Appendix A: Monitoring tools

Measuring tapes, stakes and flags are available through most hardware stores and natural resource supply catalogs. Manufacturers of, and instructions to build, less widely available tools are listed below. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. The tools are not patented. None of the authors receive any compensation from manufacturers.

Caution. Fabrication of these tools, like any shop fabrication project, can result in injury. If you are not comfortable with the required procedures and standard safety protocols, *find someone who is*.

Table A.1. List of specialized tools used in methods described in the manual.

Tools	Manufacturers (as of June, 2004)
Soil stability kit*	Synergy Resource Solutions
Impact penetrometer*	Darbyshire Machine Synergy Resource Solutions
Single-ring infiltrometer*	Synergy Resource Solutions
Cover pole*	Synergy Resource Solutions
Riparian channel vegetation survey pole*	Synergy Resource Solutions
Laser pointer for Line-point intercept	Synergy Resource Solutions

* Instructions for constructing these tools included below.

Manufacturer contact information:

Darbyshire Machine, Inc.
P.O. Box 4410, Anthony, NM 88021
1-800-291-6818 —darby@darbyshire.com
www.darbyshire.com

Synergy Resource Solutions, Inc.
5393 Hamm Rd., Belgrade, MT 59714
406-388-9378 —Synergy@countgrass.com
www.countgrass.com

Soil stability kit (Quick Start)

Materials needed for construction of stability kits:

- Schedule 40 PVC pipe with a $^3/_4$ in inside diameter
- PVC pipe cutter and hacksaw
- Tape measure and pencil
- A section of metal window screen (mesh size approx. 1.5 mm [$^1/_{16}$ in])
- A bottle of water-resistant contact cement
- A plastic trash bag
- 2 plastic "parts" boxes (21 x 11.5 x 3.5 cm outside dimensions [8 $^1/_2$ x 4 $^{15}/_{32}$ x 1 $^5/_{16}$ in]) with 18 cells, approximately 3 x 3 x 3 cm each (1 $^1/_4$ x 1$^1/_4$ x 1 $^1/_4$ in each)
- One small tube of silicone sealant
- A small piece of sheet metal, handle of an old spoon, or pocket knife

1. Stability basket construction.

1.1 Cut pieces of PVC pipe into 3 cm (1 $^1/_4$ in) lengths.

1.2 Make a 2 cm deep, cross-sectional cut, 5 mm from one end (Fig. A.1).

1.3 Make the second cut perpendicular to the first, ending at the end of the cross-sectional cut in step 1.2 (Fig. A.2). This forms the basket handle.

1.4 Remove burrs from all cuts.

1.5 Lay out a section of window screen on top of a plastic trash bag. Make sure the screen is flat and has no creases.

1.6 Apply contact cement to the bottom of the cut PVC and quickly place on top of the screen (Fig. A.3). Apply glue only in areas with adequate ventilation.

1.7 Allow contact cement to dry overnight.

1.8 After 24 hours, remove the plastic trash bag from the screen. Cut out each basket from the screen (Fig. A.4).

2. Plastic box preparation.

2.1 If the plastic box has removable parts, be sure to glue them into place.

2.2 Use silicone caulk or sealant to seal all corners inside the box.

3. Stability shovel construction.

3.1 Using tin snips, cut out the shape of the stability shovel from a piece of thin sheet metal, tin can, aluminum weighing tin or similar material with a thickness of 1 mm ($^1/_{32}$ in) or less (Fig. A.5).

Figure A.1. First cut on PVC.

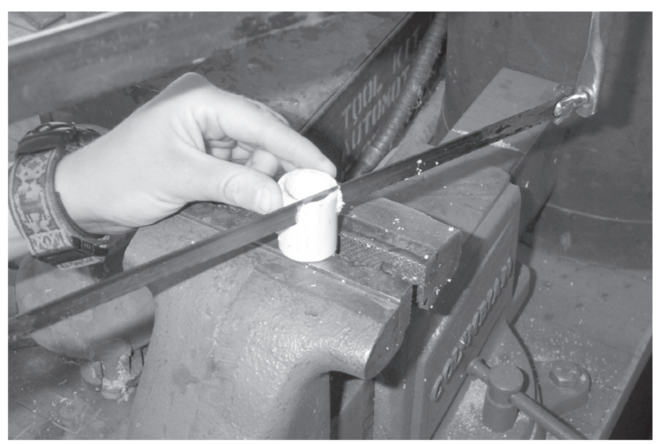

Figure A.2. Second cut on PVC.

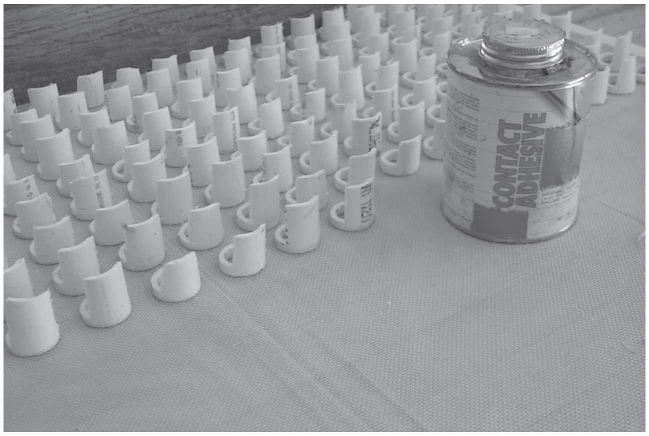

Figure A.3. Baskets glued to screen.

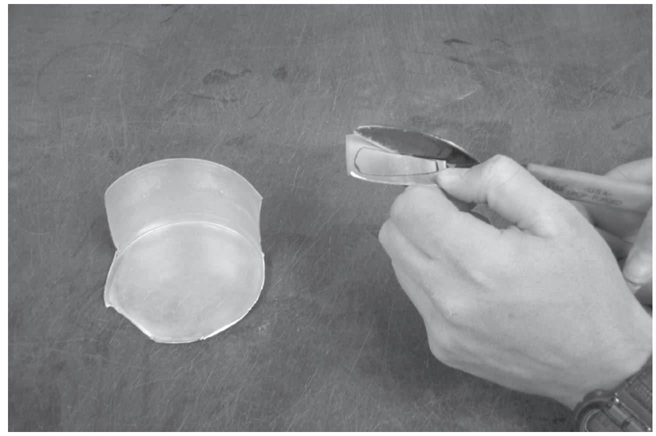

Figure A.5. Cutting shovels with tin snips.

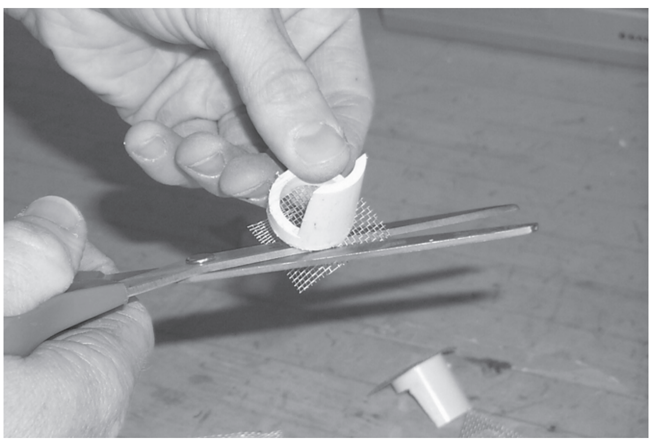

Figure A.4. Cutting out baskets from screen.

Impact penetrometer (Chapter 7)

Materials needed for construction of impact penetrometers:

- 0.625 in (15.9 mm) diameter steel rod 60.0 in (152.40 cm) long
- Removable steel cone, hardened and smoothed to a shiny finish (see Fig. A.6 for dimensions)
- 2.0 kg sliding steel hammer, 15.75 in (40 cm) long with internal diameter of 0.688 in (17.5 mm) and external diameter of 2.0 in (5.1 cm)
- 0.5 in (12.7 mm) thick steel striker plate with 1.25 in (3.18 cm) external diameter
- Adjustable steel collar

Note:
Most machine shops should be able to construct the impact penetrometer from Figure A.6 and the instructions below.

1. Steel penetrometer rod construction.

1.1 The 60 in (152.4 cm) steel rod is 0.625 in (15.9 mm) in diameter and is constructed of 2 pieces (Fig. A.6).

1.2 Etch the lower rod at 5 cm (1 $^{31}/_{32}$ in) increments, starting from the top of the cone and ending at 50 cm (19 $^{11}/_{16}$ in).

1.3 Thread the bottom of the upper rod (male) to join with the striker plate (female).

1.4 The striker plate extends 0.39 in (1 cm) out of the rod.

1.5 The upper rod contains the sliding steel hammer and adjustable steel collar.

2. Removable steel cone construction.

2.1 The removable steel cone is 0.015 in (0.38 mm) in radius at its point and 0.8 in (20.3 mm) in diameter at its base.

2.2 See Figure A.6 for cone angle specifications.

2.3 The base of the cone contains a threaded end (male) that connects to the lower, etched rod.

2.4 The cone is one seamless, hardened unit, and the cone is smoothed to a shiny finish (Fig. A.6).

3. 2.0 kg (4.51 lbs) sliding steel hammer construction.

