includes some of the indicators that can be generated from each measurement. Use Monitoring Plot Design Form II (end of Ch. 4) and Table 4.2, together with your objectives (outlined in Monitoring Program Design Form I, Ch. 1) and the results from your assessment, to select the appropriate measurements for each monitoring unit.

Short-term. Short-term indicators should reflect short-term management objectives. Most management plans require very few short-term indicators. For example, if management calls for eliminating off-road vehicle traffic from an area, the only indicator you need to monitor is vehicle tracks (modified Belt transect, Gap intercept or simply recording the number of tracks per 100 paces). For livestock grazing in arid and semi-arid ecosystems, residual ground cover (step-point transect), together with stocking rate information, is often sufficient. Typical short-term indicators are listed on the form at the end of the Quick Start volume.

Long-term. Long-term indicators should reflect long-term changes in the landscape caused by changes in management, climate and so on. Monitoring objectives (Ch. 1), together with assessment results (Ch. 3) and state and transition models (Ch. 24), can be used to help identify appropriate indicators.

Table 4.2. Overview of measurements and indicators. Appendix C includes estimated measurement requirements for the indicators listed in **bold**. See Chapter 17 or the Glossary for a definition of each indicator.

Measurement	Include…	Indicator	Attributes		
			Soil & Site Stability	Hydro-logic Function	Biotic Integrity
Line-point intercept (Quick Start and Ch. 15)	…for soil erosion risk, water infiltration, changes in species composition or cover (i.e., in nearly all monitoring programs)	**Foliar cover (%)**	X	X	X
		Basal cover (%)	X	X	X
		Bare ground (%)	X	X	X
		Ground cover (%)	X	X	
		Species richness (minimum estimate) (no.)		X	X
		Proportion of dead plant intercepts (by species)			X
		Cover by functional group, or species resistant to fire, grazing, traffic, etc. (%)			X
		Litter cover (%)		X	X
		Visual obstruction and foliage height diversity (when height measured)			X
Plant and Basal Gap intercept (Quick Start)	…for wind erosion and exotic plant invasion risk (canopy), and for soil water erosion risk and water infiltration (basal)	**Soil surface in canopy gaps > 25 cm (%)**	X	X	X
		Soil surface in canopy gaps > 50 cm (%)	X	X	X
		Soil surface in basal gaps > 50 cm (%)	X	X	X
		Soil surface in basal gaps > 100 cm (%)	X	X	X
		Soil surface in gaps > ___ cm or ___ ft	X	X	X
Soil stability test (Quick Start)	…for soil erosion risk (both), organic matter cycling (subsurface) and microbiotic crust development (surface)	**Surface stability (class)**	X	X	X
		Sub-surface stability (class)	X	X	X
		Proportion of surface values = class 6	X	X	X
Belt transect (Quick Start)	... to detect changes in species with low cover or density (e.g., early detection of invasives)	Plant density			X
		Plant density by size class			X
Compaction test – impact penetrometer (Ch. 7)	…when soil compaction is a current or potential problem	**Number of strikes per depth increment**	X	X	X
		Ratio of interspaces:under-plant canopies	X	X	X
Single-ring infiltrometer (Ch. 8)	…where infiltration is currently or potentially limited by soil structure	**Infiltration rate (mm/hr)**		X	
		Ratio of interspaces:under-plant canopies		X	
Plant production (Ch. 9)	…for herbivore carrying capacity estimates and ecosystem energy flow	Total production and production by plant species and functional groups (e.g., forage)		X	X
		Species richness (minimum estimate)		X	X
Plant species richness (Ch. 10)	…for precise estimates of species richness (see Line-point intercept and Plant production)	Species richness			X
Vegetation structure (Ch. 11)	…for standard indicator of habitat cover (see Line-point intercept)	Visual obstruction			X
		Foliage height diversity			X
Tree density (Ch. 12)	…for populations too widely dispersed for Belt transects	Plant density			X
		Plant density by size class			X
Riparian channel vegetation survey (Ch. 13)	…for documenting vegetation change along streambanks	Foliar cover (%)	X	X	X
		Cover by functional group (e.g., woody, bank-stabilizing species, etc.) (%)	X	X	X
Riparian channel and gully profile (Ch. 14)	…where channel morphology is expected to change or gullies are deepening or recovering	Width-depth ratio	X	X	
		Bank angle	X	X	

For example, many land managers in the western United States need to identify and monitor grass-dominated states that are at risk of changing to shrub-dominated states, which are associated with higher erosion rates. State and transition models define the states and transitions for the area of interest. The assessment would help identify areas potentially at risk of a change in state. The assessment, as well as the state and transition model, assist in identifying indicators associated with a state change (e.g., grass mortality, reduced infiltration and/or shrub establishment). The qualitative indicators included in the *Interpreting Indicators of Rangeland Health* protocol help focus attention on processes and the associated properties that should be monitored (Pellant et al. 2005).

