LFA METHODOLOGY

B FIELD DATA ACQUISITION

Introduction

It is the objective of this section to explain how the field data are collected. The same procedure is used across the full range of soils, landscapes and land uses, because the methods are based on the landscape function principles described in section A rather than being dependent on specific organisms.

There are 3 principal steps in this process.

1. Describing the geographic setting of the site.
2. Characterising landscape organization, the spatial distribution of the fertile-patches and inter-patches.
3. The soil surface assessment (SSA) of each of the patch/inter-patch types identified in step 2.

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STEP 1. THE GEOGRAPHIC SETTING OF THE SITE

The objective of this task is to identify the location of the monitoring site in its landscape or watershed so that the nature and magnitude of water run-off processes can be gauged. This process will group land systems or land units, which have similar terrain shape. The classifications are those proposed by McDonald *et al.* 1990, without change. Typically, this task is done only once at the outset of the monitoring program.

A Site Description

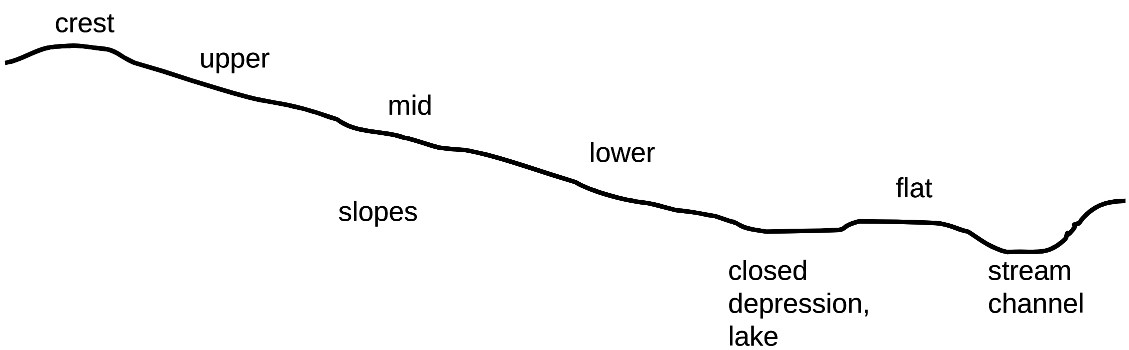
In monitoring it is important to record the location of site and its position in the landscape. The type of detail suggested are position, GPS if available, compass bearing of the transect, slope, aspect, lithology, soils, vegetation type and its landuse.

B Topographic Location

This procedure identifies the location of the study site within the overall landform pattern, e.g. rate of runoff increases with slope, chronic dryness (crest) and periodic ample water (closed depression) (Fig.19). These classifications are important for assessment of differential soil water storage and erosion potential at landscape scale.

Monitoring sites located on different land systems but with the same landform pattern/landform element classification should behave similarly. This classification will help to group sites from a wide geographic spread in order to reduce the large number of possible permutations by using a functional rather than descriptive discrimination.
The following topographic classification is appropriate for rangelands:

Crest
Upper slope
Mid slope



Lower slope
Closed depression, or lake
Flat
Open depression or stream channel
Figure 19. The identification of topographic position in the landscape for monitoring sites.

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STEP 2 CHARACTERISING LANDSCAPE ORGANISATION

The objective of this step is to characterise and map the monitored site in terms of the spatial pattern of resource loss or accumulation.

Procedure

1. Locate the transect directly downslope, bends or kinks may be necessary in some cases to follow the slope.
2. Collect a continuous record of patch/inter-patch classification on the transect as per guidelines for patch/inter-patch classification (see worked example page 24).
3. Complete this task before commencing soil surface assessment (step 3).
4. The transect should be permanently located to facilitate repeated measurements over time. This is essential for long term monitoring to be meaningful. Typically, the transect is located by a GPS reading of the upslope starting point and a compass bearing.

Rules for measuring transect parameters

Transect rules

The line transect along which the data are collected must be aligned with the maximum slope. If slope is very low to flat then the direction of the transect is not so critical. In the case where wind is the dominant resource mobilising agent, the transect should be aligned in the direction of the strongest prevailing wind.
To facilitate comparisons overtime, measurements are to be made with a taut, straight tape between two fixed points.

Guidelines for Transect Selection:

Know your site:

Traverse or study recent aerial images of the area that is to be monitored whether it is a small area that is being rehabilitated or the whole paddock. How "even" is the landscape? In extensive rangelands a number of sites may be needed along a gradient running out from water to the furthest extremity of the paddock. There is a need to be realistic about how many sites within a paddock that can be handled, so start at the more sensitive areas and add more transects if time and circumstances permit. If there are major variations, e.g. soil type change, transects will need to be established in each variant.

How to set up transects

Start the transect at the upslope edge of the local watershed, at the downslope edge of a patch. Pull the transect tape straight and tight. This is extremely important if the transect is to be revisited. Permanently located transects are very useful for time-series data collection and assessment. (see interpretational process section page 59). Note that if there is a clear indication of a change in resource flow direction, the transect should follow this by putting a bend or turning point in the line and noting its location and the new compass bearing.

How many Transects?

In most sites, from experience, two transects are sufficient. However, to test this, compare the means and variances for the stability, infiltration and nutrient cycling indices for each patch and inter-patch type**.** Whole-of-site values are not appropriate for this analysis. **Note: Five replicates of each patch/inter-patch type are usually essential for statistical reliability**. A rule of thumb is that if the patch means are similar for each transect, and the standard errors overlap, then the data from both transects can be combined, giving a new mean and standard error. However, if the means are quite different and the standard errors do not overlap, then measure a third transect and add these data to the existing data for two transects. If the mean for the third transect falls between the first two transects and their standard errors now overlap, then further transects are not necessary. If the standard error changes very little, then 2 transects are sufficient. This exercise only needs to be done once for each site at an early stage of rehabilitation.

Guidelines for correct patch/inter-patch classification

Patches tend to accumulate resources by restricting the downslope flow of water, topsoil and organic matter. If they are in good functional status, they will retain these resources which will be subsequently used by biota. Patches can be comprised of physical features, such as furrows or bays created by active landforming processes, or biological features such as plants or fallen logs. Typically, patches become a combination of both, over time. The patch identification task also involves finding and measuring its boundaries. Deposition of alluvium or litter is a common identifying factor in helping to recognize patches.

The processes identified at this scale are extremely informative about rangeland health and function, and forms the backbone of the assessment.

In grasslands, much of the regulation of scarce resources is managed by the vegetation itself. In particular, the role of the spacing of perennial grasses in arresting the flow of runoff water, and filtering out sediment and organic matter is crucial: a change from 20 cm between grass plants to 35 cm may result in erosion and excessive runoff.

The processes by which this happens are described and illustrated in detail in Figures 8, 9 and 11). Because of the fine-scale nature of grasslands, it is possible to quickly measure the spatial arrangement of the vegetation elements, and to summarise it in ways that reflect the control the vegetation has on run-off and erosion.

Three parameters are measured to characterise the functional status of the monitoring site

(1) the number of obstructions to overland flow per unit length of transect
(2) the width of obstruction elements per unit length of transect
(3) the mean distance, and range, between obstructions (inter-patch length), per unit length of transect.

Figures 20 and 21 show how these 3 parameters are measured in the field, and the rules specified in the boxes below are to ensure that the data are collected in a consistent way between observers over time.

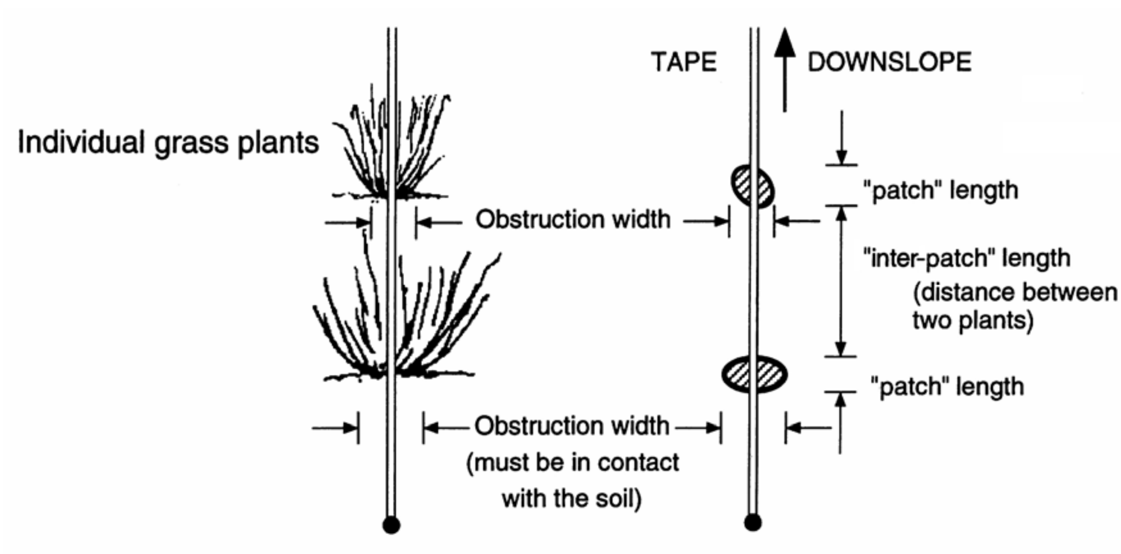

Figure 20. Illustrates the measurements of individual grasses when they form the patches on a monitoring transect.

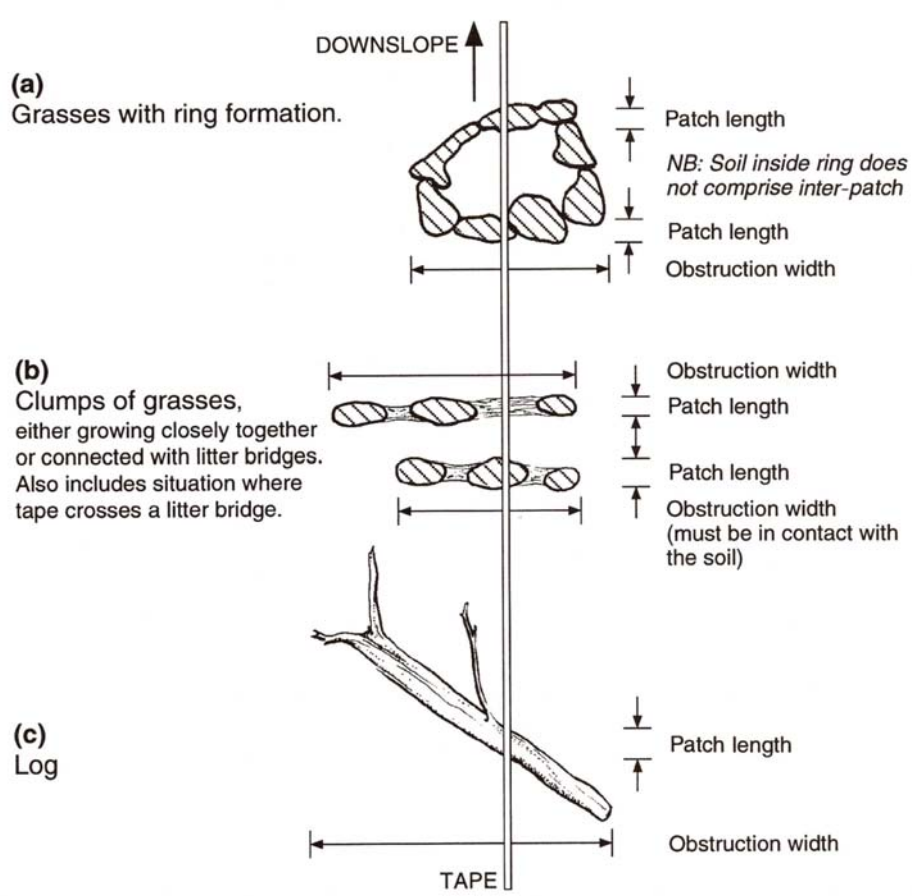

Figure 21. A diagrammatic illustration showing how to measure the length (along the transect) and the width of patches (right angles to the transect).