3.1 The sliding steel hammer should be exactly 2.0 kg (4.51 lbs).

3.2 Stamp the exact weight on the hammer.

3.3 The steel hammer should be approximately 15.75 in (40.0 cm) in length, and must slide over the upper rod (Fig. A.6).

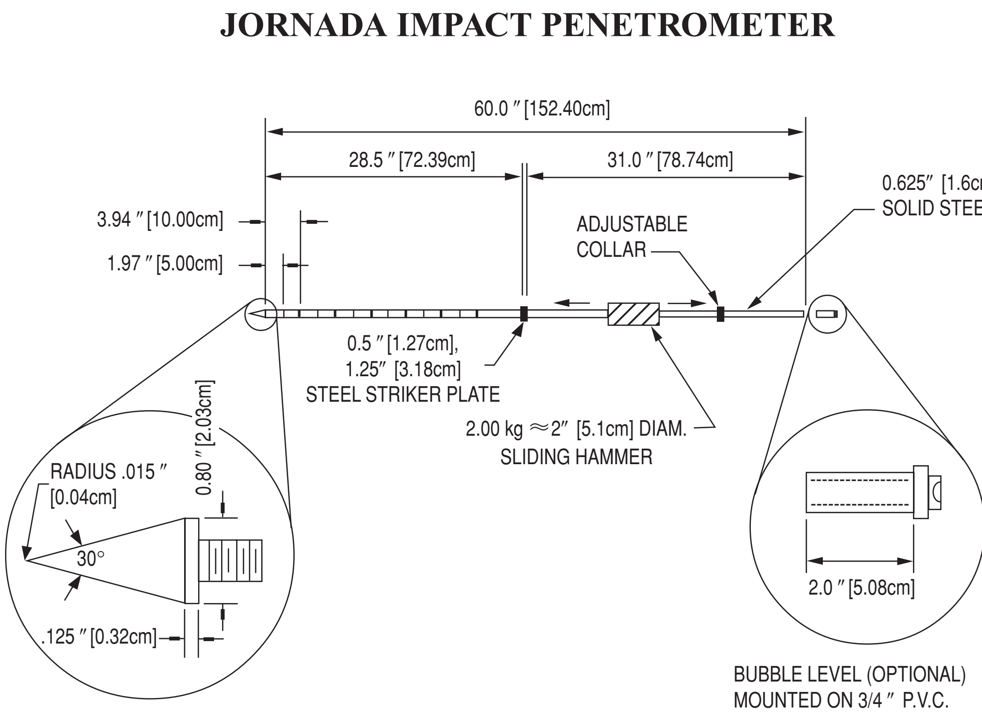

Figure A.6. Impact penetrometer design (Herrick and Jones 2002). All dimensions are in inches [cm]. Use steel for all parts except for the bubble level mount. Weld the striker plate to the center of a single rod, or to the bottom half of a two-piece rod. Thread the top half. Cut the cone, from steel, on a lathe and then harden. Shorten the penetrometer for transport by threading the bottom end of the top section of the shaft into the striker plate. Always wear protective clothing when using the penetrometer (ear plugs and heavy leather gloves).

Single-ring infiltrometer (Chapter 8)

Materials needed for construction of six infiltrometers:

- At least 72 cm (28 $^{11}/_{32}$ in) of 12.5 cm (5 in) diameter thin-walled (max 1.5 mm [$^{1}/_{16}$ in] thick) metal cylinders (irrigation pipe is ideal; stovepipe is OK provided that seams [if any] are sealed).
- 1 hacksaw
- 1 grinder or metal file
- Bath towels
- Two 20-oz plastic pop bottles
- Flexible plastic grocery bags
- One five-gallon bucket of water
- One 15 cm (6 in) ruler
- One stopwatch
- At least six (ideally 18) wide-mouthed, smooth-sided, 32-oz plastic soda bottles
- 18 to 20 gauge steel wire
- A drill and $^{29}/_{64}$ in or $^{7}/_{16}$ in bit
- At least six (ideally 18) plastic serological pipette tubes (10 ml in $^{1}/_{10}$)
- Silicone caulking
- Six 0.5 in (1 $^{5}/_{16}$ cm) rubber stoppers with a hole in the center that is slightly smaller than the diameter of the pipettes.
- Six thin rubber bands, large enough to stretch around the bottle
- Black felt-tip permanent marker

1. Infiltrometer ring construction.

1.1 Cut 12.5 cm (4 $^{15}/_{16}$ in) diameter irrigation pipe (or stove pipe) into 12 cm (4 $^{23}/_{32}$ in) lengths and remove burrs.

1.2 Sharpen the end that will be inserted into the soil to a 45° angle, using a grinder or metal file.

1.3 Drill 2 small holes, 5 mm (0.2 in) apart and 1 cm (0.4 in) below the top edge of the ring, at three equally spaced locations around the ring (Fig. A.7).

1.4 Thread wire through the rings so that a triangle is formed inside the ring (Fig. A.8).

1.5 Pull the wire tight.

1.6 Using a permanent marker, draw an insertion depth line around the outside of the ring, 3 cm above the bottom.

1.7 Repeat steps 1.1 through 1.6 until six (ideally 18) rings are constructed.

2. Infiltration bottle construction.

2.1 Remove the label from the 32 oz, wide-mouthed, smooth-sided soda bottle.

2.2 Drill a hole in the bottom center of the bottle that is slightly larger than the small end of the rubber stopper. The hole should be 12 mm in diameter. A $^{29}/_{64}$ in drill bit works best. A $^{7}/_{16}$ in drill bit will work, but requires widening the hole.

2.3 Position a rubber stopper in hole (Fig. A.9).

2.4 Slide a plastic pipette into the rubber stopper so the end is almost to the cap. Lubricate pipette with silicone grease.

2.5 Cut off the end of the pipette if it protrudes more than 10 cm (3.9 in) outside the bottom of the bottle.

2.6 Apply three 10 cm (3.9 in) beads of silicone caulking at equally spaced intervals around the bottle. Start at the top of the bottle and go to about its mid-section (Fig. A.10).

2.7 Using a marker, draw a line down the smooth portion of the bottle (Fig. A.11).

2.8 Slide the rubber band around the bottle.

2.9 Repeat steps 2.1 through 2.8 until six (ideally 18) bottles are constructed.

3. Accessories

3.1 Cut up bath towels into five 25 x 50 cm (10 x 20 in) pieces.

3.2 Cut the tops off of the two 20 oz plastic soda bottles. Draw a line indicating the 375 ml water level, using a permanent marker.

3.3 Cut the flexible plastic grocery bags into two 30 x 30 cm (12 x 12 in) sheets.

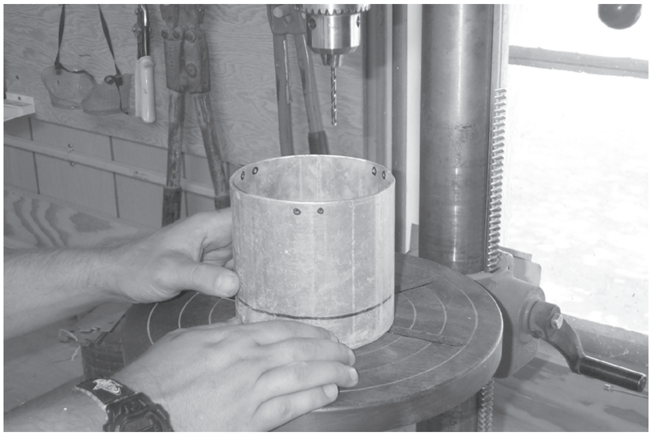

Figure A.7. Drill three equally spaced pairs of holes 1 cm from the top of the ring. Each hole should be 5 mm from its pair.

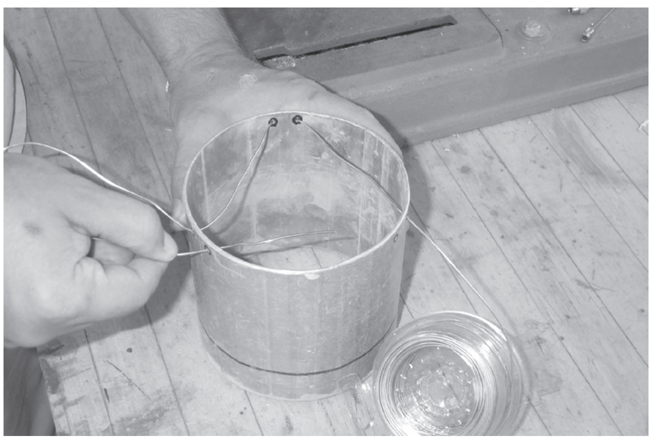

Figure A.8. Thread wire through holes and tighten.

Figure A.9. Drill hole in bottom of wide-mouthed, 32 oz soda bottle and insert stopper.

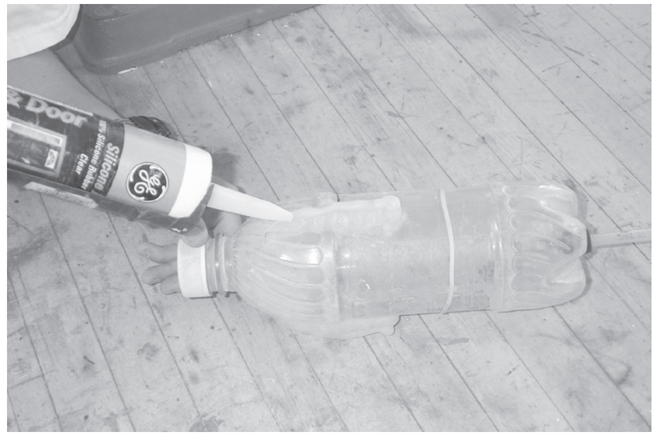

Figure A.10. Apply three 10 cm silicone beads from top of bottle to mid-section.

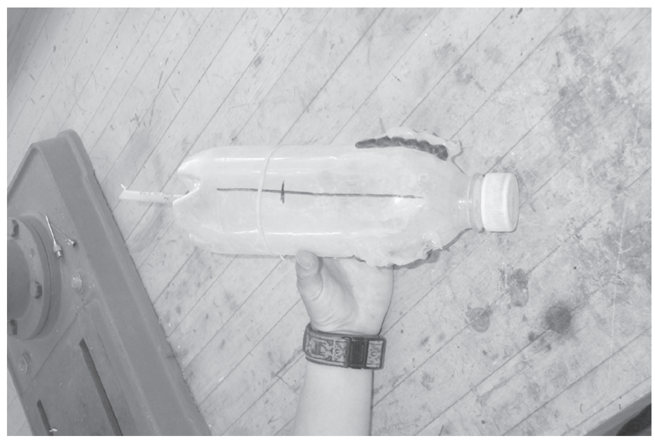

Figure A.11. Draw line along smooth length of bottle.