Step 4.2. Define number of monitoring plots

Defining the number of monitoring plots is a balancing act between what changes need to be detected (benefits) and the resources available (costs). Use the factors listed below, along with Appendix C, to determine the number of plots needed. The number of short-term monitoring plots should be determined separately from the number of long-term monitoring plots. After determining time estimates (Step 4.4), it may be necessary to revisit this step to reduce costs.

Short-term. Use the recommendations listed for long-term measurements (below and in Appendix C) as a general guide for how many measurements you need. As with long-term measurements, monitoring more locations (plots) is generally better than increasing the number of measurements at each plot.

Long-term. The number of measurements required depends on four factors:

(1) the amount of variability within the ecological site (lower variability requires fewer measurements);
(2) the size of the change you want to detect (larger minimum changes require fewer measurements for detection);
(3) how sure you want to be that if you say a change has occurred (or has not occurred), you'll be right (statistical certainty – less certainty requires fewer measurements);
(4) whether you want to detect change at the plot scale (a plot selected to represent the soil-landscape-vegetation management unit) or at the landscape scale (ranch or watershed level). Fewer measurements are required to detect change at the plot scale than at the landscape scale. However, to detect change at the landscape scale, fewer measurements are required per plot because multiple plots are used.

Appendix C describes three options for estimating the number of vegetation transects and soil measurements you will need. It includes tables that allow you to create unique recommendations based on each of the four factors listed above. These tables are based on spreadsheets that allow even more flexibility in monitoring program design. The downloadable (http://usda-ars.nmsu.edu) spreadsheets will allow you to change transect length and number of points per transect, as well as minimum detectable change and statistical parameters.

Table 4.3 lists one set of recommendations for a semiarid grassland monitoring unit, based on Option 2 in Appendix C. Each of the long-term factors listed above affects measurement recommendations. For example, referring to the information presented in Table 4.3, if we wanted to detect a minimum change of five percent bare ground we would need four plots, while for a change of ten percent, only two plots are needed.

Step 4.3. Define measurement frequency

Measurement frequency should be matched to expected rates of change based on minimum detectable change selected in Step 4.2. If the smallest change in basal cover you can detect is five percent and it takes at least five years for this change to occur, it's a waste of time to repeat measurements more frequently.

Step 4.4. Estimate time requirements

Use Monitoring Program Design Form II to estimate total time requirements. Time requirements can vary by a factor of four or more, depending on vegetation structure, species identification requirements, weather, and observer experience and condition. Some people prefer to work by themselves, while others prefer a data recorder. Expect to double total time requirements for the first year to allow for plot establishment and characterization. Double them again if it is the first time a person has established plots and completed these measurements.

If the time requirements seem too high, don't give up! Carefully review the assumptions you have made about the indicators needed and statistical precision required. Review your objectives. Many indicators are interesting, but often just a few are essential.

Table 4.3. Number of plots required to detect change within a semi-arid grassland monitoring unit (landscape scale). These estimates were based on Tables C.15-C.17 in Appendix C (Option 2), using the median (middle estimate) for stoloniferous grassland (sandy soil), mixed rhizomatous/stoloniferous grassland and stoloniferous grassland (degraded) for three 50 m transects per plot.

Measurement (indicator)	Minimum Detectable Change*	Plots	Minimum Detectable Change*	Plots
Line-point intercept (bare ground: 50 points per transect)	5%	2,6,4 Median=4	10%	2,2,2 Median=2
Line-point intercept (foliar cover: 50 points per transect)	5%	2,7,6 Median=6	10%	2,2,2 Median=2
Canopy Gap intercept (gaps > 50 cm [~1.7 ft])	5%	8,6,11 Median=8	10%	2,2,3 Median=2
Soil stability test (surface stability: 6 measurements per plot)	1 unit	6,2,3 Median=3	2 units	2,2,2 Median=2

*p = 0.2; power = 0.8; rho = 0.5; see Appendix C for explanation.