Patches

Patches are long-lived features which obstruct or divert water flow and/or collect/filter out material from runoff, e.g. perennial grass plants, rocks > 10 cm, tree branches in contact with the soil. There should be clear evidence of resource accumulation.

The decision to include, or exclude, biennial plants should be made with available local botanical knowledge, combined with the functional criteria described here. Once the local decision is made, it must be adhered to.
The minimum plant butt size for inclusion in the data is 1 cm.

- All measurements of grass plants for obstruction width and cover length are taken to and from the edge of the grass tussock, ignoring any soil hummock.
- Measure the **obstruction width** at right angles to the transect line, i.e. on the local contour. This is the maximum width of the patch (Fig. 21).
- Measure the **cover length** along the transect line.
- Measure both of these parameters at about 1 cm height above the ground level (as though in an overland flow situation).

- Patches can be **simple** (i.e. a single plant, rock or branch (Fig. 22), or **complex** (Figure 21).

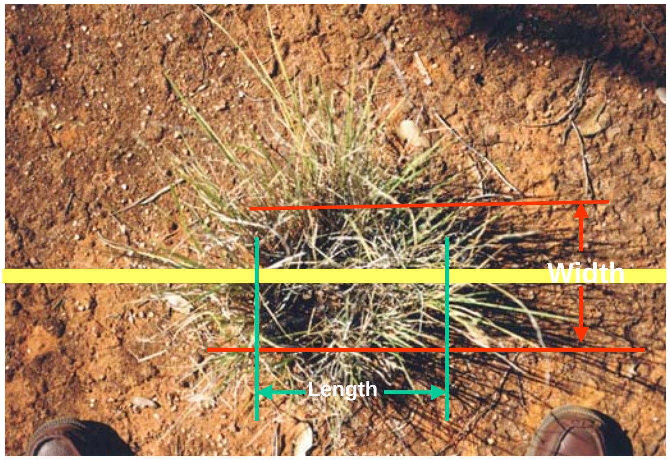

Figure 22. Illustrates a simple patch that captures some resources that are flowing down the transect.

Grass Swards

Not all landscapes have a patch/inter-patch organization. As grasslands become denser, there comes a point when litter and soil are no longer mobilized and transported by flowing water. The patch is then a large area comprised of a sward made up from a large number of functionally linked plants acting as a single unit rather than a series of isolated individuals as is the case with sparse tussock grasslands.

To identify swards look for evidence of alluvium or litter movement between grass plants.

- If there is no evidence of soil or litter transport between or around grass butts, then a sward or very large patch (resource retaining zone) exists. Litter may be present, but should show no evidence of movement. An ideal time to observe this is just after a rainfall/run-off event to judge the extent of litter and alluvium movement (Fig. 23d).
- The upslope edge of a sward may capture large quantities of material out of a transporting flow.
- Landscapes comprised of individual tussocks may have more obstructions per unit length of transect, but the obstruction width will be very low. Many swards will be greater than 10 metres wide.

Figure 23a – single grass plants

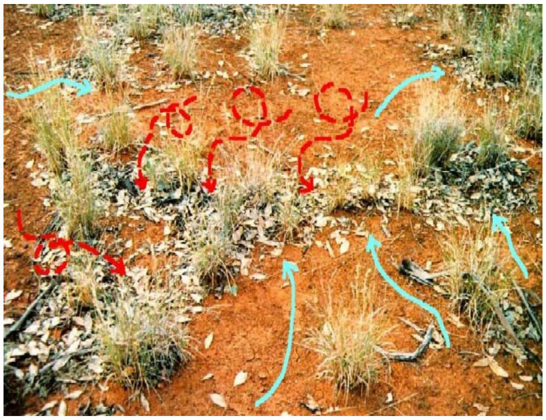

Figure 23b – several grass plants in a patch

Figure 23c – grass plants acting as a sward

Figure 23d – dense sward. Note the capture of plant litter within the sward.

Figure 23. Showing (23a) a landscape where the only resource control is by single grass plants, and patches of grass plants (23b). 23c shows the litter being retained by the grasses in a sward, and 23d has arrested a large flow of alluvium down the slope.

Inter-patch Type Criteria

Inter-patches are characterized as a zone where resources such as water, soil materials and litter may be mobilized and freely transported either downslope when water is the active motive agent or down wind when aeolian processes are active (Fig. 24).

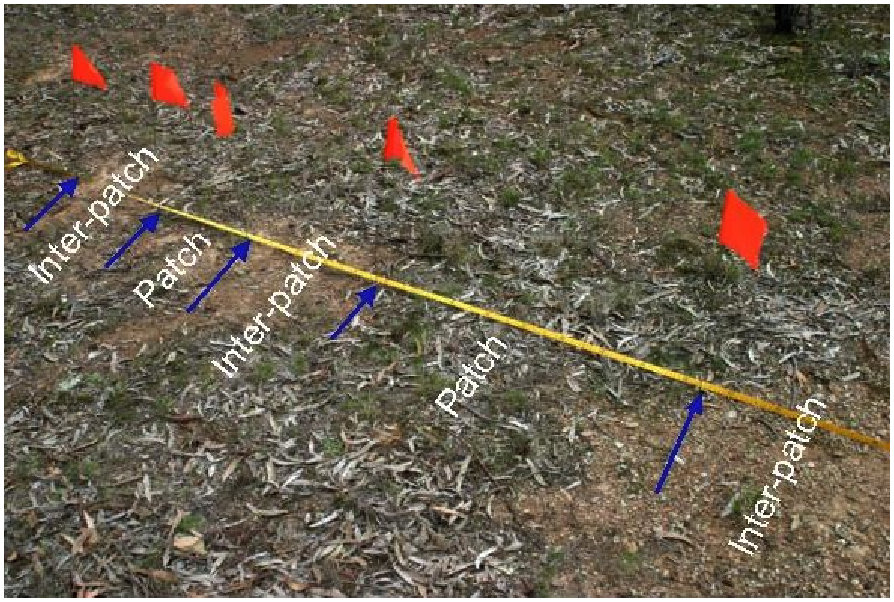

Figure 24. Section of a monitoring transect showing the patch/inter-patch boundaries.

Different types of inter-patch are possible, for example “bare crusted soil” or “bare stony soil”. This discrimination is useful but should be rapidly determined. Do not make subtle distinctions.

Inter-patch Measurement

- The distance between successive patches. (Figs 20, 21 and 24).
- Measure with a precision of ± 2 cm.
- Inter-patch width (on the contour) is **not** assessed, by convention.

Inter-patch Identification

Each patch and inter-patch needs a descriptive name, both to distinguish different types and to use as a record for future reference. For example, bare soil and bare soil with a stony surface could be describe as ‘bare soil’ and ‘bare stony’ rather than just “inter-patch”. The nature of the patches may change over time, and the soil surface condition data representing this change will show its magnitude. Photographic records of the individual zones as well as a fixed point general photo are very useful as a reminder of former assessments. Use a simple descriptive term to describe the inter-patch, for example “bare crusted soil” (Fig. 25a) or “bare sandy” (Fig. 25b) or “bare + gravel” (Fig.25c).

25a **25b** **25c**

Figure 25. Showing three examples of bare classification for inter-patch zones.

Worked Example

Figure 26 and Table 4 demonstrate a typical LFA landscape organization data set.

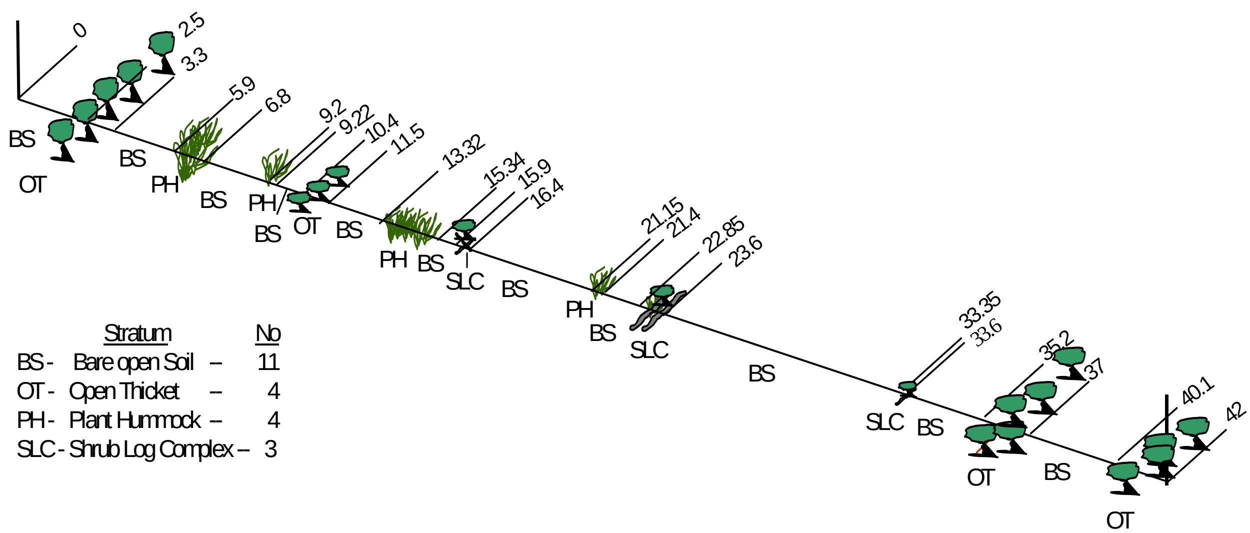

Figure 26. A diagrammatic representation of a monitoring transect showing the "logging of the line" into its inter-patch (bare open soil) and 3 types of patches (open thicket, plant hummock and shrub log complex).

Table 4. The landscape organisation data for the transect line illustrate in Fig. 26.

Distance	Patch width (cm)	Patch/Inter-patch Identification	Notes
0			
2.5		BS	Bare open soil (inter-patch)
3.3	710	OT	Open Thicket (patch)
5.9		BS	
6.8	80	PH	Plant Hummock (patch)
9.2		BS	
9.22	10	PH	
10.4		BS	
11.5	130	OT	

13.32		BS	
15.34	10	PH	
15.9		BS	
16.4	105	SLC	Shrub Log Complex (patch)
21.15		BS	
21.4	30	PH	
22.85		BS	
23.6	105	SLC	
33.35		BS	
33.6	35	SLC	
35.2		BS	
37	650	OT	
40.1		BS	
42	200	OT	

A summary of the organization data is given in Table 5. The landscape organization index is the proportion of the length of patch to the total length of the transect *i.e.*, a totally bare transect would have an index of 0 (zero) or if it was all patch (*e.g.*, a sward) the index would be 1.

Table 5. Summarises the landscape organisation data from Table 4.