Cover pole (Chapter 11: Vegetation structure)

Materials needed for cover pole:

- 2 m (78 $^3/_4$ in) of 1-in (2.5-cm) diameter PVC pipe
- One male-threaded PVC coupling
- One female-threaded PVC coupling
- PVC pipe cleaner, primer and glue
- One aluminum $^3/_4$ in (1.9 cm) wide tent stake
- One 1 in (2.5 cm) diameter PVC tube cap
- Masking tape
- Enamel paint (white, fluorescent orange, black)
- Spar-urethane glossy varnish
- Epoxy
- Drill with $^1/_4$ in (6 mm) drill bit
- Hacksaw

Materials needed for sight pole:

- 1.1 m (43 $^5/_{16}$ in) of $^1/_2$ in (1.3 cm) PVC pipe
- Two $^1/_2$ in (1.3 cm) PVC tube caps

1. Cover pole construction:

1.1 Cut the 1 in (2.5 cm) diameter pipe into two 1 m (39 $^3/_8$ in) lengths.

1.2 Attach male coupling to pipe, using the cleaner, primer and glue.

1.3 Repeat process with other pipe half and female coupling (Fig. A.12).

1.4 Connect two halves at coupling.

1.5 Measure and trim the connected pipe back to a 2 m (78 $^3/_4$ in) length.

1.6 Drill one hole each at 1 in and at 2 in (2.5 and 5 cm) above the bottom of the pipe. Each hole should be $^1/_4$ in (6.4 mm) in diameter.

1.7 Cover all holes, except for the one at the 2 in (5 cm) level, using the masking tape.

1.8 Drill two $^1/_4$ in holes into the tent spike in the area that will be between the end of pipe and the 2 in hole.

1.9 Insert tent spike into the bottom of the pipe so that at least 3 in of the spike protrudes below the end of the pipe (in areas with very loose topsoil increase protruding spike length).

1.10 Using masking tape, seal the bottom of the pipe to hold the spike in place and inject epoxy into one of the open holes until epoxy reaches the 2 in level.

1.11 Let epoxy dry, with spike straight in the pipe (Fig. A.13).

1.12 Using masking tape and paint, paint alternate 10 cm segments white and black with every 5th section painted fluorescent orange (Fig. A.14).

1.13 Once dry, coat with spar-urethane to avoid scratches and UV degradation of paint colors.

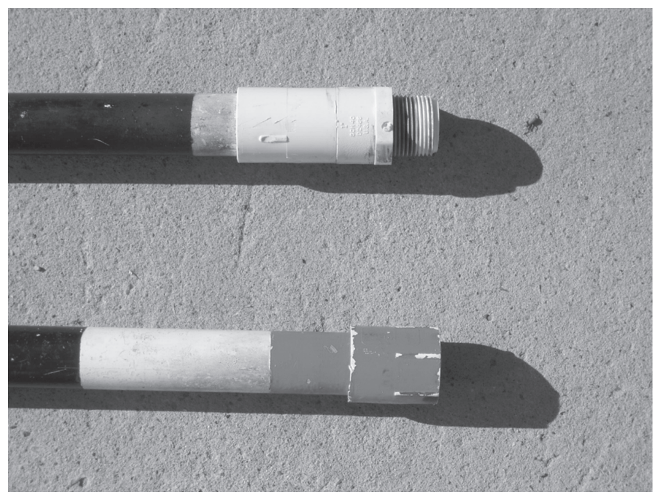

Figure A.12. Male and female couplings for cover pole.

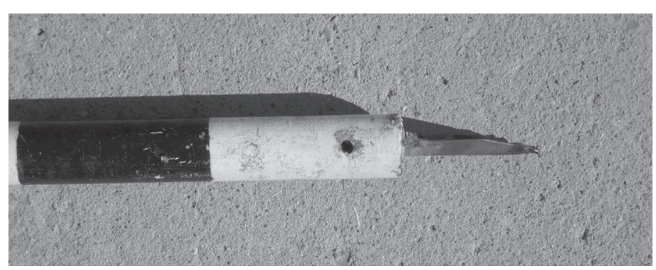

Figure A.13. Spike attached to cover pole.

2. Sight pole construction:

2.1 Using the cleaner, primer and glue, attach one cap to end of pipe.

2.2 Measure 1 m from end of cap and drill $^{1}/_{4}$ in hole through pipe.

2.3 Attach cap to other end of pipe without using glue (can be used as storage for Line-point intercept pin flags).

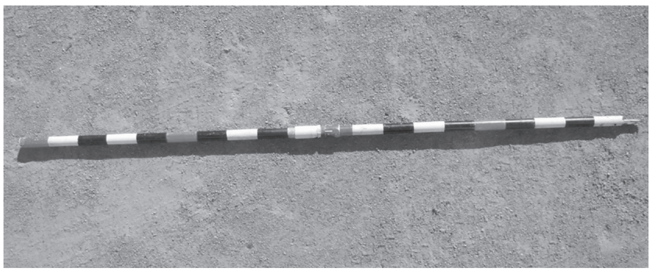

Figure A.14. Completed cover pole.

Monitoring tools

Riparian vegetation survey pole (Chapter 13)

Materials needed for construction of L-tool for Riparian channel vegetation survey:

- 2 m (78 $^{3}/_{4}$ in) of $^{3}/_{4}$ in (1.9 cm) inside diameter schedule 40 PVC pipe
- One $^{3}/_{4}$ in PVC elbow joint
- One $^{3}/_{4}$ in PVC T-joint
- PVC cement
- One hacksaw
- One meter stick
- One permanent marker

1. L-tool construction.

1.1 Cut four pieces of $^{3}/_{4}$ in diameter PVC pipe, as follows: one 50 cm (11 $^{11}/_{16}$ in) piece, one 100 cm (39 $^{3}/_{8}$ in) piece and two 10 cm (3 $^{15}/_{16}$ in) pieces.

1.2 Connect and glue the 100 cm (39 $^{3}/_{8}$ in) pipe to the 50 cm (11 $^{11}/_{16}$ in) pipe with the elbow joint.

1.3 Connect the T-joint to the end of the 50 cm (11 $^{11}/_{16}$ in) pipe and position it parallel with the 100 cm (39 $^{3}/_{8}$ in) pipe. Glue in place.

1.4 Place a 10 cm (3 $^{15}/_{16}$ in) piece on each open end of the T-joint and glue in place.

1.5 The finished product should look like Figure A.15.

1.6 Mark and label lines every 10 cm (3 $^{15}/_{16}$ in) on the 100 cm (39 $^{3}/_{8}$ in) pipe to determine plant height.

2. Optional laser installation.

2.1 The L-tool works much better with a double-ended laser pointer in place of the "T".

2.2 For sources, see Table A.1.

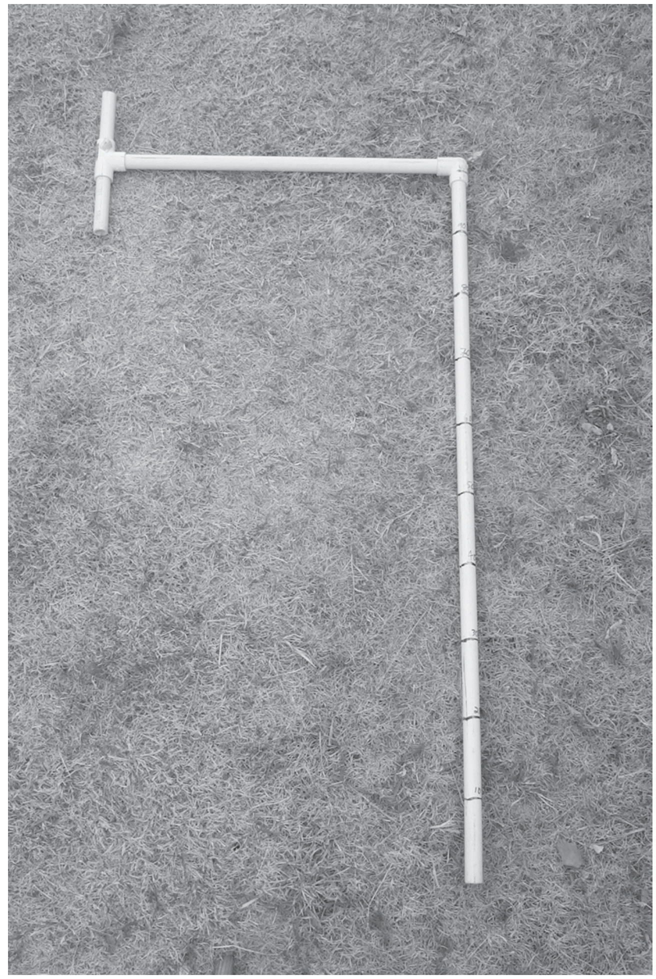

Figure A.15. L-tool design.