Monitoring Program Design Form II. List of monitoring plots and number of transects planned for each plot. Use this list and the equipment list in Chapter 6 to plan time and equipment requirements. Describe site selection approach and list rejection criteria (Ch. 5) on the back of this form.

Standard transect length:____(m or ft) circle one			Record number of transects per plot in each cell									
Monitoring Unit Name (from Monitoring Program Design Form I)	**Plot (name or no.)**	**GPS Datum/Zone:____ UTM or Lat/Long?**	**Transect(s) compass directions (azimuths)**	**Photo Points** photos/ transect: ______	**Line-point intercept** pts/ transect: _______	**Gap intercept** min. canopy gap: ______cm or ft min. basal gap: ______cm or ft		**Soil stability** measurements/ transect: ______		**Belt transect** width: _____ (**ft** or **m**) circle one	**Other measure-ment:**	**Other measure-ment:**
		Coordinates				**Canopy**	**Basal**	**Surface**	**Sub-surface**			
Total:												
Time/measurement or transect[1]:												
Total time[2]:												

[1] Most accurate if based on time required after at least three days of experience. Most people need two to four times as much time on the first day.
[2] Multiply "Total" by "Time/measurement or transect."

Plot rejection criteria (see Ch. 5):

Chapter 5

Step 5: Select monitoring plot locations

Checklist

Step 5.1. Choose and apply site selection approach .... _________

Step 5.2. Select "rejection criteria" and use to eliminate unsuitable locations . _________

Step 5.1. Choose and apply site selection approach

There are three approaches to selecting monitoring plot locations: (a) random, (b) stratified random and (c) subjective. Each approach has advantages and disadvantages. The one you select depends on your monitoring objectives, knowledge of the area to be monitored and the number of plots you can afford to monitor. In most cases, we recommend the stratified random approach for developing cost-effective, statistically valid monitoring programs.

Regardless of the site selection approach you choose, use Monitoring Program Design Form II (Ch. 4) to record information for each plot selected. Describe the approach used to select the transects, and any rejection criteria, on the form.

Step 5.1(a) Random Plot Selection. Plots can be randomly selected using any map or aerial photograph. Simply create a fine-scale grid and place it on top of the map or photo. This can be easily done by placing one ruler on the bottom of the map with the "0" end in the lower left corner and a second ruler perpendicular to it along the left edge, again with the "0" end in the lower left corner. Randomly select two distances on each ruler (e.g., 6.1 and 10.7 in Fig. 5.1) and find the point where the two lines intersect. Repeat until you have selected all plot locations. Make sure each plot is at least 200 m from the closest neighboring plot.

If a DOQQ or other orthorectified image is available, the same process can be applied using a grid of UTMs instead of the ruler. These coordinates can then be entered directly into a GPS unit.

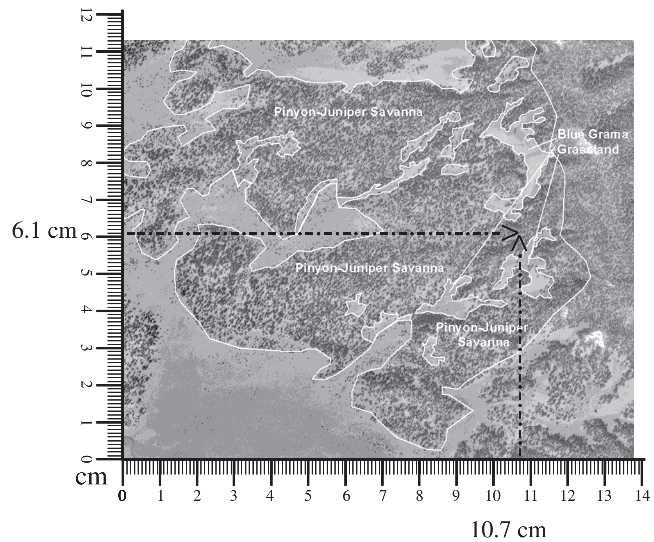

Figure 5.1. Random selection of monitoring locations using rulers and an aerial photo. The numbers 10.7 and 6.1 were randomly selected (see text).

Advantages

- Can be representative of all areas (if sufficient number of plots included).
- Easy to apply.
- Statistically valid.
- Is clearly "unbiased."

Disadvantages

- Not very cost-effective.
- Rarely includes locations in sensitive areas or areas of special concern because they usually represent a relatively small proportion of the total land area.
- Not sensitive enough to monitor degradation and recovery except where changes are occurring throughout all parts of the monitoring unit.