No. Patch zones per 10m	Total Patch zone Width (m/10m)	Average Inter-patch Length and *range* (m)	Landscape Organisation Index*
2.44	4.13	3.17 *0.56 – 9.75*	0.22

* length of patches/length of transect

Major Erosion Features

The location of erosion features such as terracettes and rills (Table 6) should also be noted in the landscape organization data record. Erosion features may self-ameliorate or become worse depending on management or seasonal conditions, so assessment of their severity is important, particularly on mine rehabilitation. Movement up or down slope between sampling periods is also important to record.

Table 6. A sample landscape organization transect log. The position, height and condition of the terracette is noted in the notes column.

Distance	**Patch Width (cm)**	**Patch/Inter-patch Identity**	Notes
0			
0.68		CBS+ litter	CBS. - Crusted Bare Soil
0.89	34	dican	dican – Dicanthium patch
1.40		litter	arist. – Aristida patch
1.64	36	dican	Chry. – Chrysopogon patch
3.10		CBS + litter	
3.66		CBS	
3.73	6	dican	
4.56		CBS	
4.60		CBS + litter	Terracette @ 4.60 – active 1 cm high
5.23		litter	
6.60	113	dican	
7.10		CBS + litter	
7.70		litter	

8.08	72	dican	
8.30		litter	
8.55	105	dican	
8.68		litter	
8.76	8	dican	
8.91		CBS + litter	
9.00	17	dican	
9.60		CBS + litter	
9.80		CBS + litter	Terracette @ 9.80 – stabilized 1.5 cm
9.97	65	dican	
10.60		CBS + litter	
10.80	37	dican	
11.02		CBS + litter	
11.10	6	arist	
11.50		CBS + litter	
11.82	59	chry	
12.70		CBS +gravel	
13.51		CBS + litter	
13.72	40	dican	
14.60		CBS + litter	
14.77	30	dican	

Rill survey

If rills are observed at the site level at less than 30 m. spacing, we recommend surveying their number, location and cross-section by the following procedure.
Using the LFA transect as a reference, establish transverse transects ± 25m. (total = 50m) on the contour. Locate these at 25, 50, 75 and 100% of the LFA transect. Record the location of each rill on the contour transect and measure the width and depth of each rill.

We adopt the following conventions for rill surveys.

- The zero point is to the left of the transect line looking down slope.
- Note if the rill is short or long.
- Note if rill is "active" by observing the nature of the bed material and shape of the walls

Rills do not necessarily increase with time. If biological response is vigorous, rills can fill with alluvium and cease to conduct runoff. (see table 7 and 8)

Table 7. Example of field data collected from a rill survey. When monitored over time changes both positive and negative can be tracked.

Transect No /rill no	Rill Base	Start Rill (m)	Finish (m)	Rill Width (m)	Rill Depth (m)	X sect area (sq m)
T1/1	Rocky	14.6	15.5	0.9	0.6	0.54
T1/2	Gravel & Alluvium	18.1	19.1	1	0.55	0.55
T1/3	Alluvium	28.6	29	0.4	0.2	0.08

1/4	Gravel & Alluvium	29.3	29.8	0.5	0.45	0.225
T1/5	Rock & Alluvium	33.3	34.2	0.9	0.45	0.405
T1/6	Rock, Gravel & Alluvium	35.8	37.25	1.45	0.28	0.406
T1/7	Rock, Gravel & Alluvium	39.6	40.4	0.8	0.25	0.2
T1/8	Rock, Gravel & Alluvium	43.3	45.5	2.2	0.54	1.188
T1/9	Gravel & Alluvium	49.4	50.1	0.7	0.11	0.077

Table 8. Number of rills and mean rill cross-section (width by depth), obtained from 4 x 50 m lines aligned on the contour. Although significant in the first years of rehabilitation, rills decreased as biological control was established.

Years since rehabilitation	No of rills per 200 m	Mean rill cross section (cm^{-2})
2	66	341
5	10	102
9	0	0
15	0	0
unmined	0	0

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MINESITE REHABILITATION MONITORING

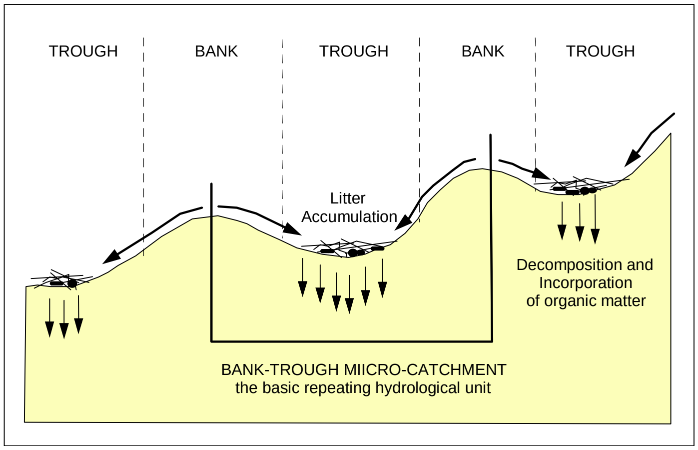
The method for monitoring minesite rehabilitation is basically the same, but some special physical features are put in place to give greater stability to the system to assist in the rehabilitation process.

Typically on mines, deep contour ripping of rehabilitated lands produces a “bank and trough” structure that forms the primary means of resource regulation from the earliest stages and often lasting many years (Fig. 27). In this system the trough is the patch (traps resources) and the bank the inter-patch (sheds resources). Figure 28 is diagrammatic illustration of this process.

Figure 27. A batter slope that has been contour ripped to produce “bank and trough” physical resource regulating means. There are no

signs of lateral flow in the troughs and hence no rills or gullies have formed.

Figure 28. A cross-sectional representation of contour ripping on a sloped landscape showing the functionality of a bank/trough system.



Note that if the ripping is not carefully aligned with the contour, lateral water flow along the trough may well ensue, with ultimately a major failure of the ripping as very large volumes of water move quickly to the lowest point in the trough and break through the banks. In this case the width of the patch (trough) is centered on the transect line and is measured 5 metres each side (max. of 10 m) or to a break in the bank where resources are being lost downslope.
The transect landscape organisation must record the successive bank intercept and trough intercept measurements. Information derived from any other treatment such as woody debris or establishing plants is also collected and used to assess the biological contribution to both landscape and zone quality development over time. Table 9 is a full transect landscape organisation record of a bank and trough system on the batter slope of a waste rock dump and Table 10 summarises that bank/trough data set.

Table 9. There are four landscape zones in this record: Bank (b), Bank with a plant (bp), Trough (t) and Trough with a plant (tp). For a trough to be classified as including a plant, the transect line must run **through/under the canopy** of a shrub or **across the butt** of grass plants.

Distance (m)	Patch width (m)	Patch/Inter-patch identity	Distance (m)	Patch width (m)	Patch/Inter-patch identity
0			12.6	1000	T
0.9		B	13.8		B
1.3	363	T	14	1000	T
2		B	14.8		B
2.3	1000	T	15	690	T
2.9		B	15.8		B
3.2	1000	Tp	16.1	770	T
4.1		B	17.4		B
4.3	760	Tp	17.7	250	T
5.1		B	18.1		B
5.2	1000	T	18.6	220	Tp
6.1		B	19.2		B
6.3	1000	T	19.4	440	T

7.4		B	19.9		B
7.6	1000	T	20.1	565	T
8.2		B	20.8		B
8.6	1000	Tp	21.1	600	Tp
9.3		B	21.9		Bp
9.6	1000	T	22	440	Tp
10.2		B	22.7		B
10.6	1000	T	23	250	T
11.3		Bp	23.7		B
11.5	1000	T	23.9	230	T
12.3		B	24.7		B

Table 10. Summary tables generated from the data collected in Table 9 for the 4 zone types identified.

Transect Patch and Inter-patch Type Summary

Zone	Mean Zone Length (m)	%
Bank	0.78	69.2
Bank + plant	0.75	6.1
Trough	0.25	17.4
Trough + plant	0.30	7.3
Total		100.0

Patch Obstruction Summary

Patch zone	Code	Total Width (cm)	Number	Mean Patch Width (cm)
Trough	t	12558	17	738.7
Trough + plant	tp	4020	6	670.0
Total		16578	23	720.8

Number of Patches/10m	9.3
Total Patch Width (m/10m)	67.1m
Average Inter-patch Length	0.81m
Landscape Organisation Index*	0.24

* length of patches/length of transect

Locating and recording the bank and trough boundaries

Figure 29 is a diagrammatic representation of a recently completed ripped slope, indicating the locations of the boundaries of banks and troughs, based on the concept of the hillslope gradient prior to ripping. The troughs would be below this line and the banks above it. This is not a critical data set and rapid consistency is more important than slow precision. This diagram also shows the "surface roughness" dimension needed in the SSA classification process.

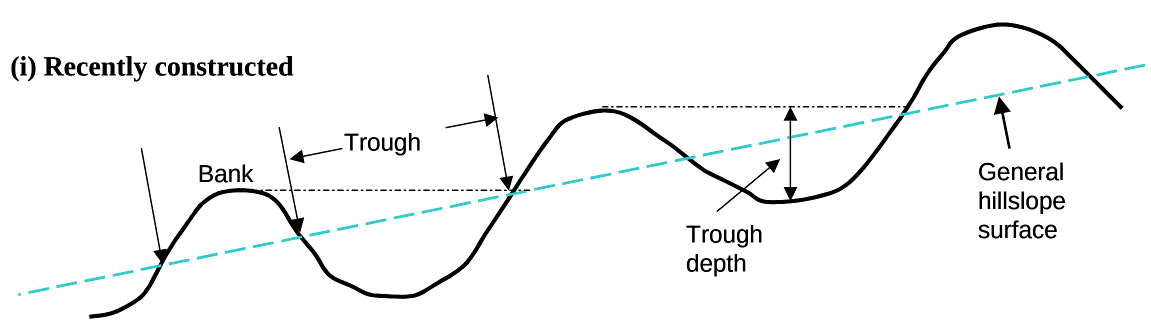


Figure 29. A diagrammatic representation of a bank/trough slope showing the measurements of patch (trough) and inter-patch (bank), and the trough depth used in the surface roughness assessment in SSA.

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Figure 30. shows the bank/trough system a couple of years after initial establishment, with sediment being built up on the bottom of the trough and banks eroding largely by sheet erosion. Troughs are likely to become wider and shallower over time. Note that alluvium in the trough may become more "soil-like" over time as plants establish and nutrient cycling progresses. (see also SSA indicators).

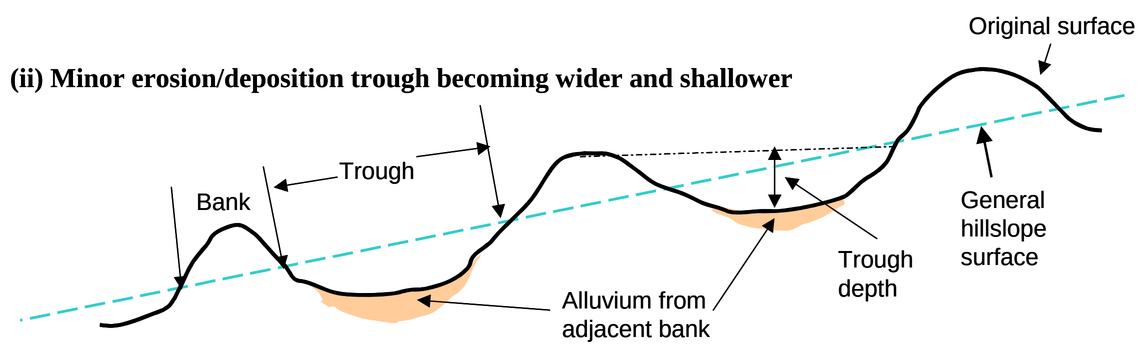

Figure 30. As for figure 29, showing some ageing and erosion processes.