Appendix B: Conversion factors

English units are used wherever practical. Metric units are used for linear measurements. The advantage of metric tapes is that a single number (cm) can be used to record distances. Decimal feet tapes may be substituted; the calculations remain the same. Metric tapes are available from Forestry Supplier, Ben Meadows, Gemplers and other catalog suppliers. They are also increasingly available at building supply stores.

feet	X	0.305	=	meters	meters	X	3.281	=	feet
inches	X	2.54	=	centimeters	centimeters	X	0.394	=	inches
inches	X	25.4	=	millimeters	millimeters	X	0.039	=	inches
miles	X	1.609	=	kilometers	kilometers	X	0.621	=	miles
acres	X	0.405	=	hectares	hectares	X	2.471	=	acres
quarts	X	0.946	=	liters	liters	X	1.057	=	quarts
ounces	X	29.57	=	milliliters	milliliters	X	0.034	=	ounces
pounds	X	0.454	=	kilograms	kilograms	X	2.205	=	pounds
ounces	X	28.35	=	grams	grams	X	0.035	=	ounces
lb/acre	X	1.12	=	kg/ha	kg/ha	X	0.891	=	lb/acre
square meters	X	10.764	=	square feet	square feet	X	0.0929	=	square meters

Appendix C: How many measurements?

Introduction

This appendix describes three options for deciding how many measurements to make for selected indicators. Option 1 is the simplest. Option 3 is the best.

Option 1
General recommendations for arid and semi-arid grasslands and shrublands based on a study of eight plant communities in southern New Mexico, USA.

Option 2
Specific results for each of the eight plant communities.

Option 3
Equations for calculating measurement requirements based on available data for your area.

For Options 1 and 2, Type I error = 0.2 and Type II error = 0.2; Power = 0.8; rho = 0.5. The Internet version will allow for modification of these parameters (select "Monitoring and Assessment" from http://usda-ars.nmsu.edu). We will update these recommendations as new information becomes available for different ecological sites.

Table C.1. Information requirements.

	Option		
	1	2	3
Minimum detectable change desired for each indicator	**Yes**	**Yes**	**Yes**
Knowledge of plant community composition and structure	No	**Yes**	**Yes**
Data from your plots	No	No	**Yes**

Definitions

Type I error. Type I error is the probability that you will conclude that a change has occurred when there has been no change.

Type II error. Type II error is the probability that you will conclude that no change has occurred when there really has been a change. Scientists often set Type I error at 0.05 and ignore Type II error, allowing it to exceed 0.5 in many cases. For most monitoring studies, we set Type I = Type II = 0.2 because it is usually just as important to be able to detect real change as it is to avoid falsely concluding that change has occurred. Reducing either type of error requires increasing the number of measurements.

Power. Power is the probability that you will conclude that a change has occurred when there really has been a change. It is equal to 1 minus Type II error.

Rho. Rho is the correlation between sampling unit values in the first time period and sampling unit values in the second time period. Increasing rho reduces the number of replications required. For example, sampling requirements decline by 50 percent if rho is increased from 0.5 to 0.75.

Returning as close as possible to the location of the original transect increases rho. Remember, however, that while it is important to place the transect in approximately the same location each year, it is unnecessary (and generally impossible) to measure exactly the same *points* each year. Note that for comparisons between two independent plots, rho = 0.

Average. Average is the sum divided by the number of values.

Median. Median is the value within a group of numbers at which half the values are larger and half are smaller.

Plot scale. Plot scale is the scale at which we normally collect monitoring data. An individual plot is defined as one hectare (2.5 acres). One hectare (2.5 acres) is the area covered by a spoke plot with three 50 m transects starting 5 m from the center. This scale is appropriate if the key area concept is applied—that is, if you are confident that change detected in an individual plot accurately reflects changes occurring across larger areas.

Landscape scale. Landscape scale is the scale at which statistically based monitoring programs are normally applied. Change is detected using multiple plots located within relatively homogeneous monitoring units (see Volume II, Section I).

Data for Options 1 and 2

The recommendations listed under Options 1 and 2 are based on a study completed in southern New Mexico, USA in 2000. Measurements were completed on three transects in each of three plots in eight plant communities (Fig. C.1; Table C.2). The plant communities represented a relatively degraded and non-degraded state in each of four ecological sites.

Caution

While this is one of the more comprehensive studies of replication requirements for a variety of soil and vegetation measurements, *it is still extremely limited*, particularly for the recommendations at the landscape (monitoring unit) scale. The Option 1 estimates are based on a total of 72 transects and 24 plots. Each Option 2 estimate is based on just nine transects and three plots. Furthermore, these data are specific to southern New Mexico. The estimates will tend to be more accurate in regions where plant communities are similar in structure to the Chihuahuan Desert (e.g., Great Basin and Sonoran Desert), and less so in regions with different plant community structure (e.g., annual grassland and shortgrass prairie). We have included footnotes highlighting specific characteristics of the plots sampled that may explain unusually high values.

See our website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Assumptions

The tables printed here are based on the following assumptions:

- Type I error (*p*-value) = 0.2
- Type II error (1 – power) = 0.2
- Rho (between-date correlation) = 0.5
- The absolute minimum number of replications is 2.

The "rho" assumption is extremely important. Sampling requirements decline by 50 percent if rho is increased to 0.75. The value of 0.5 is conservative. The value will be higher (and therefore sampling requirements lower) in most monitoring programs. Rho = 0.5 was selected based on the results of a different multi-year study in a semi-arid environment where a 30 m transect was shifted left or right at least 1 m (3 ft) within a 6 m (18 ft) band each year.

The absolute minimum number of transects was set to two to ensure that the data can be statistically analyzed. In some cases, our analyses (for Options 1 and 2) generated replication recommendations that were less than two.

These assumptions are for design purposes only. Your ability to detect change depends on site variability. If your site is more variable than the sites used to generate these recommendations, the minimum detectable change will be larger for a given sample size. If your site is less variable, you will be able to detect a smaller change. It is nearly always better to establish more transects than you think you need, as the number can later be reduced without information loss.

When you analyze your data, you can calculate rho, set Type I and II errors at any level, and determine how many transects need to be re-measured in future years using the equations in Option 3.

Instructions: Option 1

Choose Option 1 if you are comfortable using the median sample size recommendations from all eight communities combined. If you are not comfortable using the median of all eight communities, use Option 2 or 3. Use Tables C.3 and C.4 to determine how many transects and measurements are required at the plot scale. Use Tables C.5 and C.6 to determine how many plots (with the specified number of transects and measurements) are required at the landscape scale. Please see the “Caution” and “Assumptions” sections in the Introduction above.

Plant Community

Sandy loam - Loamy sand

(Sandy Ecological Site)

A. Stoloniferous grasses (*Bouteloua eriopoda* [black grama])

B. Large shrubs (*Prosopis glandulosa* [honey mesquite])

Sandy loam

(Shallow Sandy Ecological Site)

C. Rhizomatous/stoloniferous/bunchgrasses (*B. eriopoda & B. gracilis* [black & blue grama])

D. Rhizomatous/stoloniferous grasses and sub-shrubs (*Gutierrezia sarothrae* [snakeweed])

Very fine sandy loam

(Gyp Upland Ecological Site)

E. Salt desert shrubland (*Atriplex canescens* [fourwing saltbush])

F. Degraded salt desert shrubland (*A. canescens* [fourwing saltbush])

Clay loam

(Clayey Ecological Site)

G. Banded (patchy) stoloniferous grasses (*Pleuraphis mutica* [tobosa])

H. Patchy stoloniferous grasses (*Scleropogon brevifolius* [burrograss])

Figure C.1. Photographs of each plant community used to generate the sampling requirement estimates listed for Options 1 and 2.

Table C.2. Average indicator values for each plant community used for Options 1 and 2.

	Cover (%)			Area in gaps > min. length (%)				Soil stability (class)		Compaction test (penetrometer strikes)		Infiltration (Single-ring)
				Canopy		Basal						
Community*	Canopy (foliar)	Basal	Bare ground	25 cm	50 cm	50 cm	100 cm	Surface	Sub-surface	0-10 cm	0-20 cm	(mm/hr)
A	70	5	22	48	36	74	51	4.6	1.6	11	37	271
B	28	7	57	76	72	91	86	2.1	1.3	6	18	241
C	57	18	24	29	9	27	6	5.2	3.6	12	27	88
D	50	9	27	30	14	33	14	4.1	2.7	15	38	86
E	25	2	29	88	84	94	89	5.8	2.5	5	17	300
F	13	1	40	93	89	95	91	5.8	3.0	14	32	170
G	47	6	43	56	44	63	45	4.8	2.9	22	56	78
H	36	6	43	62	42	62	36	4.3	2.2	19	43	58
Average	**41**	**7**	**36**	**60**	**49**	**67**	**52**	**4.6**	**2.5**	**13**	**34**	**161**

*See Figure C.1 for key. For each community, values are based on 3 plots with 3 50 m transects per plot (vegetation), 18 soil stability and compaction per plot and 9 infiltration measurements per plot.

Table C.3. Typical number of 50 m (~150 ft) transects to detect vegetation change at the **plot*** scale. Sample sizes (number of transects) represent the median number of transects required based on all eight plant communities.

Vegetation indicators (units)	Minimum detectable change (%)	Transects	Minimum detectable change (%)	Transects	Minimum detectable change (%)	Transects
Line-point intercept (50 points/transect)**						
Foliar cover	5	6	10	2	20	2
Basal cover	2	9	5	2	10	2
Bare ground	5	8	10	2	20	2
Canopy Gap intercept**						
% transect in gaps >25 cm	5	6	10	2	20	2
% transect in gaps >50 cm	5	9	10	3	20	2
Basal Gap intercept**						
% transect in gaps >50 cm	5	5	10	2	20	2
% transect in gaps >100 cm	5	6	10	2	20	2

Table C.4. Typical number of measurements to detect soil change at the **plot*** scale. Sample sizes (number of measurements) represent the median number of measurements required based on all eight plant communities.