Step 5.1(b) Stratified Random Plot Selection. Stratified random sampling is identical to random sampling except the number of plots in each type of monitoring unit is predetermined. Plot location within each type of monitoring unit is randomly selected. This allows monitoring to focus on areas with a high degradation risk or recovery opportunity.

For example, in Figure 5.1, if the primary objective is to monitor for degradation risk and the primary degradation process is tree invasion, then a higher proportion of the plots should be located in the blue grama grassland, even though most of the monitoring unit is pinyon-juniper savanna.

Calculating indicator averages is slightly more complicated with stratified random than with random. For stratified random, calculate the average value for each type of monitoring unit. Then multiply each average value by the proportional area covered for the corresponding type of unit (e.g., 0.3 for a type of unit covering 30% of the total area monitored). The average for the total area monitored is the sum of all the products (monitoring unit x proportion of area). The example in Table 5.1 shows that it's easier than it sounds.

Table 5.1. Calculating average bare ground for a watershed with three types of monitoring units (based on stratified random plot selection approach).

Unit Type	Proportion Total Area	Average Bare Ground	Proportion x Average Bare Ground
A	0.8	20%	16%
B	0.1	50%	5%
C	0.1	40%	4%
Avg.			25%

Advantages

- Can be representative of all areas (if sufficient number of plots included, plots are located in all types of monitoring units, and the total area of each type of monitoring unit is known).
- Statistically valid.
- Cost-effective.
- More sensitive to areas with a high probability of change (degradation and/or recovery).

Disadvantages

- Requires pre-stratification (this should already be done as part of the design process. See Ch. 2).

Step 5.1(c) Subjective Plot Selection. Subjective plot selection includes all approaches in which the person designing the monitoring program decides where to locate the plots without using a grid system. This nonrandom approach has been used to select a majority of existing monitoring plots. Most historic USFS and BLM monitoring transects were selected subjectively by experienced range conservationists using the "key area" concept discussed below.

Subjective site selection can result in much more sensitive and representative monitoring programs. However, this is only possible where qualified personnel with a good understanding of local soil and vegetation patterns and processes design such monitoring programs.

Advantages

- Sensitive to local patterns and land use.
- Does not necessarily require access to maps and photographs.
- Inexpensive.

Disadvantages

- High potential for bias.
- Difficult to extrapolate.

Key areas

A key area is a tract of land that is assumed to be representative of much larger areas ***and*** is likely to reflect the effects of management changes on these larger areas. Key areas are often used in subjective plot selection.

Key areas have been used in the design of many monitoring programs throughout the world. Key areas, like any subjective approach, can be extremely effective when applied by qualified personnel.

Where used for monitoring livestock grazing effects, key areas are usually placed in an area that reflects typical livestock use. They are not located near watering points, mineral supplements, fences, trails or isolated areas of a pasture that are infrequently visited. The recommended distance from water varies with topography, vegetation and species or class of livestock.

Step 5.2. Select “rejection criteria” and use to eliminate unsuitable locations

List the rejection criteria in the space at the bottom of the Monitoring Program Design Form II (Ch. 4). Thoroughly describe the reasoning used to select these criteria. This is important because the criteria are used to help define how the monitoring data will be extrapolated and because what seems intuitive to us today may not seem intuitive to other individuals, or even to ourselves, many years later.

Rejection criteria can be based on almost anything. Many monitoring programs exclude areas that are thought to be anomalous because they receive unusually high or low levels of disturbance. Examples of rejection criteria include: (1) plots must be located a minimum of 100 yards from a road or watering point (to avoid unrepresentative high disturbance areas); (2) no plots on rock outcrops or slopes greater than 50 percent (these areas are unlikely to be disturbed).

Specific locations may also be anomalous because of landscape position. For example, areas that receive unusual amounts of runoff or have unusually dense stands of trees in a savanna may be rejected because they are not representative of larger areas.

Large areas that are not expected to change because they have crossed a threshold are also often omitted from monitoring programs. The state and transition model and indicators used to justify omission of these areas should be listed.

Rejection criteria should be carefully selected to ensure areas that should be monitored are not omitted. Also, the most unusual areas are often those that change the most quickly and may serve as early-warning indicators of degradation or recovery in other parts of the landscape. Rather than excluding these anomalous areas, we suggest that a stratified random site selection approach be used where possible. This allows apparently anomalous areas to be clearly identified as part of the monitoring program and potentially included in a future expansion of the monitoring program. Where there are areas of less interest (e.g., the post-threshold areas), monitoring may be limited to a few photo points.