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Figure 31 shows a situation encountered reasonably frequently. The trough has filled with alluvium to its capacity, with the result that a "flat and slope" geomorphic system is created, where the slope is the former downslope edge of a bank. Renewed erosion of the slope may then ensue, depending on the erodability of its materials, the length and angle of the upslope flats and slopes. At this stage, the patch/inter-patch structure disappears to form a continuous inter-patch. [Image]

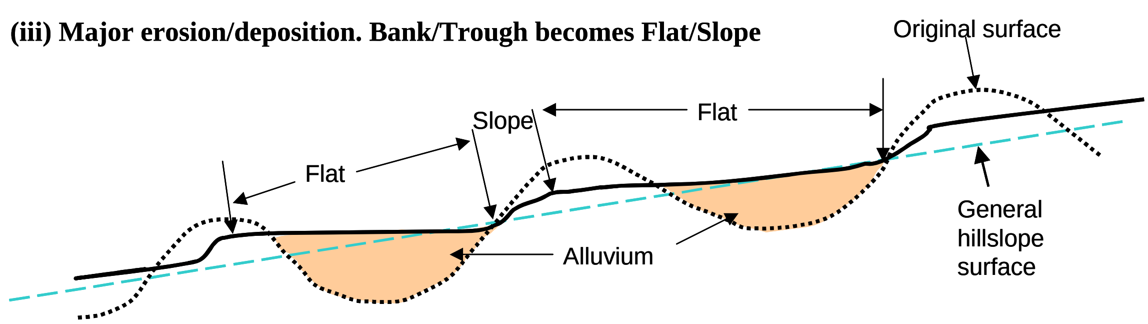

Figure 31. Showing the filling of the trough with alluvium and the resultant loss of resource control.

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Analogue/Reference Sites

The selection and use of analogue or reference sites is crucial to the effective use of LFA. Data from these sites provide both goal or target values for the LFA indices in rehabilitation and the landscape organization indices that represent a mature, highly functional landscape.

The field procedure for analogue sites is exactly the same as for the monitored sites. Figure 32 illustrates the range of patch and inter-patch zone types typically found in natural landscapes.

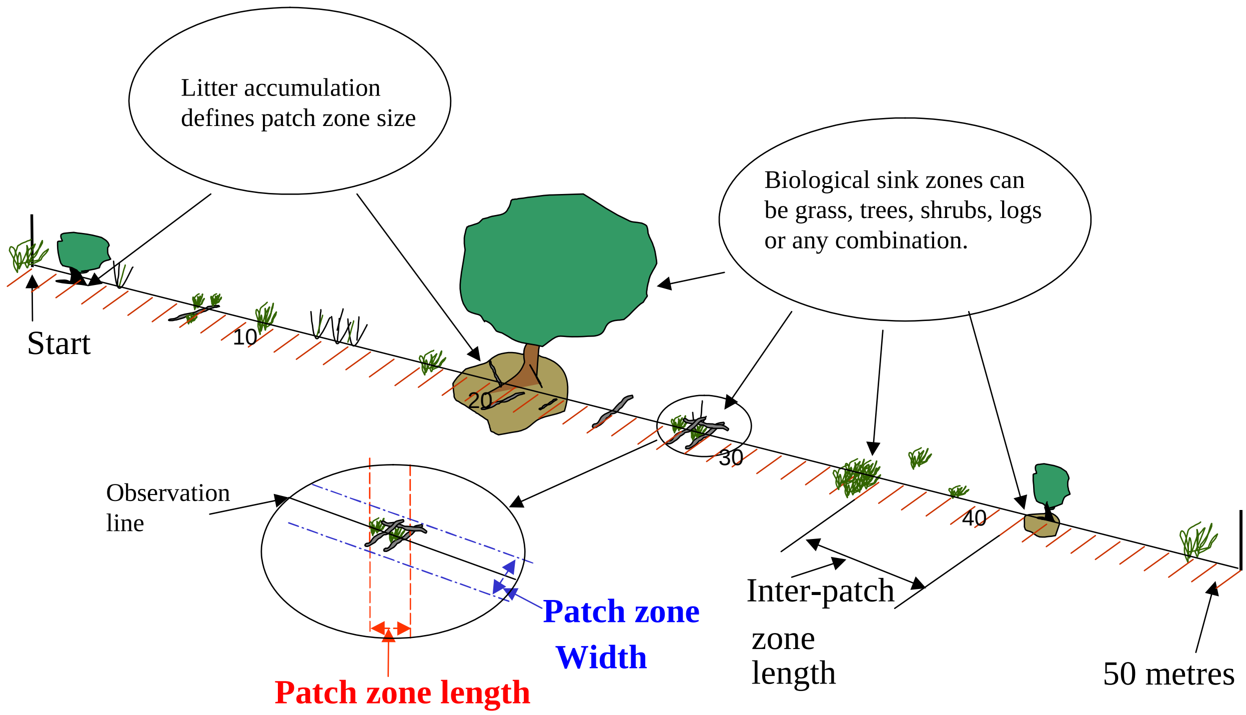


Figure 32. Illustration of an analogue monitoring transect. The short lines indicate metres. The assessment time should not exceed 20 minutes.

An analogue site is one that has many of the attributes of the final rehabilitated landscape and is self-sustaining, particularly in respect to functioning and serves to provide a goal or target for rehabilitation. The objective is to define a bunch of values that the rehabilitation site needs to converge on.

"Functioning" refers to the biophysical efficiency of the site, rather than an inventory of its biological components as such.

A landscape with high functionality has a high retention of vital resources such as water, topsoil and organic matter, whereas dysfunction implies that some of these resources are lost from the system.

Analogue Site Criteria
Analogue sites would have comparable slope, aspect, soil texture, soil cover, resource regulation and many of the vegetation species required in the mature rehabilitation. The biophysical functioning would yield values justifiably worthy of emulation in a rehabilitating landscape. Data from analogue sites is an integral part of the monitoring procedure throughout the monitoring process, so that varying seasonal conditions ultimately result in a "band" of values that act as the long-term target for rehabilitation.

In addition, data recording the response and recovery dynamics to stochastic disturbances of the analogue site (e.g. fire, storm) would provide a test of the resilience of a rehabilitated site (rate of recovery of function after specified disturbance).

The term "homologue" would be used to specify a landscape whose components would be replicated to a high degree in every respect: parent material, soil type, slope, aspect, species composition and land use. LFA does not expect this to be an objective.

STEP 3. SOIL SURFACE ASSESSMENT

Each patch/inter-patch type identified in the landscape organisation log must have its soil surface properties classified according to the Soil Surface Assessment Method detailed below. This assessment is made after the landscape continuous log record is compiled (step 2), on a set of **query zones** located within examples of each patch and inter-patch type. In selecting query zones the following guidelines should be observed:-

1. Observations of soil surface features are made using the landscape organization transect tape to define the **query zone**. Each SSA feature is therefore estimated on a linear basis and percentages calculated according to the length of the particular query zone (ie standard line intercept rules).

2. The assessment needs a minimum of 5 replicates of each patch/inter-patch type (if possible) for statistical reliability. If fewer than 5 examples are available for a given patch/inter-patch type, more than one query zone can be located in a long single zone.

3. Use the transect log to select the 'query zones'. (Hint: Avoid looking at the transect itself while making the selection as this can introduce a bias by selecting 'interesting' sites).

4. Ensure that the query zones are distributed along the full length of the transect, e.g. the transect in figure 18 in step 2 the query zones would be (Table 11):-

Table 11. The query zones for the transect in figure 26.

Type/Query zone	1 (m)	2 (m)	3 (m)	4 (m)	5 (m)
BS	0.5 – 1.5	12 - 13	17 - 18	27 - 28	38 -39
OT	2.6 – 3.1	10.5 – 11.5	35.5 –36.5	40.5 – 41.5	
PH	6.1 – 6.6	13.6 – 14.6	21.2 – 21.4		

SLC	15.9 – 16.4	21.2 – 21.4	33.4 – 33.6		

Note:- For OT, PH and SLC there were insufficient number to have 5 query zones for each of these type so use what there is available.

5. The actual query zone should be sited symmetrically within the selected zone patch/inter-patch. e.g. a bare surface is 73 cm long, 50 cm is an appropriate query length. The 50 cm length should be sited in the middle of the 73 cm length.

6. The standard query zone length is **1 metre.** If the patch/inter-patch length is insufficient, for a 1 m query zone, particularly where individual grass plants are patch zones, for convenience, use simple fractions of a metre if possible.

7. The boundary between two zones should be avoided where possible, as it is often diffuse at the cm scale, leading to confusion unless it is very distinct such as at the start and end of a patch. In the case where the patch is a single plant the query zone will be quite small and may be less then 10 cm, in this case assess the whole patch.

LANDSCAPE FUNCTION ANALYSIS

SOIL SURFACE ASSESSMENT METHOD

The nature, meaning and scope of each surface feature, together with a classification procedure is detailed below. In the full LFA manual images are provided for each indicator and class.

1. Rainsplash Protection

The objective is to assess the degree to which physical surface cover and projected plant cover ameliorate the effect of raindrops impacting on the soil surface. Raindrops can cause soil erosion or "physical crust" formation, which reduces infiltration.

Assess the combined projected percentage cover of: perennial vegetation to a height of 0.5 m; rocks > 2 cm in diameter; woody material such as branches and bark > 1 cm in diameter; and/or other long-lived, immoveable objects. These objects intercept and break up raindrops, making them less erosive and less liable to form soil physical crusts. This indicator relates to the Stability Index.

What doesn't count:

(i) Ephemeral herbage. This type of material may not be present when rain events are unpredictable such as in the more arid areas.

(ii) Foliage at heights greater than 0.5 m. "Gravity" drops falling from foliage are much larger than raindrops and have higher erosive capacity when falling from heights greater than 0.5m

(iii) Litter. This is assessed separately (Indicator 3) and inclusion here would "double-up" the contribution of litter when calculating the stability index.

Projected Cover	Class	Interpretation
1% or less	1	No rainsplash protection: bare, crusted soil, high run-off
1 to 15%	2	Low rainsplash protection: some woody stony or live plants will intercept some rain. Soil crusted
15 to 30%	3	Moderate rainsplash protection: noticeable protective effect, but some crusting
30 to 50%	4	High rainsplash protection: crusting variable or weak
More than 50%	5	Very high rainsplash protection: soil surface not crusted.

- -

2. Perennial Vegetation Cover

The objective is to estimate the "basal cover" of perennial grass and/or the density of canopy cover of trees and shrubs.

This indicator assesses the contribution of the below-ground biomass of perennial vegetation to nutrient cycling and infiltration processes through aboveground measurements. Grass cover is assessed by summing the **butt diameters** of perennial grass plants in the query zone. Tree and shrub cover is assessed from the cover and density of the canopy overhanging the query zone.