Indicators (units)	Minimum detectable change	Measure-ments	Minimum detectable change	Measure-ments	Minimum detectable change	Measure-ments
Soil stability test						
Surface stability (classes)	0.5	44	1	12	2	4
Sub-surface stability (classes)	0.5	35	1	9	2	3
Compaction test***						
0-10 cm (strikes)	10%	54	20%	14	50%	3
0-20 cm (strikes)	10%	51	20%	14	50%	3
Infiltration test***						
Rate (mm/hour)	20%	33	30%	15	50%	6

* 1 ha (~2.5 acre) plot.

** Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

*** Relative change (e.g., increase from 10 to 15 strikes is a 50 percent change).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.5. Typical number of plots with one or three 50 m (~150 ft) transects needed to detect vegetation change at the monitoring unit **(landscape unit)*** scale. Sample sizes (number of transects) represent the median number of transects required based on all eight plant communities.

Indicator (units)	Minimum detectable change (%)	Transects per plot		Minimum detectable change (%)	Transects per plot		Minimum detectable change (%)	Transects per plot	
		1	**3**		**1**	**3**		**1**	**3**
Line-point intercept (50 points/transect)**									
Foliar cover	5	8	4	10	3	2	20	2	2
Basal cover	2	12	6	5	3	2	10	2	2
Bare ground	5	11	5	10	4	2	20	2	2
Canopy Gap intercept**									
% transect in gaps >25 cm	5	11	6	10	3	2	20	2	2
% transect in gaps >50 cm	5	11	6	10	3	2	20	2	2
Basal Gap intercept**									
% transect in gaps >50 cm	5	13	8	10	4	3	20	2	2
% transect in gaps >100 cm	5	9	5	10	3	2	20	2	2

Table C.6. Typical number of plots with specified number of measurements needed to detect soil change at the monitoring unit **(landscape unit)*** scale. Sample sizes (number of measurements) represent the median number of measurements required based on all eight plant communities.

Indicator (units)	Minimum detectable change	Measure-ments per plot		Minimum detectable change	Measure-ments per plot		Minimum detectable change	Measure-ments per plot	
		6	**18**		**6**	**18**		**6**	**18**
Soil stability test									
Surface stability (classes)	0.5	10	5	1	3	2	2	2	2
Sub-surface stability (classes)	0.5	6	3	1	2	2	2	2	2
Compaction test***									
0-10 cm (strikes)	10%	24	20	20%	7	6	50%	2	2
0-20 cm (strikes)	10%	27	24	20%	7	6	50%	2	2
Infiltration test***									
Rate (mm/hour)	20%	11	7	30%	6	3	50%	2	2

* A monitoring unit is assumed to fall in a single ecological site in a particular state (similar soil, landscape position, and status).

** Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

*** Relative change (e.g., increase from 10 to 15 strikes is a 50 percent change).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Instructions for Option 2: PLOT scale

Choose this option to determine how many vegetation transects and soil measurements you need to detect change within a plot (plot scale). Complete the Plot Scale Worksheet (see Table C.7) to calculate the recommended number of measurements for your plot-scale monitoring project. The recommendations are based on data from the southern New Mexico study (Tables C.8 through C.13). Before beginning, please see the "Caution" and "Assumptions" sections in the Introduction to this appendix.

Step 1. Using Figure C.1 and Table C.2, select at least three plant communities that appear to be most similar to your own. Record them under "Plant communities" in the worksheet (Table C.7). We strongly recommend that you select at least three communities, even if your community appears to have very similar characteristics to only one of the eight.

Step 2. Define the minimum change you want to be able to detect at the plot scale for each indicator. Record this value under "Minimum detectable change" in the Plot Scale Worksheet.

Step 3. Copy appropriate values for the number of measurements and transects from Tables C.8 through C.13 for each community to the Plot Scale Worksheet. Make sure to copy the values from the correct rows and columns.

Step 4. Record the median or maximum number of measurements and transects in the last column.

Table C.7. Plot Scale Worksheet. Use this form, together with Tables C.8 through C.13, to determine the appropriate number of transects (vegetation) or measurements (soil) needed to detect change at the **plot** scale. "Absolute %" means that a change from 10 to 15 percent cover would be 5 percent.

Indicators	Minimum detectable change	Plant communities					Median*
Line-point intercept	**Absolute %**	Number of 50 m (150 ft) transects with 50 points/transect					
Bare ground							
Basal cover							
Foliar cover							
Canopy Gap intercept	**Absolute %**	Number of 50 m (150 ft) transects					
Gaps > 25 cm (~0.8 ft)							
Gaps > 50 cm (~1.7 ft)							
Basal Gap intercept	**Absolute %**	Number of 50 m (150 ft) transects					
Gaps > 50 cm (~1.7 ft)							
Gaps > 100 cm (~3.3 ft)							
Soil stability test	**Stability classes**	Number of measurements					
Surface stabliity							
Sub-surface stability							
Compaction test	**% change in strikes**	Number of strikes					
0-10 cm							
0-20 cm							
Infiltration (Single-ring infiltrometer)	**% change in rate**	Number of measurements					
Rate							

* Middle value of those listed at left. For a more conservative estimate, use maximum.

Table C.8. Line-point intercept replication requirements (number of 50 m transects with 50 points per transect) for the **plot** scale. Use median or maximum of at least three communities. See Table C.15 for landscape scale.

	Minimum detectable change (%)*		
Foliar cover	**5**	**10**	**20**
Community	Transects required		
A	**6**	**2**	**2**
B	**5**	**2**	**2**
C	**13**	**4**	**2**
D	**6**	**2**	**2**
E	**4**	**2**	**2**
F	**2**	**2**	**2**
G[1]	**32**	**8**	**2**
H	**16**	**4**	**2**
Median	**6**	**2**	**2**

	Minimum detectable change (%)*		
Basal cover	**2**	**5**	**10**
Community	Transects required		
A	**12**	**2**	**2**
B	**9**	**2**	**2**
C	**10**	**2**	**2**
D	**8**	**2**	**2**
E	**6**	**2**	**2**
F	**3**	**2**	**2**
G	**9**	**2**	**2**
H	**10**	**2**	**2**
Median	**9**	**2**	**2**

	Minimum detectable change (%)*		
Bare ground cover	**5**	**10**	**20**
Community	Transects required		
A	**2**	**2**	**2**
B	**7**	**2**	**2**
C	**13**	**4**	**2**
D	**8**	**2**	**2**
E	**5**	**2**	**2**
F[2]	**28**	**7**	**2**
G[1]	**22**	**6**	**2**
H	**7**	**2**	**2**
Median	**8**	**2**	**2**

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

[2]High values due to highly variable lichen cover (not counted as bare ground).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.9. Canopy gap replication requirements (number of 50 m transects) for the **plot** scale. Use median or maximum of at least three communities. See Table C.16 for landscape scale.

Canopy Gap intercept % transect in gaps >25 cm	**Minimum detectable change (%)***		
	5	**10**	**20**
Community		Transects required	
A[1]	**23**	**6**	**2**
B	**11**	**3**	**2**
C	**6**	**2**	**2**
D	**4**	**2**	**2**
E	**2**	**2**	**2**
F	**2**	**2**	**2**
G[2]	**24**	**6**	**2**
H	**5**	**2**	**2**
Median	**6**	**2**	**2**

Canopy Gap intercept % transect in gaps >50 cm	**Minimum detectable change (%)***		
	5	**10**	**20**
Community		Transects required	
A[1]	**22**	**6**	**2**
B	**11**	**3**	**2**
C	**6**	**2**	**2**
D	**5**	**2**	**2**
E	**3**	**2**	**2**
F	**3**	**2**	**2**
G[2]	**37**	**10**	**3**
H	**13**	**4**	**2**
Median	**9**	**3**	**2**

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to presence of unvegetated rodent mounds on some transects.

[2]High values due to patch structure associated with banded vegetation.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.10. Basal gap replication requirements (number of 50 m transects) for the **plot** scale. Use median or maximum of at least three communities. See Table C.17 for landscape scale.

Basal Gap intercept % transect in gaps >50 cm	Minimum detectable change (%)*		
	5	**10**	**20**
Community	Transects required		
A	**5**	**2**	**2**
B	**2**	**2**	**2**
C	**5**	**2**	**2**
D	**14**	**4**	**2**
E	**2**	**2**	**2**
F	**2**	**2**	**2**
G[1]	**26**	**7**	**2**
H[2]	**11**	**3**	**2**
Median	**5**	**2**	**2**

Basal Gap intercept % transect in gaps >100 cm	Minimum detectable change (%)*		
	5	**10**	**20**
Community	Transects required		
A	**7**	**2**	**2**
B	**4**	**2**	**2**
C	**4**	**2**	**2**
D	**6**	**2**	**2**
E	**5**	**2**	**2**
F	**3**	**2**	**2**
G[1]	**43**	**11**	**3**
H[2]	**15**	**4**	**2**
Median	**6**	**2**	**2**

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

[2]High values associated with variable decreases in plant patch size. This is typical of degradation in grass communities where reproduction is predominately vegetative.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.11. Soil stability test replication requirements for the **plot** scale. Use median or maximum of at least three communities. See Table C.18 for landscape scale.

Surface Soil	Minimum detectable change (units)		
stability test	0.5	1	2
Community	Measurements required		
A	50	13	4
B	37	10	3
C	35	9	3
D	77	20	5
E	12	3	2
F	13	4	2
G	57	15	4
H	57	15	4
Median	44	12	4

Sub-surface Soil	Minimum detectable change (units)		
stability test	0.5	1	2
Community	Measurements required		
A	24	6	2
B	19	5	2
C	43	11	3
D	36	9	3
E	46	12	3
F	34	9	3
G	44	11	3
H	28	7	2
Median	35	9	3

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.12. Compaction test replication requirements for the **plot** scale. Use median or maximum of at least three communities. See Table C.19 for landscape scale.