It is highly recommended that a list of rejection criteria be developed prior to selecting and visiting monitoring locations. Deciding to reject areas after visiting them because they “don’t look right” introduces bias. See Chapter 17 for additional guidance on the use of soil and landscape features to improve monitoring data interpretation.

Chapter 6

Step 6: Establish monitoring plots

Checklist

6.1. Establish and permanently mark plots and transects .... _________
6.2. Describe monitoring plots and record GPS locations, including coordinate system, datum and zone .... _________
6.3. Record long-term data .... _________
6.4. Error check and copy the data and keep copies in different locations ..... _________

After you have gone through the previous five steps, this one should seem easy. It's important to carefully mark and describe each monitoring plot for two reasons: so you can find it again and so you can compare your data against data collected on plots with similar soils, topography and climate — all of the things that determine site potential. Use the equipment checklist for pre-field planning.

Step 6.1. Establish and permanently mark plots and transects

By now you should have already selected where the plots are to be located (Ch. 5). Be sure to verify that the site is suitable by checking it against the "rejection criteria" you list on the back of the Monitoring Program Design Form II (Ch. 4).

Step 6.1(a) Upland spoke design plots (Fig. 6.1). Place a permanent stake into the ground at the center of the monitoring plot. This stake will also serve as the photo point (Quick Start).

Using a randomly selected azimuth (compass direction: 1° to 360°), extend a tape in the azimuth direction to a distance of 5 m (15 ft) further than the length of the transect. Install a stake at the 5 m mark. This will serve as the 0 m end of your transect, because the transect begins 5 m from the center point (Fig. 6.1). Mark the far end of the transect with a stake.

Repeat transect establishment at regular intervals in a circle around the plot. The interval depends on the number of transects. For most applications, there will be three transects, with 120° between each.

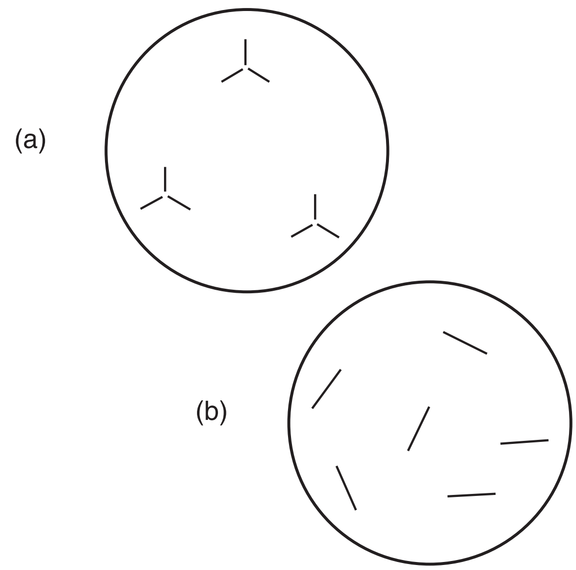

Figure 6.1. (a) Three spoke design plots located within an upland monitoring unit. The starting point of each transect is 5 m from the plot's center. (b) Single transect design maximizes spatial distribution across the landscape.

Step 6.1(b) Single transect upland plots. Anchor and mark the 0 m end of the transect. Using a randomly selected azimuth (compass direction: 1° to 360°), extend a tape in that direction the length of the transect. Mark the far end of the transect with a stake.

Step 6.1(c) Single transect riparian plots *(Fig. 6.2).* Anchor and mark the 0 m end of the transect. Ensure the 0 m end is placed such that the transect will cross the riparian channel perpendicular to the channel, and the 0 m end is 5 m beyond the riparian zone. Extend the tape perpendicular to the riparian channel. Mark the far end of the transect with a stake.