Basal and Canopy Cover	Class	Interpretation
1% or less	1	Very low root biomass likely
1 to 10%	2	Low root biomass due to a number of small plants
10 to 20%	3	Moderate root biomass due to medium sized plants
More than 20%	4	High root biomass, due to large plant presence

What is not included:

All non- perennial plants. The contribution of non-perennial plants is included in the litter indicator. Some bi-annual and annual grasses may be robust enough to act as pseudo perennials. The decision to include them in the assessment will depend on 'local knowledge' of the biology of the species. It is essential to be consistent across monitoring rounds. Use the "notes" column on the data sheet to indicate what decision has been made about a particular species functional role.

****

3. Litter

The objective is to assess the amount, origin and degree of decomposition of plant litter, to assess nutrient cycling

"Litter" refers to annual grasses and ephemeral herbage (both standing and detached) as well as the detached leaves, stems, twigs and fruit of other species and animal dung, etc.

This indicator is strongly related to the concentration of carbon, nitrogen and other elements stored in the surface soil layers.

Note: recent fire usually eliminates litter, temporally decreasing the nutrient cycling index, as it relies strongly on the litter indicator. Unless the effect of the fire itself is being assessed a period of at least one growing season should elapse before assessing burnt sites. This should remove a potential negative "spike" in the data.

There are three properties of litter that need to be assessed in the following order:

(i) **The cover** (in 10 classes) as per the table. When litter is more than 100% cover, the depth is assessed my compressing it with the flat of your hand to remove "air-gaps".

% Cover of plant litter	Class
<10	1
10-25	2
25-50	3
50-75	4
75-100	5
100 up to 20 mm thick	6
100, 21-70 mm thick	7
100, 70-120 mm thick	8
100, 120-170 mm thick	9
100, > 170 mm thick	10

(ii) **The origin** of the litter:

Litter Origin	Class
local (l) = derived from plants growing in very close proximity to the query zone and showing no signs of transport/deposition by wind or water flows	**l**
transported (t) = litter has clear signs of being washed or blown to the current location.	**t**

Litter patches in the surrounding landscape may assist in defining the origin of litter in the query zone (where they may be associated with parent plants or transported to a location where litter accumulates).

(iii) **The degree of decomposition/incorporation** in 4 classes:

Litter Origin	Class
Nil decomposition (n): the litter is loosely spread on the surface with few, if any, signs of decomposition and incorporation.	**n**
Slight decomposition (s): litter is broken down into small fragments and intimately in contact with soil; some fragments may be partially buried.	**s**
Moderate decomposition (m): litter is in several distinct layers; some fungal attack is visible; the layer next to the soil is somewhat humified; some darkening of the soil to a depth of less than 10 mm.	**m**
Extensive decomposition (e): litter has at least 3 layers or stages in decomposition ranging from fresh material on top to 20 mm or more of comprehensively humified (very dark, with no identifiable fragments) at the soil-litter interface; mineral soil may have significant organic darkening in excess of 10 mm.	**e**

Litter assessment examples

- 25-50% cover, local origin, slight decomposition is recorded as 3ls

- 100% cover but less than 20 mm thick, local origin, moderate decomposition is recorded as 6lm
- 10-25% cover, transported, nil decomposition is recorded as 2tn

Write the full coding into the SSA data-recording sheet and also type into the Excel SSA template.

****

4. Cryptogam Cover

The objective is to assess the cover of cryptogams visible on the soil surface.

For the purpose of this assessment, “Cryptogam” is a generic term that includes algae, fungi, lichens, mosses, liverworts and fruiting bodies of mycorrhizas. When these are present, they indicate soil surface stability and elevated levels of available nutrients in the surface layers of soil. They are known to exchange minerals and water with vascular plants in return for carbohydrates.

Typically (though not exclusively), they colonise soils with pre-existing stable physical crusts. They tend to impart flexibility to the physical crust, due to the ramification of hyphae through the surface few mm. Cryptogams may be early colonisers of recovering soil surfaces, but may later decline as vascular plant cover increases. Typically, they need high light levels to persist and are seldom found under dense, particularly woody, litter. They have been observed under light grassy litter and shallow sandy strews. Soils with physical crusts, in the open, are their typical habitat.

The soil surface may need close inspection to assess the presence of cyano-bacteria, which may appear as black stains. Adding a little water and observing the “greening” of organism over a period of 10 –20 seconds can be very useful. Some cryptogams may be “detached” from the soil surface after long periods of desiccation, but cover is assessed normally in such a case.

When cryptogams are not relevant:
Where the soil surface is clearly mobile, e.g. loose, active sands; “naturally active”, e.g. self-mulching clays or has an extensive deep litter cover, no habitat for cryptogams exists and a “**not applicable**” or zero recording should be made. Generally, if Crust Broken-ness (observation 5) has been assessed as “zero” (not applicable) then Cryptogam Cover will also be “zero” as it requires a stable surface for them to grow. In rare cases, lichens can grow on sandy soils, or on undisturbed self-mulching clays. Where this is observed, the cryptogam indicator must be assessed.

Cryptogam Cover	**Class**	**Interpretation**
Not applicable	0	No stable soil surface present
1% or less	1	No contribution
1 to 10%	2	Slight contribution
10 to 50%	3	Moderate contribution

More than 50%	4	Extensive contribution

5. Crust Brokenness

The objective is to assess to what extent the surface crust is broken, therefore to what extent loosely attached soil material is available for erosion.

A crust is defined as a physical surface layer that overlies sub-crust material.
Physical crusts in good condition are smooth and conform to the gentle undulations in the soil surface. Such crusts yield little soil material in a runoff event, but do restrict infiltration. However crusts can become unstable, brittle and easily disturbed by grazing animals, the materials becoming available for wind or water erosion. Typically sections of crust are lost, forming a micro-crater that may be filled with loose alluvium. Both the area and severity of broken crust need to be assessed. Fine polygonal cracking of the crust without curled-up edges is not considered broken and scores 4, the maximum value.

When crust broken-ness is irrelevant:
Record “Zero” in the following circumstances.

- Loose, sandy soil
- Self-mulching (surface crumb-structure) soils
- Soil under high, permanent perennial plant cover (no crust present, typical under permanent full litter cover)
- When less than 25% of the 1-m line transect is crusted

Crust Brokenness	Class
No crust present	0
Crust present but extensively broken	1
Crust present but moderately broken	2
Crust present but slightly broken	3
Crust present but intact, smooth	4

****

6. Soil Erosion Type and Severity

The objective is to assess the type and severity of recent/current soil erosion i.e. <u>soil</u> loss from the query zone.

Erosion in this context refers to accelerated erosion caused by the interaction of management and climatic events, rather than the background levels of geologic erosion.
There are five distinct types of soil erosion (see box) that are caused by water and/or wind action. It is useful to note which type or types are active and how serious is the soil loss. This involves both the aerial extent and the severity. The conventions of McDonald et al 1990 p 92-96 are used. A number of images are presented in the box to assist accurate classification.

Sometimes the erosion occurred at some time in the past and spontaneous restoration has since taken place. For example; rill edges may be rounded or terracettes may have cryptogam colonization (example) in these cases, reduce the severity by one class.

Forms of Erosion

Five major forms are described here and with the photographs referred to, enable the form/s of erosion on the query zone to be determined.

Sheeting, or **sheet erosion (E)** is the progressive removal of very thin layers of soil across extensive areas, with few if any sharp discontinuities to demarcate them.
This is not always easy to detect with assurance, and may need to be inferred from other soil surface features, such as downslope eroded materials, or surface nature. It is sometimes confused with scalded surfaces, but characteristically is associated with gradational or uniform textured soils.

Many sheeted surfaces are covered by layers of gravel or stone (collectively called "lag") left behind after erosion of finer material, when at an advanced stage (example).
Pedestalling (P) is the result of removing soil by erosion of an area to a depth of at least several cm, leaving the butts of surviving plants on a column of soil above the new general level of the landscape. Exposed roots are a hallmark of this erosion form. This is a sign that the soil type itself is very erodible and that loss of vegetation in the landscape was preceded by erosion, and not the other way about. Often associated with stones in the post mining environment.

Rills and gullies (R) are channels cut by flowing water. Rills are less then 300 mm deep and gullies are greater then 300 mm deep (McDonald *et al*). They may be initiated by water flowing down sheep or cattle paths. Their presence is a sure sign that water flows rapidly off the landscape, often carrying both litter and soil with it. They are aligned approximately with the maximum local slope.

Terracettes (T) are abrupt walls from 1 to 10 cm or so high, aligned with the local contour,. Terracettes progressively cut back up-slope, the eroded material being deposited in an alluvial fan down-slope of the feature. The location of a terracette should be noted in the comments of the landscape organisation sheet for the line transect so that its progress upslope can be monitored over time. A change of zone will occur at the location of the terracette and it is assessed as occurring in the upslope zone (i.e. it will have a Erosion type and Severity class value of 1 or 2. The erosion type downslope of the terracette may be sheeting with alluvial deposits.

Scalding (S) is the result of massive loss of A-horizon material in texture-contrast soils which exposes the A2 or B horizon which are typically very hard when dry and have extremely low infiltration rates.

Scalds have a productive potential of zero, and pond or shed water readily. They are often on flat landscapes, though not exclusively, whereas sheeting is on gentle slopes.

Erosion Severity	Insignificant	Slight	Moderate	Severe

Erosion Type	Class	Class	Class	Class
Sheeting (E)	**4**	**3**	n/a	n/a
Pedestal (P)	n/a	n/a	**2**	**1**
Terracette (T)	n/a	n/a	**2**	**1**
Rill (R)	n/a	n/a	**2**	**1**
Scalding (S)	n/a	n/a	n/a	**1**

****

7. Deposited Materials

The objective is to assess the nature and amount of alluvium recently transported to and deposited within the query zone.

The presence of recently transported soil and litter materials on the query zone indicates that instability upslope has permitted loose material to be transported to the query zone. Silts, sands and gravels usually comprise the alluvium. Absence does not necessarily imply a lack of deposition, as erosion may sweep all these materials out of the system. Alluvial fans can quickly become quite stable and productive, depending on the stress and disturbance impacting on the surface. An alluvial fan may become a productive patch within a short time if the right seasonal conditions occur. The amount or volume of deposited material is more important than the simple cover.

Hummocking is an indication of the movement large quantities of materials by wind. It is not to be confused with pedestalling which is the eroding away of material around plants and other objects. It is most often associated with adjacent scalding.

Hummocking is confined to soils with sandy-textured surface layers and is the result of re-sorting of sand by wind, which accumulates around obstructions, often to depths of many centimetres, or even metres.
The soil in the hummock is unconsolidated, and if sectioned reveals layers of accumulated soil (inter-bedding) and/or organic matter. The soil in pedestals is coherent and has no sign of layering.
A consequence of hummocking is that fine-grained materials and litter maybe widely dispersed during windy phases and are lost to the system. It is rare in the tropical grasslands.

Deposited Material	Class
Extensive amount present. Greater then 50% cover, several cm deep	1
Moderate amount of material present 20 to 50% cover, significant depth	2
Slight amount of material present, 5% to 20% cover	3
None or small amount of material present, 0-5% cover or a “dusting” of loose material	4

****

8. Soil Surface Roughness

The objective is to assess the surface roughness for its capacity to capture and retain mobile resources such as water, seeds, topsoil and organic matter.