Compaction test 0-10 cm (strikes)	**Minimum detectable change (%)***		
	10	**20**	**50**
Community	Measurements required		
A	**60**	**15**	**3**
B[1]	**122**	**31**	**5**
C	**24**	**6**	**2**
D	**32**	**8**	**2**
E	**52**	**13**	**3**
F	**72**	**18**	**3**
G	**56**	**14**	**3**
H	**34**	**9**	**2**
Median	**54**	**14**	**3**

Compaction test 0-20 cm (strikes)	**Minimum detectable change (%)***		
	10	**20**	**50**
Community	Measurements required		
A	**30**	**8**	**2**
B	**92**	**23**	**4**
C	**88**	**22**	**4**
D	**33**	**9**	**2**
E	**55**	**14**	**3**
F	**49**	**13**	**2**
G	**53**	**14**	**3**
H	**35**	**9**	**2**
Median	**51**	**14**	**3**

* Relative change (e.g., increase from 10 to 15 strikes is a 50 percent change).

[1]High values due to extreme differences between soil under shrubs and soil in shrub interspaces.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.13. Infiltration test replication requirements for the **plot** scale. Use median or maximum of at least three communities. See Table C.20 for landscape scale.

Single-ring infiltration rate	**Minimum detectable change (%)***		
(mm/hour)	**20**	**30**	**50**
Community	Measurements required		
A	**19**	**9**	**3**
B	**35**	**16**	**6**
C	**30**	**14**	**5**
D	**47**	**21**	**8**
E	**15**	**7**	**3**
F	**22**	**10**	**4**
G[1]	**232**	**103**	**38**
H[1]	**115**	**52**	**19**
Median	**33**	**15**	**6**

* Relative change (e.g., increase from 50 to 75 mm/hour is a 50 percent change).

[1]High values due to strong influence of different types of vegetation on infiltration rates, together with variability in soil surface texture in the test plots.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Instructions for Option 2: LANDSCAPE scale

Choose this option to determine how many vegetation transects and soil measurements are required to detect change within a monitoring unit (landscape scale). Complete the Landscape Scale Worksheet (Table C.14) to calculate the recommended number of measurements for your landscape-scale monitoring project. The recommendations are based on data from the southern New Mexico study (Tables C.15 through C.20). Before beginning, please see the "Caution" and "Assumptions" sections in the Introduction to this appendix, Appendix C.

Step 1. Using Figure C.1 and Table C.2, select at least three plant communities that appear to be most similar to your own. Record them under "Plant communities" in the worksheet (Table C.14). We strongly recommend that you select at least three communities, even if your community appears to have very similar characteristics to only one of the eight.

Step 2. Define the minimum change you want to be able to detect at the landscape scale for each indicator. Record this value under "Minimum detectable change" in the Landscape Scale Worksheet.

Step 3. Circle the number of transects (1 vs. 3 for vegetation) and measurements (6 vs. 18 for soil) per plot for each method.

Step 4. Copy the appropriate values for the number of measurements and transects from Tables C.15 through C.20 for each community to the Landscape Scale Worksheet. Make sure to copy the values from the correct rows and columns.

Step 5. Record the median or maximum number of plots required in the last column of Table C.14.

Table C.14. Landscape Scale Worksheet. Use this form, together with Tables C.15 through C.20, to determine the appropriate number of transects (vegetation) or measurements (soil) needed to detect change at the **landscape** (monitoring unit) scale. For each method, specify whether plots include 1 or 3 transects and 6 or 18 soil measurements, and use appropriate values from Tables C.15 through C.20.

Indicators	Minimum detectable change	Plant communities					Median*
Line-point intercept: Plots with (1 or 3) 50 m (150 ft), 50 point-transects							
Bare ground (%)							
Basal cover (%)							
Foliar cover (%)							
Canopy Gap intercept: Plots with (1 or 3) 50 m (150 ft) transects							
Gaps > 25 cm (~0.8 ft)							
Gaps > 50 cm (~1.7 ft)							
Basal Gap intercept: Plots with (1 or 3) 50 m (150 ft) transects							
Gaps > 50 cm (~1.7 ft)							
Gaps > 100 cm (~3.3 ft)							
Soil stability test (stability class): Plots with (6 or 18) measurements							
Surface stabliity							
Sub-surface stability							
Compaction test (% change in average strikes): Plots with (6 or 18) measurements							
0-10 cm							
0-20 cm							
Infiltration test (% change in average rate): Plots with (6 or 18) measurements							
Rate							

* Middle value of those listed at left. For a more conservative estimate, use maximum.

Table C.15. Line-point intercept replication requirements (50 m transects with 50 points per transect) for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.8 for plot scale.

Foliar cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	6	2	2	2	2	2
B	5	2	2	2	2	2
C	15	4	2	7	2	2
D	6	2	2	2	2	2
E	9	3	2	7	2	2
F	2	2	2	2	2	2
G[1]	32	8	2	11	3	2
H	16	4	2	6	2	2
Median	8	3	2	4	2	2

Basal cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	2	5	10	2	5	10
Community	Number of plots required					
A	13	3	2	6	2	2
B	19	3	2	13	3	2
C	17	3	2	11	2	2
D	19	3	2	14	3	2
E	9	2	2	5	2	2
F	3	2	2	2	2	2
G	9	2	2	3	2	2
H	10	2	2	4	2	2
Median	12	3	2	6	2	2

Bare ground cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	2	2	2	2	2	2
B	7	2	2	3	2	2
C	14	4	2	6	2	2
D	13	4	2	7	2	2
E	5	2	2	2	2	2
F[2]	46	12	3	28	7	2
G[1]	22	6	2	8	2	2
H	9	3	2	4	2	2
Median	11	4	2	5	2	2

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

[2]High values due to highly variable lichen cover (not counted as bare ground).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.16. Canopy Gap intercept replication requirements (50 m transects) for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.9 for plot scale.

% transect in canopy gaps > 25 cm	**1 transect/plot**			**3 transects/plot**		
	Minimum detectable change (%)*					
	5	**10**	**20**	**5**	**10**	**20**
Community	Number of plots required					
A[1]	**23**	**6**	**2**	**8**	**2**	**2**
B	**11**	**3**	**2**	**4**	**2**	**2**
C	**11**	**3**	**2**	**7**	**2**	**2**
D	**11**	**3**	**2**	**9**	**3**	**2**
E	**2**	**2**	**2**	**2**	**2**	**2**
F	**2**	**2**	**2**	**2**	**2**	**2**
G[2]	**24**	**6**	**2**	**8**	**2**	**2**
H	**6**	**2**	**2**	**3**	**2**	**2**
Median	**11**	**3**	**2**	**6**	**2**	**2**

% transect in canopy gaps > 50 cm	**1 transect/plot**			**3 transects/plot**		
	Minimum detectable change (%)*					
	5	**10**	**20**	**5**	**10**	**20**
Community	Number of plots required					
A[1]	**22**	**6**	**2**	**8**	**2**	**2**
B	**12**	**3**	**2**	**5**	**2**	**2**
C	**10**	**3**	**2**	**6**	**2**	**2**
D	**8**	**2**	**2**	**5**	**2**	**2**
E	**3**	**2**	**2**	**2**	**2**	**2**
F	**5**	**2**	**2**	**4**	**2**	**2**
G[2]	**37**	**10**	**3**	**13**	**4**	**2**
H	**19**	**5**	**2**	**11**	**3**	**2**
Median	**11**	**3**	**2**	**6**	**2**	**2**

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to presence of unvegetated rodent mounds on some transects.

[2]High values due to patch structure associated with banded vegetation.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.17. Basal Gap intercept replication requirements (50 m transects) for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.10 for plot scale.

% transect in basal gaps > 50 cm	**1 transect/plot**			**3 transects/plot**		
	Minimum detectable change (%)*					
	5	**10**	**20**	**5**	**10**	**20**
Community	Number of plots required					
A	**5**	**2**	**2**	**2**	**2**	**2**
B	**2**	**2**	**2**	**2**	**2**	**2**
C	**16**	**4**	**2**	**13**	**4**	**2**
D	**21**	**6**	**2**	**12**	**3**	**2**
E	**3**	**2**	**2**	**2**	**2**	**2**
F	**4**	**2**	**2**	**3**	**2**	**2**
G[1]	**26**	**7**	**2**	**9**	**3**	**2**
H	**19**	**5**	**2**	**12**	**3**	**2**
Median	**11**	**3**	**2**	**6**	**2**	**2**

% transect in basal gaps > 100 cm	**1 transect/plot**			**3 transects/plot**		
	Minimum detectable change (%)*					
	5	**10**	**20**	**5**	**10**	**20**
Community	Number of plots required					
A	**7**	**2**	**2**	**3**	**2**	**2**
B	**4**	**2**	**2**	**2**	**2**	**2**
C	**4**	**2**	**2**	**2**	**2**	**2**
D	**8**	**2**	**2**	**5**	**2**	**2**
E	**11**	**3**	**2**	**8**	**2**	**2**
F	**14**	**4**	**2**	**12**	**3**	**2**
G[1]	**45**	**12**	**3**	**17**	**5**	**2**
H	**21**	**6**	**2**	**12**	**3**	**2**
Median	**10**	**3**	**2**	**7**	**2**	**2**

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.18. Soil stability test replication requirements for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.11 for plot scale.