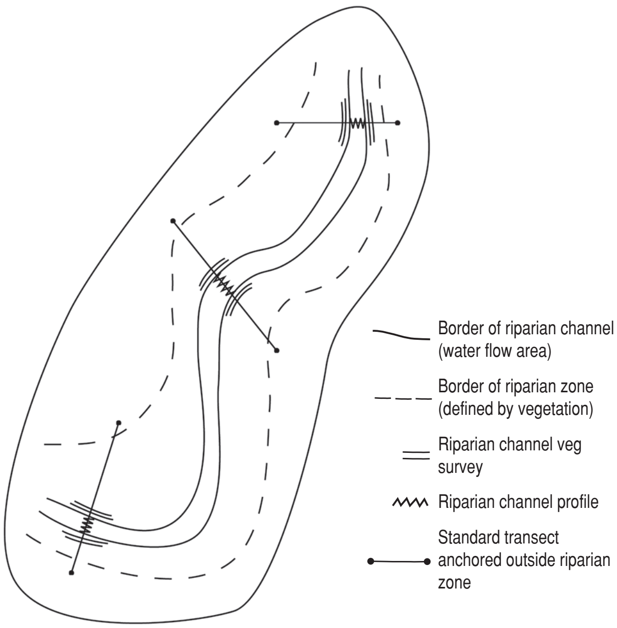

Figure 6.2. Single-transect plots crossing a stream within a riparian monitoring unit. Note that transects are anchored outside the riparian zone. See Chapters 13 and 14 for the Riparian channel vegetation survey and the Riparian channel profile measurements associated with riparian transects. Single-transect plots can be used in upland areas.

Step 6.2. Describe monitoring plots and record GPS locations, including coordinate system, datum and zone

At a minimum, fill out the Required section of the Monitoring Plot Description Form (found at the end of this chapter) when you establish each monitoring plot. This will ensure the same physical location is always monitored.

The Recommended section provides information regarding the plot's potential to support a given plant community, and enables you to verify the plot is on the mapped soil and ecological site. The data in this section allow you to determine how similar this plot is to other plots within the same ecological site. The information gathered here can help identify potential offsite influences. Data gathered in this section also assist in determining applicability of extrapolating plot data to the landscape level.

The Optional section addresses plot disturbances and management history. This information is valuable for data interpretation. It can help identify potential causes of trends and assist with important land management decisions.

The Recommended and Optional sections of the data form are important for data interpretation. It is best to fill out this information when you establish the plot, as you need to be on the plot to complete these sections. However, if you have time constraints, these sections can be completed during a second plot visit.

Required Section. Record the site, management unit and/or pasture name where the monitoring plot is located. A site, management unit or pasture is a distinct geographic unit typically with the same landowner and a relatively homogeneous management/disturbance regime. There are often multiple plots located within the same site, management unit or pasture.

Complete the remaining portions of the Required section to ensure a permanent record of plot and transect locations. Record the locations (e.g., GPS coordinates) on the Monitoring Program Design Form II and the Monitoring Plot Description Form. If you are using GPS coordinates, make sure to record the coordinate system, datum and zone, and whether the data are in English or metric units. Record geographic locations of the plot's center and the beginning and end of each transect. Document each transect's compass azimuth and record the declination used, if any.

Recommended Section. Record the average long-term precipitation under "Avg. Precip," indicating whether the units are English or metric. Determine the soil series by comparing soil observations (recorded in the table) with a soil survey. Do not rely on soil maps alone, although they can be used as guides. Soils can be extremely variable within broadly defined map units.

Dig a small pit at the plot's center and at the end of each transect. The pit should be deep enough to detect soil horizons that significantly affect plant growth. An auger or soil probe can be used instead of a pit if you are already familiar with the soils in the area. Any soil information is helpful. Don't worry if you are not sure how to distinguish soil horizons.

If you suspect there may be more than one type of soil within your plot boundaries, be sure to locate at least one of your mini pits within each soil type. It is very important to record the soil depth. Record the depth to any horizon that is likely to restrict water movement or root growth. If no restricting horizon is encountered, record the maximum depth of the pit and write "no restricting horizon."

Record the upper and lower boundary of each major horizon under soil depth (e.g., "Btk horizon" or "horizon with clay and carbonate accumulation" from 23 to 40 cm) (refer to USDA-NRCS 1999). Record information about each horizon in a separate row on the data form. Refer to *The Field Book for Describing and Sampling Soils,* Version 2.0 (Schoeneberger et al. 2002), for additional guidance.

If available, the soil survey will also provide information on soil parent material. For areas in the United States that have been mapped by the NRCS, the ecological site can be determined by looking up the soil series online (http://esis.sc.egov.usda.gov) or by consulting the Field Office Technical Guide in your local NRCS office or NRCS website. If ecological sites have not been developed, this space can be used to record any other land classification information (e.g., USFS Terrestrial Ecosystem Unit) that may assist with data interpretation.

Record the slope using a clinometer or other instrument. Record the slope's aspect, looking downslope, in compass degrees (e.g., 108°) or cardinal direction (SE). Record the slope shape as convex ($\cap$), concave ($\cup$) or linear (straight, not curved) (Lal 2003).