Surface roughness may be due to depressions in the soil surface which retain flowing resources (depressions, gilgais etc) or to high grass plant density such that water flows are highly convoluted at the 5-cm horizontal scale. High surface roughness slows outflow rates, permitting a longer time for infiltration and may comprise a safe site for the lodgment of plant seeds and litter. Soil surface relief that does not facilitate resource retention attracts low scores (eg stones with no captured resources)

Surface roughness	Class
<3 mm relief in soil surface. Smooth: little or no retained materials	1
Shallow depressions 3-8 mm relief. Low visible retention	2
Deeper depressions 8-25 mm or grass plants growing close together. Moderate visible retention	3
Deep depressions that have a visible base Large visible retention	4
Very deep depressions or cracks >100mm. Gilgai depressions Extremely high retention.	5

9. Surface Nature (resistance to disturbance)

The objective is to assess the ease with which the soil can be physically disturbed to release material suitable for removal by wind or water.

- This assessment should only be done on dry soil, as all moist soils are soft. All the criteria below presume dry soil is being assessed. <u>If the local climatic conditions do not allow the soil to dry out, a sample can be collected and dried under cover for later testing.</u>

    - A very hard soil surface implies high mechanical strength, but very low infiltration, due to low porosity and massive crusting or "hard setting". This is taken into account by the Excel template which weights the stability and infiltration indices appropriately via the automated algorithms.

- Crust flexibility and coherence are assessed, as per the table. Note that classification here is not necessarily intuitive: barren, hard scald surfaces are classified 4. The spreadsheet deals with this apparent anomaly with appropriate re-scaling based on values that would be recorded for other indicators.

Surface Nature	Class	Interpretation
Non -brittle	5	Shows some “springiness” when pressed with finger, typically with A_0 layer; **or** Surface is a self-mulching clay; **or** Surface has no physical crust and is under a dense perennial grass sward (i.e. not just an isolated plant).
Crust is very hard and brittle	4	Needs a metal implement to break the surface, forming amorphous fragments or powder. The sub-crust is also very hard, coherent and brittle.
Moderately hard	3	Surface is moderately hard, may have a physical crust, and needs a plastic tool (e.g. pen-top) to pierce, breaking into amorphous fragments or powder; the sub-crust is coherent.
Easily broken	2	Surface is easily penetrated with finger pressure (to about first knuckle joint). Surface may have a weak physical crust and sub-crust is non-coherent *e.g.* sandy.
Loose sandy surface	1	Surface is not crusted, easily penetrated by finger pressure to about second knuckle joint. Sub-surface soil is non-coherent.

****

10. Slake Test

The objective of this test is to assess the stability of natural soil fragments when rapidly wetted.

- The test needs to be done on each patch and inter-patch type identified. Stable soil fragments maintain their cohesion when wet, implying low water erosion potential. The test is performed by gently immersing **air-dry soil fragments** of about 1-cm cube size **in rain quality water** and observing the response over a period of a minute or so. . If local climatic conditions restrict availability of dry soil, samples can be collected and dried for this test.
  - Water quality is important.
  - Saline water is unsuitable.
  - The soil crust must remain uppermost after immersion.

The fragment can be obtained with a chisel or knife blade, breaking the fragment with the fingers to the appropriate size. Some soils with high organic matter levels may float in the water.

Usually, these are stable (Class 4). Soils that do not permit coherent fragments to be picked up and tested (e.g. loose sands) should be scored as “not applicable” (record zero in the spreadsheet).

Exclusions:- Do not test moist soil. Take a sample back to the laboratory, allow it to air-dry, then test

Observed Behaviour	Class	Interpretation
Not Applicable	**0**	No coherent fragments available to test. e.g. loose sand
Very unstable	**1**	Fragment commences slumping in less then 5 seconds. Very fine air bubbles may emerge
Unstable	**2**	Fragment substantially slumps in 5-10 seconds but a thin surface crust remains: >50% of the sub-crust volume slakes
Moderately stable	**3**	Surface crust remains intact with some slumping of the sub-crust but less then 50% of the volume
Very stable	**4**	Whole fragment remains intact with no swelling. Large air bubbles may emerge

****

11. Soil Surface Texture

The objectives of this test are to assess the texture class of the surface soil as it affects infiltration.

This procedure is an initial measurement at the establishment of the site, and does not require being repeated at each monitoring event. The field technique is described by McDonald et al. 1990 as follows: *Take a sample of soil from a depth of 0-5 cm that will comfortably fit into the palm of the hand. Moisten the soil with water, a little at a time, and knead until the ball of soil, so formed, just fails to stick to the fingers. Add more soil or water to attain this condition, known as the sticky point, which approximates field capacity for that soil. Continue kneading and moistening until there is no apparent change in the soil ball, usually 1-2 minutes.*

The behaviour of the soil ball, or bolus, and the ribbon it produces by pressing out between the thumb and forefinger characterizes the field texture.

The flow-chart below enables soil texture indicator to be quickly determined.

Exception: Self-mulching, cracking clays should be assessed as class 3, because of their moderate infiltration rate

Table 12. The rating scales for individual soil texture features.

Texture	Class
Silty clay to heavy clay (very slow infiltration rate)	1
Sandy clay loam to sandy clay (slow infiltration rate)	2
Sandy loam to silt loam (moderate infiltration rate)	3
Sandy to clayey sand (high infiltration rate)	4

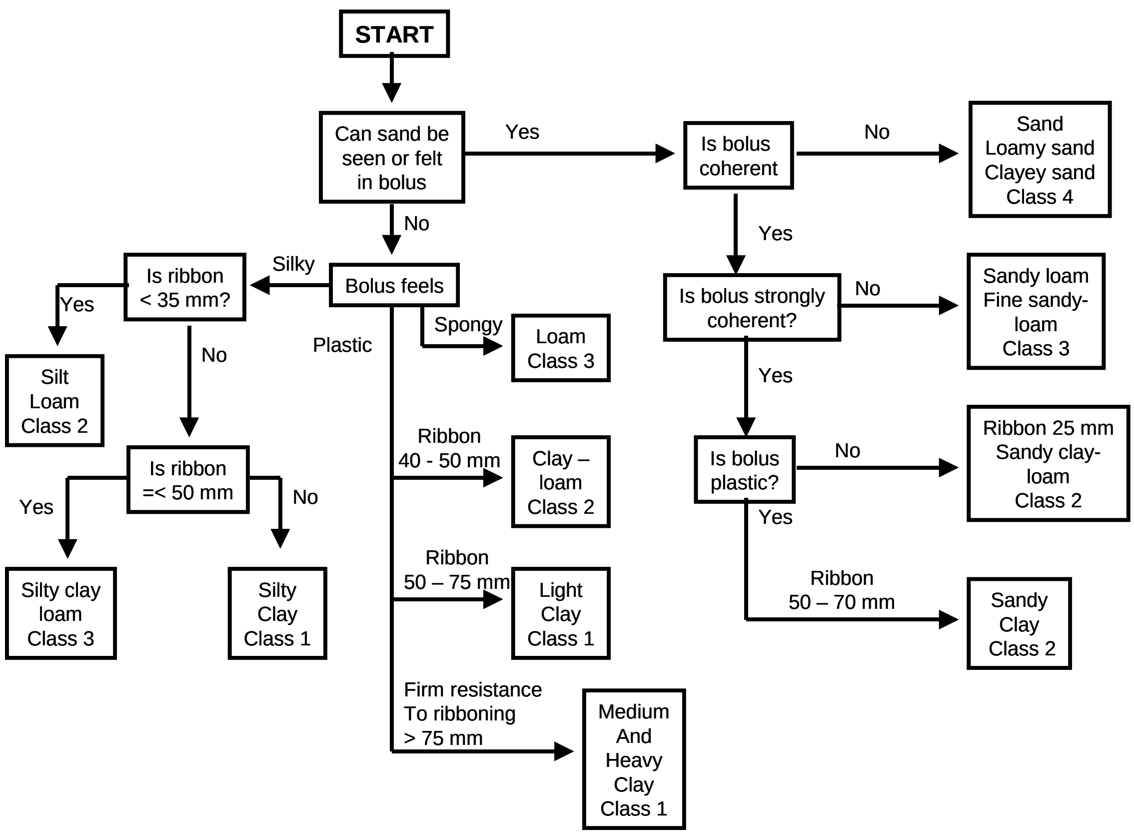


Fig. 12 Soil Texture Flow Chart.

APPENDIX 1.

PROCEDURE FOR CALCULATING SAMPLE SIZE: A GENERALISED DISCUSSION.

SAMPLE SIZE

Preamble

Determining the number of samples, N (observations, plots, quadrats, transects, etc.) required to accurately reflect a parameter (e.g., mean surface stability) for a population (e.g., for interpatches on a rehabilitated landscape) depends on the inherent (spatial) variability of the population. If this variability is high, a larger sample size will be needed to achieve an acceptable level of accuracy for the parameter of interest. For example, if variations in surface stability of interpatches across the landscape are high, a large number of samples (observations on the surface stability of interpatches) will be needed to accurately estimate the mean surface stability for this rehabilitated landscape.

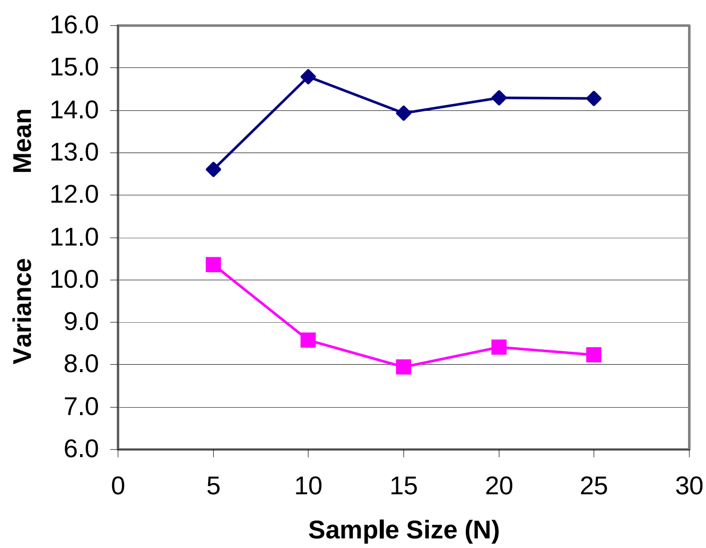
Background

The key words or terms in the above Preamble are "number of samples" (N), "to accurately reflect a parameter" (mean), and "variability of the population" (variance). As implied in the above, these terms are usefully related to each other. Let's look at this relationship in two ways, graphically and statistically:

First lets plot an example of mean and variance as they relate to N. For this example, lets assume we have made 25 observations for soil surface stability on interpatches along two transects positioned across a rehabilitated landscape. These 25 observations were:

10, 8, 16, 9, 20, 16, 18, 15, 19, 17, 9, 16, 10, 12, 14, 18, 22, 8, 15, 14, 18, 13, 19, 9, 12

Now lets plot the 'travelling' or 'running' means and variances after every 5 observations for this set of 25 observation (i.e., means and variance for 5, 10, 15, 20, 25, etc. observations).



Note how the mean goes up, then down, and then up slightly to a constant. The variance starts out high (> 10), and then declines and levels off at a value of about 8.2.