Surface Soil stability test	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (units)					
	0.5	1	2	0.5	1	2
Community	Number of plots required					
A	**21**	**6**	**2**	**16**	**4**	**2**
B	**10**	**3**	**2**	**6**	**2**	**2**
C	**6**	**2**	**2**	**2**	**2**	**2**
D	**16**	**4**	**2**	**8**	**2**	**2**
E	**2**	**2**	**2**	**2**	**2**	**2**
F	**3**	**2**	**2**	**2**	**2**	**2**
G	**10**	**3**	**2**	**4**	**2**	**2**
H	**11**	**3**	**2**	**5**	**2**	**2**
Median	**10**	**3**	**2**	**5**	**2**	**2**

Sub-surface Soil stability test	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (units)					
	0.5	1	2	0.5	1	2
Community	Number of plots required					
A	**6**	**2**	**2**	**3**	**2**	**2**
B	**5**	**2**	**2**	**3**	**2**	**2**
C	**9**	**3**	**2**	**4**	**2**	**2**
D	**6**	**2**	**2**	**2**	**2**	**2**
E	**10**	**3**	**2**	**4**	**2**	**2**
F	**6**	**2**	**2**	**2**	**2**	**2**
G	**8**	**2**	**2**	**3**	**2**	**2**
H	**6**	**2**	**2**	**3**	**2**	**2**
Median	**6**	**2**	**2**	**3**	**2**	**2**

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.19. Compaction test replication requirements for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.12 for plot scale.

Compaction test 0-10 cm (strikes)	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (%)*					
	10	20	50	10	20	50
Community	Number of plots required					
A[1]	**171**	**43**	**7**	**164**	**41**	**7**
B[2]	**144**	**36**	**6**	**131**	**33**	**6**
C	**21**	**6**	**2**	**18**	**5**	**2**
D	**13**	**4**	**2**	**10**	**3**	**2**
E	**11**	**3**	**2**	**5**	**2**	**2**
F	**16**	**4**	**2**	**8**	**2**	**2**
G	**47**	**12**	**2**	**41**	**11**	**2**
H	**26**	**7**	**2**	**22**	**6**	**2**
Median	**24**	**7**	**2**	**20**	**6**	**2**

Compaction test 0-20 cm (strikes)	6 measurements/plot			18 measurements/plot		
	Minimum detectable change (%)*					
	10	20	50	10	20	50
Community	Number of plots required					
A	**22**	**6**	**2**	**19**	**5**	**2**
B[2]	**149**	**38**	**6**	**139**	**35**	**6**
C	**40**	**10**	**2**	**30**	**8**	**2**
D	**32**	**8**	**2**	**28**	**7**	**2**
E	**17**	**5**	**2**	**11**	**3**	**2**
F	**12**	**3**	**2**	**6**	**2**	**2**
G	**39**	**10**	**2**	**33**	**9**	**2**
H	**19**	**5**	**2**	**15**	**4**	**2**
Median	**27**	**7**	**2**	**24**	**6**	**2**

* Relative change (e.g., increase from 10 to 15 striked is a 50 percent change).

[1]High levels due to variable density of rodent mounds at landscape scale.

[2]High levels due to variable development of mesquite coppice dunes at the landscape scale.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Table C.20. Infiltration test replication requirements for the **landscape** (monitoring unit) scale. Use median or maximum of at least three communities. See Table C.13 for plot scale.

Single-ring infiltration rate (mm/hour)	**6 measurements/plot**			**18 measurements/plot**		
	Minimum detectable change (%)*					
	20	**30**	**50**	**20**	**30**	**50**
Community	Number of plots required					
A	**5**	**2**	**2**	**3**	**2**	**2**
B	**6**	**3**	**2**	**2**	**2**	**2**
C	**13**	**6**	**3**	**10**	**5**	**2**
D	**12**	**6**	**2**	**7**	**3**	**2**
E	**3**	**2**	**2**	**2**	**2**	**2**
F	**10**	**5**	**2**	**7**	**4**	**2**
G[1]	**59**	**27**	**10**	**34**	**15**	**6**
H	**20**	**9**	**4**	**7**	**3**	**2**
Median	**11**	**6**	**2**	**7**	**3**	**2**

* Relative change (e.g., increase from 50 to 75 mm/hour is a 50 percent change).

[1]High values due to strong influence of different types of vegetation on infiltration rates, together with variability in soil surface texture among the test plots.

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Instructions for Option 3: Calculations based on available data

In Option 3 you conduct your own research to determine how many transects and measurements are needed to detect change. This option requires data from a pilot study within the monitoring unit of interest. Sometimes data from a previous monitoring study or research project can be used. Use one of the equations provided below to determine the necessary number of vegetation transects or soil measurements required at the plot scale, or for the number of plots at the landscape scale.

A pilot study is a small-scale version of your monitoring program. Conducting a pilot study allows you to more accurately estimate the population mean(s), the standard deviation(s) and the degree of correlation between years. These values are used in Equations 1 and 2.

Equation 1. Equation 1 is used to determine requirements for detecting differences between two means from permanent plots, using a paired *t*-test. This is similar to the equations used to generate the recommendations listed in Options 1 and 2. It is the test used to detect change over time.

If you wish to detect change at the plot scale, use a plot's transect data (or soil measurement data) from a single sampling period to generate the population mean and standard deviation.

If you wish to detect change at the landscape (monitoring unit) scale use data from all of the plots within the landscape unit (or monitoring unit) from a single sampling period to generate the population mean and standard deviation. At the landscape scale, the number of replications is equal to the number of plots, not the number of transects or soil measurements.

Equation 2. Equation 2 is used to determine requirements for detecting differences between a single mean and a threshold value, using a one-sample *t*-test. It is assumed that the means will be compared using a paired *t*-test.

If you wish to detect a difference between a plot's mean and a threshold value (at the plot scale), use data from the plot's transects (or soil measurements) to generate the population mean and standard deviation.

If you wish to detect a difference between a landscape unit's (monitoring unit's) mean and a threshold value (landscape scale), use data from all of the plots within the landscape unit (or monitoring unit) to generate the population mean and standard deviation.

For more detailed information, please see Elzinga et al. (2001) or Bonham (1989).

Option 3, Equation 1: determining the necessary sample size for detecting a difference between two means with permanent sampling units that will be evaluated with a paired t-test.

When paired sampling units are being compared, or when data from permanent plots or transects are being compared between two time periods, then sample size determination requires a different procedure than if samples are independent of one another. The equation for determining the number of samples necessary to detect some true difference between two sample means generated at different times from the same monitoring plot or transect is:

$$n = \frac{(s_{diff})^2 (Z_\alpha + Z_\beta)^2}{(MDC)^2} \qquad \text{(Equation 1)}$$

Where:

s_{diff} = Standard deviation of the differences between paired samples (see equation and examples below).

Z_α = Z-coefficient for the false-change (Type I) error rate from Table C.21a below.

Z_β = Z-coefficient for the missed-change (Type II) error rate from Table C.21b below.

MDC = Minimum detectable change size. This needs to be specified in absolute terms. For example, if you wanted to detect a 20 percent change in the sample mean from one year to the next and your first year sample mean = 10 plants/plot or transect, then *MDC* = (0.20 x 10) = 2 plants/plot or transect. Similarly, a change from 10 to 15 percent bare ground is a 5 percent change.

Table C.21a. Table of standard normal deviates for Z_α.

False-change (Type I) error rate (α)	Z_α
0.40	0.84
0.20	1.28
0.10	1.64
0.05	1.96
0.01	2.58

Table C.21b. Table of standard normal deviates for Z_β.

Missed-change (Type II) error rate (β)	Power	Z_β
0.40	0.60	0.25
0.20	0.80	0.84
0.10	0.90	1.28
0.05	0.95	1.64
0.01	0.99	2.33

How many measurements?

If the objective is to track changes over time with permanent sampling plots and only a single year of data is available, then you will not have a standard deviation of differences between paired samples. If you have an estimate of the likely degree of correlation between the two years of data, and you assume that the among-sampling units standard deviation is going to be the same in the second time period, then you can use the equation below to estimate the standard deviation of differences.

$$s_{diff} = (s_1)(\sqrt{(2(1 - corr_{diff}))})$$

Where:

s_{diff} = Estimated standard deviation of the differences between paired samples.

s_1 = Sample standard deviation among sampling units at the first time period.

$corr_{diff}$ = Correlation coefficient, or rho, between sampling unit values in the first time period and sampling unit values in the second time period (this is the square root of r^2 (=r) from a regression and is the "rho" discussed in the introduction above).

Example 1:
Management objective:
Achieve at least a 20 percent higher density of Species F at Site Y in areas excluded from grazing as compared to grazed areas in 1999 (landscape scale).

Sampling objective:
I want to be able to detect a 20 percent difference in mean plant density in areas excluded from grazing versus adjacent paired grazed areas. I want to be 90 percent certain (power = 0.9) of detecting that difference, if it occurs. I am willing to accept a 10 percent chance ($\alpha = 0.1$) that I will make a false-change error (concluding that a difference exists when it really does not).

Results from pilot sampling:
Five paired plots (a total of 10 plots) were sampled where one member of the pair was excluded from grazing (with a small exclosure) and the other member of the pair was open to grazing.

Table C.22. Summary statistics for the differences between the two sets of plots.

Plot number	Number of plants/plot		Difference between grazed and ungrazed
	Grazed	Ungrazed	
1	2	3	1
2	5	8	3
3	4	9	5
4	7	12	5
5	3	7	4
	$\overline{X}$=4.20 s=1.92	$\overline{X}$=7.80 s=3.27	$\overline{X}_{diff}$=3.60 s_{diff}=1.67

Given:
The sampling objective specified a desired minimum detectable difference (i.e., equivalent to the *MDC*) of 20 percent. Taking the larger of the two mean values (ungrazed from Table C.22) and multiplying by 20 percent leads to: (7.80 x 0.20) = ***MDC* = 1.56** plants/plot. The larger mean is used because the result generates a more conservative test.

The appropriate **standard deviation** to use is **1.67** (from Table C.22), the standard deviation of the differences between the pairs of plots.

The acceptable **False-change error rate (α)** is 0.10. Therefore the appropriate Z_α from Table C.21a is **1.64**.