Record the landscape unit on which your plot is located. If the plot is located on a hill/mountain, select the appropriate hillslope profile component (see list on data form). If the plot is located on a terrace, indicate whether it is on the riser (fairly short, steep, linear slope that forms the sideslope of the terrace) or the tread (a broad, relatively level planar portion forming the top of the terrace that can extend laterally for great distances). Refer to any of the following for assistance: *Encyclopedia of Soil Science* (Lal 2003), the *Field Book for Describing and Sampling Soils* (Schoeneberger et al. 2002), *Landforms of the Basin and Range Province* (Peterson 1981), *Geomorphology of Soil Landscapes* (Wysocki and Zanner 2003) and *National Soil Survey Handbook,* Part 629, Glossary of Landform and Geologic Terms, online at http://soils.usda.gov/technical/handbook/detailedtoc.html#629 (USDA-NRCS 2003).

Optional Section. Record recent weather patterns for the previous 12 months and the year prior. Record any disturbances and management information that might impact the plot. Describe all known or observed wildlife and livestock use, including utilization, seasonality, intensity and residual cover. Describe previous management history dating as far back as possible. Describe offsite influences, including, but not limited to (a) unusually high runoff or erosion from upslope areas, (b) management practices, (c) presence of invasives in the area, and (d) roads. Document any other pertinent information under "Other comments." Draw a depiction of the plot and record all potential drivers and other influences.

Step 6.3. Record long-term data

There are four options:

(1) Enter data onto paper data forms photocopied from each chapter.
(2) Enter data onto paper Microsoft® Excel spreadsheet forms printed from the website listed below.
(3) Enter directly onto downloaded Excel spreadsheet forms using a laptop or tablet computer.
(4) Enter directly into a database (see website for future download at http://usda-ars.nmsu.edu).

Step 6.4. Error check and copy the data and keep copies in different locations

All data should be checked for errors, using the steps below. This process can and often should take as long as data entry.

Step 1. Before leaving the plot, review all forms for completeness and legibility. If you used a digital camera, review all of the photos to be sure that plot information is visible. If the data were entered directly into a computer, open and inspect each file and make a backup copy on a separate device.

Step 2. Immediately upon returning from the field, copy the data and store in at least two different buildings. This is especially important if you are using electronic data entry. Unless you have at least one backup copy on media that you are sure will be readable in the future (remember $5^1/_2$ in disks, punch cards and tape drives?), then we recommend printing copies of your data for archiving. Be sure that someone else knows where the extra copies are.

Step 3. Review all data for obvious errors. For example, check to see that each column on the Line-point intercept form includes only those codes assigned to that column. Gap intercepts should not overlap. Soil stability values should be between 1 and 6. See Table 6.1 for an example of a Compaction test (Ch. 7) dataset that includes potential outliers (extreme values) at positions 3 and 6 that may or may not be errors. If we know that this site had shallow soil or large rocks or near-surface bedrock, we could justify deleting the two bolded data points by assuming that the penetrometer struck a rock. We could also delete them if we were fairly certain that the data recorder had lost count. However, it is also possible that both measurements were made on a game or livestock trail. In this case, they should be retained. When in doubt, retain the data and make a note.

Step 4. If the data were originally recorded on paper forms, re-check each value after computer entry. One way to do this is for one person to read the values aloud from the data form while another checks the values in the spreadsheet or database. Your data are now ready for indicator calculation (Ch. 16 and individual methods chapters) and interpretation (Ch. 17).

Table 6.1. Example of Compaction test data with two outliers (in bold type) that may or may not be "out-and-out liars."

Pos on Line	Cumulative Strikes			
	5cm	10cm	15cm	20cm
1	5	11	18	28
2	3	9	18	30
3	4	10	20	**74**
4	4	11	22	30
5	6	11	19	27
6	5	10	24	**98**
7	4	12	22	33
8	3	9	17	26
9	4	12	19	27
10	5	13	20	29

"Outliers"

Values that are clearly outside the range of expected variation may be omitted if it is clear that these values were due to measurement or data recording errors. Extreme care should be taken to ensure that these values are in fact mistakes before omitting them.

A famous ecologist once said, "There are data that are outliers (meaning that they lie outside the normal range of variation) and then there are "*out-and-out liars*." Be sure that you only exclude the "out-and-out liars." The other outliers may be extremely important in defining the current status of the system.