Second, we can now use the statistical relationships evident in the above graph to calculate the sample size (N) needed to achieve a defined level of accuracy about the mean estimate for surface stability. A statistical relationship between a mean (Xbar), its variance (xVar), and sample size (N) is given by the equation for Standard Error, SE (also referred to as the Standard Deviation of the Sample Mean):

$$SE = sqrt (xVar/N).$$

Now, we simply square both sides of this equation and rearrange it for sample size:

$$(SE)^2 = xVar / N$$

$$N = xVar / (SE)^2$$

or in other words, N = Variance/(Standard Deviation of the Sample Mean)^2

Next, we define the level of accuracy about the sample mean we are willing to accept, and call this level a "Standard Deviation of the Sample Mean", as in the above equation. For many ecological studies, a 10 % level of accuracy about a sample mean would be quite acceptable. So, let us define:

Standard Deviation of the Sample Mean = 0.10 times Xbar

Minimum Adequate Sample Size (N)

From the above, we now have the equations we need to calculate the sample size (number of observations) needed to estimate a mean with an accuracy of 10 %.

To illustrate this calculation, let us return to our preliminary or pilot sample of 25 observation of soil surface stability for interpatches on a rehabilitated landscape. After 25 observations, the sample mean Xbar = 14.3, and the variance about these observations xVar = 8.2.

First we define our acceptable level of accuracy about our surface stability mean as:

Standard Deviation of the Sample Mean = 0.10 x 14.3 = 1.43

Now, we solve our minimum adequate sample size (N) equation as:

N = Variance/(Standard Deviation of the Sample Mean)^2

$$N = xVar/(0.10 * Xbar)^2$$

$$N = 8.2 /(1.43)^2 = 8.2 / 2.045$$

N = 4.0 for a 10 % error about the sample mean

This says that, given our pilot sample data, the minimum adequate sample size (number of observations) needed to achieve a level of accuracy about our sample mean of 10 % is 4, which is good news. Of course, to cover the case where a rehab site may be slightly more variable, a slightly larger sample size of, say, 5 would be needed. As more site data is obtained, the minimum adequate sample size can be re-evaluated.

Although details will not be shown here, for a acceptable level of accuracy of 10 % the above equation can be written in the simple form of:

$$N = (100 * xVar) / (Xbar)^2$$

or, $N = (100 * 8.2) / (14.3)^2$

N = 820 / 204.5 = 4.0 for a 10 % error about the sample mean

For an acceptable level of accuracy about the mean of 20 %, the equivalent equation is:

$N = (25 * xVar) / (Xbar)^2$ for a 20 % error about the sample mean.

APPENDIX 2

LFA report writing checklist

Preamble

The following is a structured set of issues that should be addressed when writing LFA reports. These are generic questions derived from a wide range of circumstances. Not all the questions will be relevant at a given site. However, referring to these questions will facilitate the appropriate attention being paid to the most informative indicators and indices.

I strongly recommend that these be addressed whilst at the site, just after the data has been collected. There is space on the Site Description sheet for appropriate notes to be made.

I urge LFA users to routinely "surf their data" to find the most dynamic and informative indicators, and not to restrict themselves just to computed indices.

A. Introduction

- What are the aims of monitoring in this particular site/landscape?
- Are the aims clearly articulated, explicit and unambiguous?
- Are the aims capable of objective assessment?
- Are they likely to change if land ownership changes?

Use the answers to these questions to design the rationale for selecting monitoring and reference transects and combination of monitoring tools.

B. Landscape Characterization

- What is the soil texture profile and the broad properties of each horizon?
- Does the landform or soil type render the landscape especially liable to rapid dysfunction? (eg exposed dispersive soil, absence of rocky surface on a steep slope, etc)
- What are the threatening processes in this landscape? Describe in terms of stress and disturbance. eg unmanaged grazing by native and feral animals such as kangaroos, rabbits, goats, fire, recreational use, infrastructure such as access roads
- What have been the major and minor effects of management in this landscape? (eg tree clearing, planting exotic species, cropping, mining)

a. Landscape Organisation

- Is the site comprised of a single patch or interpatch?
- Is L/O due to biological or physical/engineering features?
- If a mixture of biological and physical, what is the current balance between them?
- Has physical patchiness declined since the last monitoring period? If so, is there cause for concern? Specify threatening processes (eg sedimentation, rill or gully initiation).
- Is biological patchiness increasing; is the rate significant?
- Has patch width increased or decreased since the previous monitoring? If decreasing, can the cause be identified (eg banks cut by rills, vegetation patches no longer linked by "litter bridges"). If increasing, what is the cause? (eg plant litter build-up between adjacent grass plants?)

- Are patches increasing or decreasing in length (ie up and down slope)?
- Is the patch area index increasing or decreasing?
- Has biological **patch quality** compensated for loss of physical patchiness, or not? Note that "whole transect" LFA indices (bottom line in last table on Summary page) are comprised of both "quality" and "proportion" values. Comment should be made on the make-up of the final number.
- Does patchiness change with season? eg massive annual plant growth that 'hays off" in the non-growing season.
- Is a stony surface a significant interpatch type? Is the stone embedded or resting on the surface?
- Is stone cover of such significance that a soil crust has not formed between stones?
- If patches are due to applied mulch, is the density and spacing of mulch having an effect on runoff and erosion/sedimentation processes? Check rill density upslope and downslope of the mulch to confirm. Look also for sediment trapped in upslope edges of mulch. Comment on whether too much or too little mulch appears to have been used, giving reasons. Assess the length of mulch downslope which appears to control the downslope movement of sediment.
- What are the major differences between the reference site and the assessed sites? (eg patch type and size).
- Are any of the assessed sites approaching the L/O of the reference sites?
- Is a rill assessment necessary? If so, observe the nature of the rill floor and note if it is rock or is unstable (loose alluvium, slaking soil)
- Are rills increasing or decreasing in number or cross-section; are live plant or litter obstructions becoming established?
- Is sediment noticeably being captured in developing patches? If so, make a note to watch these areas in future for plant germination. If no sediment is being trapped, consider an intervention to supply more resource flow "obstructions"
- Are patch/interpatch types changing in character; are new, more accurate names necessary? The need to do so should be explained, as both beneficial and detrimental changes can occur: explain in terms of resource regulation (patches may now be more complex: grass-shrub clumps forming? shrubs colonising? troughs growing plants? troughs becoming flats? banks becoming slopes?

D. Soil Surface Assessment

- Is rainsplash protection due to physical or biological factors? Is the protection potentially threatened by disturbance? If so, specify and discuss. Is rainsplash protection likely to increase over time (vegetation growth) or remain the same (rock)
- Is litter accumulating noticeably? Is decomposition becoming a more conspicuous process? What is the balance between litter derived from perennial vs annual plants? Is annual litter robust enough to be considered perennial (eg from biennial plants)? Is litter decomposition being reflected in soil darkening (look at the boundary between the litter and the mineral soil colour)?
- Is the surface physical crust becoming more or less pronounced? Is the sub-crust soil coherent (hard or weakly aggregated or single-grain) Are there any bio-aggregates (eg worm pellets, termite carton) present?

- Is all the litter accumulated subject to consumption by fire? (some landscapes have highly discontinuous litter beds, reducing the potential for complete loss in fire; grasslands are likely to lose all litter in a fire)
- Is plant litter (or applied mulch) sufficiently dense as to effectively filter out all particulate matter during overland flow? Look for deposited materials (physical or biological) near the upslope edge of the litter or mulch patch.
- Does the architecture of plant foliage tend to trap or accumulate resources at ground level, or is there a "gap" between the soil surface and the plant canopy? Can this be used to infer litter accumulation potential? Consider deploying the full vegetation function procedure.

Are there some indicators that do not alter across the function/dysfunction continuum? (eg soil texture, surface roughness) If so, comment on this and concentrate on the more informative dynamic indicators.

- What are the threatening processes for the patch types assessed? (eg grazing, trampling, vehicular traffic, erosion, burial under sediment, fire)
- Do the indicators of cryptogam cover, surface condition and slake test "match" each other, or can a mis-match be interpreted in functional terms?
- If evidence of current erosion is rarely observed, is this because potentially available material is held in a "safe" location in the landscape, or because there is no erodable material present, or remaining?
- Is alluvium frequently or infrequently encountered? If infrequent, is this due to its rapid outflow from the landscape, or is little soil available for transport: look for clues off the line transect for guidance. Look for alluvial fans at the foot of the slope to confirm.
- How strongly differentiated are the index values for patches and inter-patches? If differences are small, discuss the significance. If marked, discuss whether patches are vulnerable to disturbance or robust. Good discrimination implies that the L/O task has been done well.
- Are any indicators reaching their maximum score? If so, identify and comment on as having reached a significant "milestone" in rehabilitation.

E. Interpretational Framework

This step involves examining both the whole-of-site LFA values and the respective patch-interpatch LFA values so as to effectively summarize the findings of successive monitoring episodes, looking for trend over time. A sigmoidal or "S" shaped curve with time should be expected.

- Are LFA indices increasing, implying that rehabilitation is progressing satisfactorily? Is there a particular factor which is restraining improved function? Is management intervention necessary? What recommendations for action can be specified from the data? Is the increase expressed at the whole site level or just within a single patch type? Discuss.
- Has there been a significant increase in LFA values from the initial value?

Can a critical threshold be discerned in the index values (ie, LFA values about mid-way between initial and reference site values)? Discuss in terms of consequences for management actions (no problem; monitor at infrequent intervals; potential problem close to critical threshold, monitor more frequently; current problem, design intervention actions based on LFA indices. Devise target values and rehabilitation success and failure criteria for future monitoring.

- Expect the stability index to reach its plateau value before the infiltration index does. The nutrient cycling index will be the slowest as, for its plateau value, a mature vegetation stand, providing substantial litter fall and decomposition is necessary. A site may be concluded to be self-sustaining well before this however, if the stability and infiltration indices have progressed well and the nutrient cycling index is on an upward plane.

The ASWAT soil stability test
From Field, McKenzie and Koppi 1997 (AJSR 35, pp 843-52)
ASWAT = **A**ggregate **S**tability in **WAT**er

Preamble: The LFA slake test does not examine the dispersive properties of soils. Dispersion of clays is a much more serious matter than slaking. It can result in hard-setting dense soils and lead to gully and tunnel erosion. The following procedure assesses the dispersion character of soil samples on a 17-point scale, and uses simple equipment

1. Use air-dry 3-5mm natural soil aggregates. Immerse at least 4 aggregates into rain water contained in a petri dish, by lowering in carefully.

2. Observe the degree of milkiness, which signifies dispersion, around the aggregates after 10 mins. For no milkiness whatever, score 0; for slight milkiness, score 1; for obvious milkiness, score 2; for considerable milkiness, score 3 and for complete dispersion (sand grains in a cloud of clay) score 4. To be sure about detecting dispersion, use a solution of 0.01M calcium chloride as a check (1.47g $CaCl_2.2H_2O$ per litre). No soil will disperse in that solution. View and photograph against a dull black background. Note that it is dispersion that we are looking at here, not slaking (see par 8 below).

3. Retain these samples undisturbed and repeat the observations at 2 hrs, scoring in exactly the same way.

4. For only those samples that scored 0, wet a small soil sample (about 1 teaspoon) slowly with a fine water spray whilst mixing and moulding with a spatula, or do it in a clean, gloved hand, working the soil into a bolus as though doing a standard soil texture assessment. The right water content is when you can roll the just-moist soil into about a 3 mm rod and it falls apart into 10 mm lengths (is, not very plastic). Be careful to wet up slowly. Do not slosh the water in and need to add more soil! The glove is to prevent any sodium from sweat adding to the sample.