The desired **Power** is 90 percent (0.90), so the **Missed-change error rate (β) = 0.10**. The appropriate Z_β coefficient from Table C.21b is **1.28.**

Calculate the estimated necessary sample size using the equation provided below:

$$n = \frac{(s_{diff})^2(Z_\alpha + Z_\beta)^2}{(MDC)^2} \qquad n = \frac{(1.67)^2(1.64+1.28)^2}{(1.56)^2} = 9.8$$

Round up 9.8 to 10 plots.

Thus, the final estimated sample size needed to be 90 percent certain of detecting a true difference of 1.56 plants/plot between the grazed and ungrazed plots with a false-change error rate of 0.10 = **10 plots.**

Example 2:
Management objective:
Increase the density of species F at site Q by 20 percent between 1999 and 2002 (landscape scale).

Sampling objective:
I want to be able to detect a 20 percent difference in mean plant density of species F at site Q between 1999 and 2002. I want to be 90 percent certain of detecting that change, if it occurs. I am willing to accept a 10 percent chance that I will make a false-change error (conclude that a difference exists when it really does not).

The procedure for determining the necessary sample size for this example would be very similar to the previous example. Replace "grazed" and "ungrazed" in Table C.22 with "1999" and "2002" and the rest of the calculations would be the same. Because the sample size determination procedure needs the standard deviation of the difference between two samples, you will not have the necessary standard deviation term to plug into the equation until you have two years of data. However, the standard deviation of the difference can be *estimated* in the first year. You will need an estimate of the correlation coefficient between sampling unit values in the first time period and the sampling unit values in the second time period (see the s_{diff} equation above).

Correction for sampling finite populations

The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than five percent of the entire population area, you should apply a correction to the sample size estimate. This correction incorporates the finite population correction factor (FPC). This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$$n' = \frac{n}{(1 + (n / N))}$$

Where:

- n' = The new sample size based upon inclusion of the finite population correction factor.
- n = The original sample size estimate from the equation: $n = \frac{(s_{diff})^2(Z_\alpha + Z_\beta)^2}{(MDC)^2}$
- N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit (plot).

Example:

If the pilot data described above was gathered using a 1 m x 10 m (10 m^2) plot and the total population being sampled was located within a 10 m x 50 m macroplot (500 m^2), then N = 500 m^2 ÷ 10 m^2 = 50. The corrected sample size would then be:

$$n' = \frac{n}{(1 + (n / N))} \qquad n' = \frac{10}{(1 + (10 / 50))} = 8.3$$

Round 8.3 to 8.

The new, FPC-corrected estimated sample size needed to be 90 percent confident of detecting a true difference of 1.56 plants/plot between the grazed and ungrazed plots with a false-change error rate of 0.10 = **8 plots**.

Note on the statistical analysis for two sample tests from finite populations

If you have sampled more than five percent of an entire population, you should apply the finite population correction factor to the results of the statistical test. This procedure involves dividing the test statistic by the square root of (1-n/N). For example, if your *t*-statistic from a particular test turned out to be 1.782 and you sampled n=8 plots out of a total N=50 possible plots, then your correction procedure would look like the following:

$$t' = \frac{t}{\sqrt{1 - (n / N)}} \qquad t' = \frac{1.782}{\sqrt{1 - (8 / 50)}} = 1.944$$

Where:

- t = The *t*-statistic from a *t*-test.
- t' = The corrected *t*-statistic using the FPC.
- n = The number of plots or units sampled.
- N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

You would then need to look up the *p*-value of t' = 1.944 in a *t*-table for the appropriate degrees of freedom to obtain the correct *p*-value for this statistical test.

Option 3, Equation 2: Determining the necessary sample size for detecting a difference between a single mean and a threshold value that will be evaluated with a one-sample t-test.

Here is the equation for determining sample size when a single mean value is going to be compared with some threshold value:

$$n = \frac{(s)^2(Z_\alpha + Z_\beta)^2}{(MDC)^2} \qquad \text{(Equation 2)}$$

Where:

s = Standard deviation of the sample.

Z_α = Z-coefficient for the false-change (Type I) error rate from Table C.21a.

Z_β = Z-coefficient for the missed-change (Type II) error rate from Table C.21b.

MDC = Minimum detectable change from the threshold. This needs to be specified in absolute terms rather than as a relative percentage. For example, if you wanted to detect a 20 percent difference from a threshold density of 30 plants/plot then *MDC* = (0.20 x 30) = 6 plants/plot. Similarly, a change from 10 to 15 percent bare ground is a five percent change.

Example 1:
Management objective:
Maintain a population of species Y in population Z with a density of at least 25 plants/plot for the next 10 years.

Sampling objective:
I want to be able to detect a 20 percent difference in mean plant density from a threshold density of 25 plants/plot. I want to be 90 percent certain of detecting this difference, if it occurs. I am willing to accept a 10 percent chance that I will make a false-change error (conclude that the mean is different from the threshold when it really is not).

Results from pilot sampling:
Mean ($\bar{x}$) = 31 plants/plot
Standard deviation (s) = **7** plants.

Given:
The acceptable **False-change error rate (α) = 0.10**, so the appropriate Z_α from Table C.21a = **1.64**.

The desired **Power** is 90 percent (0.90) so the **Missed-change error rate (β) = 0.10** and the appropriate Z_β coefficient from Table C.21b = **1.28**.

The **Minimum Detectable Change (*MDC*)** is 20 percent of the threshold value or (0.20 x 25)= **5** plants/plot.

Calculate the estimated necessary sample size using the equation provided above:

$$n = \frac{(s)^2(Z_\alpha+Z_\beta)^2}{(MDC)^2} \qquad n = \frac{(7)^2(1.64 +1.28)^2}{(5)^2} = 16.7$$

Round up 16.7 to 17 plots.

Final estimated sample size needed to be 90 percent confident of detecting a difference of five plants from the threshold density of 25 plants with a false-change error rate of 0.10 **= 17 plots.**

Correction for sampling finite populations

The above formula assumes that the population is very large compared to the proportion of the population that is sampled. If you are sampling more than five percent of the entire population area, you should apply a correction to the sample size estimate. This correction incorporates the finite population correction (FPC) factor. This will reduce the sample size. The formula for correcting the sample size estimate is as follows:

$$n' = \frac{n}{(1 + (n / N))}$$

Where:

n' = The new sample size based upon inclusion of the finite population correction factor.

n = The sample size from the equation: $n = \frac{(s)^2(Z_\alpha+Z_\beta)^2}{(MDC)^2}$

N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

Example 2:

If the pilot data described above was gathered using a 1 m x 10 m (10 m^2) plot and the total population being sampled was located within a 20 m x 50 m macroplot (1000 m^2) then N = 1000 m^2/10 m^2 = 100. The corrected sample size would then be:

$$n' = \frac{n}{(1 + (n / N))} \qquad n' = \frac{17}{(1 + (17 / 100))} = 14.5$$

Round up 14.5 to 15.

The new, FPC-corrected estimated sample size needed to be 90 percent certain of detecting a difference of five plants from the threshold density with a false-change error rate of 0.10 **= 15 plots**.

Note on the statistical analysis for two sample tests from finite populations

If you have sampled more than five percent of an entire population, you should apply the finite population correction factor to the results of the statistical test. This procedure involves dividing the test statistic by the square root of the finite population factor (1-n/N). For example, if your t-statistic from a particular test turned out to be 1.645 and you sampled n=26 plots out of a total N=100 possible plots, then your correction procedure would look like the following:

$$t' = \frac{t}{\sqrt{1 - (n / N)}} \qquad t' = \frac{1.645}{\sqrt{1 - (26 / 100)}} = 1.912$$

Where:

- t = The *t*-statistic from a *t*-test.
- t' = The corrected *t*-statistic using the FPC.
- n = The number of plots (or units) sampled.
- N = The total number of possible plot locations in the population. To calculate N, determine the total area of the population and divide by the size of each individual sampling unit.

You would then need to look up the *p*-value of $t' = 1.912$ in a *t*-table at the appropriate degrees of freedom to obtain the correct *p*-value for this statistical test.

Appendix D: Soil Quality Information Sheets

Additional information on soil indictors is available in a series of information sheets about soil quality and rangelands. Rangeland Soil Quality Information Sheets (USDA-NRCS 2001) address soil properties that change in response to management and climate. Refer to these sheets for a description of soil properties that can serve as indicators, factors affecting them and general management strategies to improve them.

Available on line at: http://soils.usda.gov/sqi/management/gl_mgmt.html (accessed June 23, 2008).

Rangeland Soil Quality Information Sheets (accessed June 23, 2008)

1. Rangeland Soil Quality — Introduction
   (http://soils.usda.gov/sqi/management/files/RSQIS1.pdf)
2. Rangeland Soil Quality — Indicators for Assessment and Monitoring
   (http://soils.usda.gov/sqi/management/files/RSQIS2.pdf)
3. Rangeland Soil Quality — Aggregate Stability
   (http://soils.usda.gov/sqi/management/files/RSQIS3.pdf)
4. Rangeland Soil Quality — Compaction
   (http://soils.usda.gov/sqi/management/files/RSQIS4.pdf)
5. Rangeland Soil Quality — Infiltration
   (http://soils.usda.gov/sqi/management/files/RSQIS5.pdf)
6. Rangeland Soil Quality — Organic Matter
   (http://soils.usda.gov/sqi/management/files/RSQIS6.pdf)
7. Rangeland Soil Quality — Physical and Biological Soil Crusts
   (http://soils.usda.gov/sqi/management/files/RSQIS7.pdf)
8. Rangeland Soil Quality — Soil Biota
   (http://soils.usda.gov/sqi/management/files/RSQIS8.pdf)
9. Rangeland Soil Quality — Water Erosion
   (http://soils.usda.gov/sqi/management/files/RSQIS9.pdf)
10. Rangeland Soil Quality — Wind Erosion
   (http://soils.usda.gov/sqi/management/files/RSQIS10.pdf)

Appendix E: Soil texture chart