Equipment checklist. All items included in this list are required each time measurements are made, except for those items found only in the "Plot Establishment and Description Equipment" list. Add columns for supplementary methods and rows for additional equipment. See Ch. 6 for more detail on monitoring plot establishment.

Plot Establishment and Description Equipment	Have?
Clipboard, data forms, pencils OR field computer with data entry software	
Clinometer	
Compass	
GPS unit, with waypoints entered, or map of monitoring plots	
Hammer for pounding in rebar	
Keys and gate combinations	
Landowner notified (if necessary)	
Measuring tape (5 m longer than the transect length) – at least 1, ideally 3, for "spoke" layout	
Metal tape measure (for soil depth)	
Rebar (3 ft) or other stakes for marking transect ends	
Shovel	
Soil characterization tools	
Steel stakes: 2-6 (tape anchors)	
Water for moistening soil for soil texture estimates	
1 M HCl (hydrochloric acid) for effervescence (only needed where soil carbonates used for soil identification). **Caution: HCl can cause burns. If used, obtain MSDS (Materials Safety Data Sheet) and follow all safety guidelines.**	

Basic Equipment (needed for nearly all data collection)	
Compass	
GPS unit with waypoints entered, or map of monitoring plots	
Keys and gate combinations	
Landowner notified (if necessary)	
Measuring tape (transect length) - at least 1, ideally 3 for "spoke" layout	
Steel stakes: 2-6 (tape anchors)	

Additional Equipment Required for Each Measurement/Method								
Equipment	**Photo points**	**Line-point intercept**	**Gap intercept**	**Soil stability test**	**Belt transect**	**Other:**	**Other:**	**Other:**
PVC pole: 1.5 m (5 ft) long	X							
Camera	X							
Whiteboard, chalkboard or Photo point ID card	X							
Thick marking pen	X							
Clipboard, data forms, pencils OR Palmtop/field computer with data entry software	X	X	X	X	X			
Pin flag or other pointer (tip <1 mm [1/25 in] diameter)		X						
Meter stick, pinning stake or other stiff stick or rod			X					
Soil stability kit				X				
Deionized water: 1 liter (32 oz) per test (18 samples)				X				
Stopwatch				X				
PVC pipe (at least 1/2 of Belt transect width)					X			

Monitoring Plot Description Form (Page 1 of 2)

Required

Site / Management Unit / Pasture: ______________ **Date:** _____________ **Line Length:** _____(m or ft?)

GPS Coordinate System: ________________ **Datum:** ___________ **Zone:** _______ **m or ft?** _______

Plot / Line	Azimuth	Location: __________ (e.g., 0 m end)		Location: _________ (e.g., 50 m end)		Elevation m or ft?
		Northing/Latitude	Easting/Longitude	Northing/Latitude	Easting/Longitude	

Directions to plot: ____

____

Recommended

State: ____ **County:** ______________ **Avg. Precip:** ___________ **Ecol. Site:** ______________________

Soil Series/Map Unit (verify on site): _________________________ **Parent Material:** __________________

Vertical Slope Shape: ____ Convex ____ Concave ____ Linear

Slope: _____% **Aspect:** ______ **Horizontal Slope Shape:** ____ Convex ____ Concave ____ Linear

Mini pit location	Soil depth (cm / in)	Texture	Rock fragments (%)	Efferves-cence	Color	Structure Grade	Structure Shape	Consistence Strength (dry or moist)

Landscape Unit:

___Hills/Mountains* ___Fan Piedmont ___Floodplain/Flood basin ___Terrace** ___Flat plain

***Hillslope Component:** __Summit __Shoulder __Backslope __Footslope __Toeslope __Other: ____________

****Terrace Component**: ___Riser ___Tread ___Other:_____________

Disturbances and Management History

(Monitoring Plot Description Form Page 2 of 2)

Optional

Recent weather: Past 12 months: Drought: ________ Normal: _________ Wet: __________

Previous 12 months: Drought: ________ Normal: _________ Wet: __________

Recent Disturbances (check all that apply):

___Wildfire

___Small rodents

___Larger mammals (not rodents)

___Water

___Wind

___Soil deposition from water

___Soil deposition from wind

___Underground utilities

___Overhead transmission lines

___Other (describe):____________________________________

Describe wildlife and livestock use:____

____

____

Describe management history (i.e., grazing plan, prescribed fire, shrub control, seeding, plowing, water units):____

____

Describe offsite influences on this plot: ____

____

____

Other comments: ____

____

____

Draw plot and surrounding landscape. Describe all off-site and on-site drivers and other influences.