5. Test these moist, moulded samples in the same way as steps 1 to 3, scoring in the same way.

6. For the full score:
   (a) for soils that showed some dispersion in steps 1 to 3, add the 10-min score to the 2-hr score and then add to 8, giving a score ranging from 9 to 16.
   (b) For soils that scored 0 in steps 1 to 3, add the remoulded scores for 10-min and 2-hr together, giving a score between 0 and 8.
   (c) The total score for all samples is therefore 0 to 16, a 17-point scoring system.

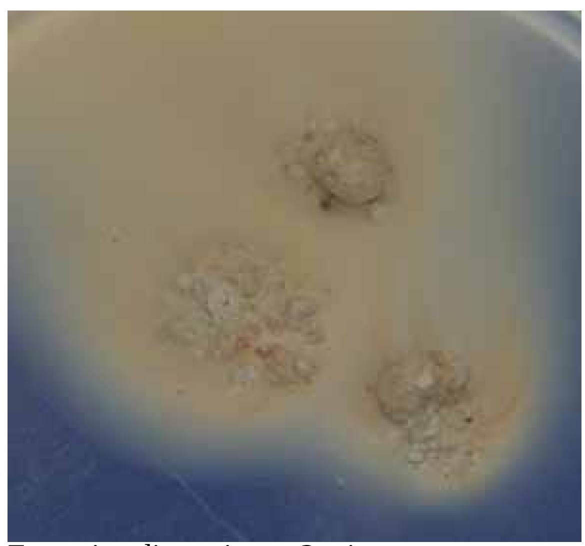
7. If the samples slake but do not disperse, the soil can be amended by organic matter incorporation alone.

8. The critical threshold value for soil dispersion in the field is 6. There is a good relationship with ESP, but the ASWAT test also integrates other factors associated with soil stability. Gypsum alone is the best ameliorant at pH values of 6 and above. For soils with pH's less than 5.5, lime (calcium carbonate) can have a long-term synergism with gypsum.


Slaked soil, no dispersion


Slight dispersion


Moderate dispersion at 2 minutes


Extensive dispersion at 2 minutes

Example of LFA Data Summary Page

Site Name **Chowilla**

Location **Bbox woodland**

Transect Name **transect 1**

Date **25/06/07**

Landscape

Zone	Mean Zone Length (m)	%
Bare soil	1.08	12.7
vegetation Pa	2.64	54.7
Tree Patch	3.67	32.5
Total		100.0

This box summarises the proportions of each patch and inter-patch type identified on the LFA transect. The data can be used "on their own" and are also used by the spreadsheet to calculate **site** LFA indices

Patches

Patch zone	Code	Width (cm)	No	Mean
vegetation Pa	vp	5520	7	788.6
Tree Patch	tp	2160	3	720.0
Total		7680	10	768.0

This box presents the widths of each patch type

Number of Patches/10m		**3.0**			
Total Patch Area		**239.9**	**sq. m.**		
Patch Area Index		**0.71**			
Landscape Organisation Index		**0.87**			
Average Interpatch Length (m)		**1.08**	**m**		
Range Interpatch length	**0.5**	**to**		**1.6**	**m.**

These six indices reflect different aspects of landscape organisation. They vary in their information content according to landscape type. Select the most useful for a given purpose

Soil Surface Assessment **Of individual Zones**

Zone	Stability	Std err	Infiltration	Std err	Nutrients	Std err
Bare soil	64.2	0.8	20.1	3.4	19.4	2.0
vegetation Pa	71.3	1.6	30.8	1.8	29.0	2.0
Tree Patch	70.4	2.3	40.5	1.7	38.8	1.5

This table summarises the mean LFA indices for each patch and inter-patch type assessed, and also presents the standard error of the mean, which should be < 2.5.

Soil Surface Assessment **Individual zones contribution to the whole Landscape**

Zone	Stability	Std err	Infiltration	Std err	Nutrients	Std err
Bare soil	8.2	0.1	2.6	0.4	2.5	0.3
vegetation Pa	39.0	0.9	16.8	1.0	15.9	1.1
Tree Patch	22.9	0.8	13.2	0.6	12.6	0.5
Total	70.1	1.9	32.6	2.1	31.0	2.0

This table calculates the relative contribution to the whole transect of each patch and inter-patch assessed, using the values from the table immediately above, **and** the table at the top of the page, which presents the relative proportions. The "site" values fr\or each Index are the bottom line on this table, together with the site standard error of the means.

The Sigmoidal curve as a basis for interpretation

There needs to be ways of interpreting monitoring data so that practical values emerge that are useful in predicting success. This is an area where relatively little work has been done at the practical level, though complex statistical models of plant species behaviour have had some attention.

Sigmoidal curves have been proposed for resource limited landscapes (Noy-Meir 1981), so there is at least a *prima facie* case to utilise this shape for interpretative purposes. The authors had independently looked at the concept in a rangeland context for the National Land and Water Audit (Tongway & Hindley 2000), and found that a sigmoidal curve was particularly useful in describing the behaviour of the data. The sigmoidal curve is intuitively attractive, because landscape values must have upper and lower biogeochemical bounds; the slope of the line between these bounds representing the transition from functional to dysfunctional status may vary, signifying differences in resilience. Noy-Meir (1981) utilised this form of relationship in his model of landscape structure and functioning, and Bastin *et al* (1993) also reported a similar spatial relationship with remotely sensed grazing gradients (See graph below). This curve form could also represent rehabilitation over time. In the reverse direction, it might represent desertification under specified circumstances.

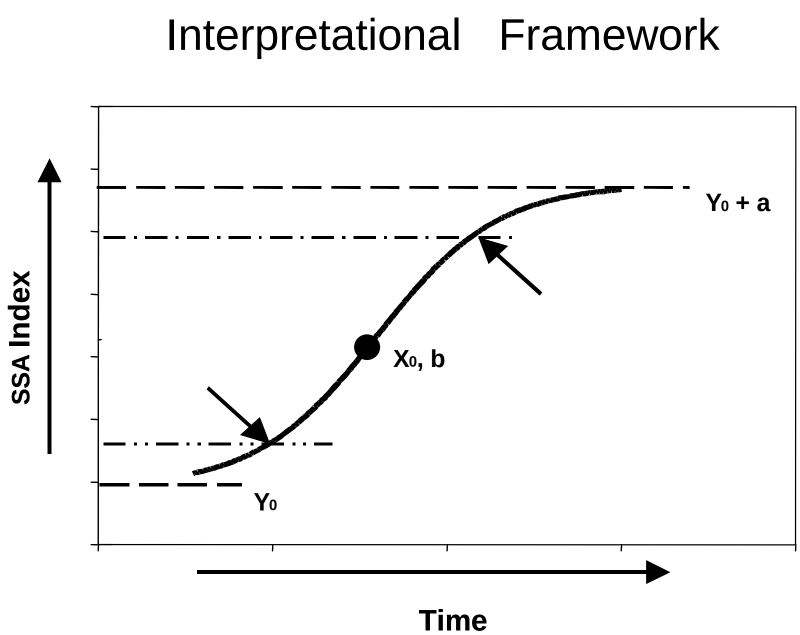


Figure 45. Depicts a fitted sigmoid relationship of the form
$y = y_o + a / 1 + e^{-(x-x_o)/b}$.

y represents an indicator of landscape function (soil stability in this case),

(y_o+a) represents the value of the upper asymptote,

y_o the computed value of the lower asymptote,

x_o represents the location of the inflection point of the curve on the x-axis and

b the gradient at the inflection point, represents the rate of increase of the assessed index over time. Low values represent quickly responding ecosystems, high values denote slow response.

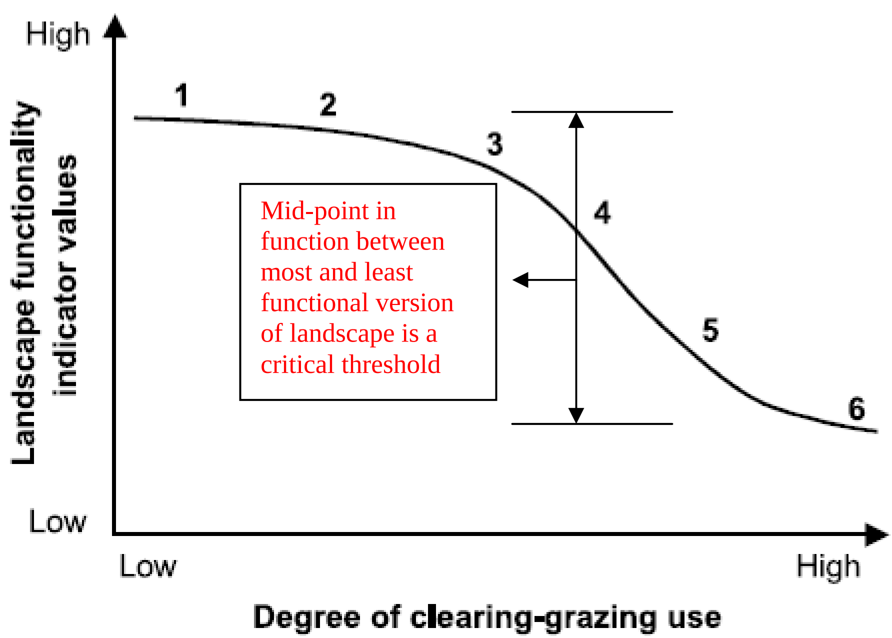
The curve parameters represent values related to functional behaviour of the landscape: how stable it can be when fully functional and how unstable when severely stressed. The dynamics of "functional" response in this case are due to the nature of the soil type and its moderate capacity to resist erosion.

The location of the points of maximum curvature (arrows) could be used as threshold values. The upper point could be used to differentiate between self-sustaining landscapes close to the 'ultimate goal', and those that are under threat of accelerated erosion. This curve can be fitted, and values for each of the curve parameters calculated by commercial software packages. The points of maximum curvature represent landscape threshold values for management and can be determined easily from the curve plot. The curve parameters can be used to characterise the functional response of different landscape types.

Rapid Assessment of Critical threshold values

The procedure briefly described above requires a lot of data, including values obtained from landscapes representing the least and the most functional that can be identified. To derive the actual curve shape and the parameters, at least 5 points located within the limits mentioned are needed, as the procedure for fitting curves of this nature require a lot of data points.

However, by using some of the principles emerging from the sigmoidal curve, estimates of critical thresholds for each of the LFA indices can be derived. The curve selected is symmetrical around the point x_0, b, so that in terms of landscape function, x_0,b is half way between the asymptote values. The point x_0,b is conceptually that point where "self-sustainability" of the landscape in the face of stress and disturbance commences and as values for landscape function climb above this critical point, landscape become more and more capable of absorbing stress/disturbance without substantive loss of function. If the search for examples of the most and least functional landscape is successful, then some simple calculations can be made. If, however, the examples available are not very close to the "extreme" values, then the process becomes reliant on curve-fitting as such, so that the extreme values are derived from the curve-fitting and not from field observations as such.



This diagram facilitates the rapid calculation of critical threshold values for each of the LFA indices:

C/T = (top value – lowest value)/2 + lowest value.

This procedure does not permit the rate of change to be assessed, until a proper time sequence of data is available. In rangelands, this is largely restricted to “distance from water” situations, unless deliberate rehabilitation procedures have commenced, when **time** can be plotted on the x-axis. This is not as rigorous a procedure as the full acquisition of data to construct a full sigmoidal curve, but enables an early estimate of critical values to be calculated. Over time, this value will become more and more reliable as data accumulates.