

Guideline

# Rehabilitation and Revegetation Monitoring Guideline

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Environment




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45-GU-EN-0009



**Fortescue**  
The New Force in Iron Ore

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<b>Checked</b>	Todd Edwards	 Signature	10/02/2017	
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Appendix 1: Landscape Function Analysis Procedure

## 1. INTRODUCTION

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These Rehabilitation and Revegetation Monitoring Guidelines have been developed to measure the performance of rehabilitation and revegetation works against site specific completion criteria.

The implementation of these Guidelines will address monitoring conditions outlined in Ministerial Statements 690, 862, 899 and Controlled Action EPBC 2010/5696.

These Guidelines addressed requirements of the Themeda Grasslands on Cracking Clays (Vulnerable) Threatened Ecological Community (TEC) and the Brockman Iron cracking clay communities Priority Ecological Community (PEC) rehabilitation monitoring program, required under CPS6710/1.

It is intended that future conditions of approval requiring rehabilitation, are also subject to these Guidelines.

### 1.1 Objective and Scope

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The objective of the rehabilitation and revegetation monitoring program is to evaluate the successional development of the rehabilitation, and thus provide useful feedback for the improvement of rehabilitation techniques, and to help assess progress towards long term rehabilitation objectives. Monitoring also provides information which can be used to set realistic and achievable rehabilitation success criteria and completion criteria. This objective can be achieved by examining changes in key parameters over time, and comparing results from the rehabilitation with those from corresponding reference sites in undisturbed areas.

The objectives of these Guidelines are:

- To provide a consistent approach for the development of effective monitoring programs.
- To ensure a qualitative, easy to implement approach for data collection, field-based monitoring and subsequent reporting of rehabilitation and revegetation performance against defined closure criteria.

## 1.2 Definitions

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Definitions applicable to these Guidelines are:

<b>Controlled sites</b>	sites that are under Fortescue's legal control including exploration sites, project sites, operational sites (sites that are managed and operated by Fortescue and sites that are managed by Fortescue but operated by contractors) and the Perth offices.
<b>Completion criteria</b>	an agreed standard or level of performance which demonstrates successful closure of a site (ANZMEC and MCA 2000).
<b>Reference site</b>	also called analogues or controls, an unmined site, usually representative of the 'natural' landscape surrounding the mine site or rehabilitated area. The reference site can include the target vegetation community, soil type, topography and terrain and can provide an example or reference for the setting of completion criteria values.
<b>Rehabilitation</b>	a return of disturbed land to a stable, productive and or self-sustaining condition, consistent with the post operational land used (DMP/Environmental Protection Authority (EPA), 2011).
<b>Revegetation</b>	establishment of self-sustaining vegetation cover after earthworks have been completed, consistent with the post-operational land use (DMP/EPA, 2011).
<b>Upper storey species</b>	Tree or Mallee species, as defined by FloraBase ( <a href="https://florabase.dpaw.wa.gov.au/">https://florabase.dpaw.wa.gov.au/</a> ). Tree or mallee species considered mature when $\geq 2\text{m}$ height, for the purposes of monitoring, and immature (juvenile) when $< 2\text{m}$ in height.

## 2. MONITORING SITE SELECTION

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A rehabilitation and revegetation monitoring program should be based on replicable sampling of rehabilitation and reference sites. Monitoring sites represent a unique sampling location within an area of rehabilitation, and its corresponding reference site. The size, nature of the rehabilitation area to be assessed, and end land use should be considered when installing monitoring sites and determining suitable sampling size. Factors to consider include topography (slope vs. flat), year of rehabilitation, and rehabilitation treatment (topsoil, ripping, revegetation, fertilizer, seeding rates and treatment types).

In general, each rehabilitation and reference monitoring site should be represented by a transect, with quadrats monitored along a transect. Smaller areas (borrow pits <1 ha, linear infrastructure <1 ha) should generally be represented by a photographic monitoring point.

Monitoring sites should be located in each closure domain or feature and may include:

- Waste Rock Landforms
- Mine Pits
- Tailings Storage Facilities
- Industrial Infrastructure
- Groundwater Infrastructure
- Borrow Pits
- Roads and Tracks
- Airport
- Other disturbances including topsoil stockpiles, laydown areas, etc.

Periodical review of newly rehabilitated areas and areas available for future rehabilitation should be conducted, and these areas added to the Fortescue rehabilitation monitoring schedule. High priority areas such as waste dumps, tailings storage facilities and large areas of rehabilitation should all be included in the program once rehabilitated and revegetated, whereas only a representative sample of areas should be selected for numerous lower priority areas (e.g. borrow pits and linear areas), of similar rehabilitation age and treatment.

A single reference site or system is usually insufficient and multiple reference sites should be used to account for site heterogeneity. It is also important not to set reference sites as exact comparative targets for the rehabilitation; rather, they are to be used as a reference. Rehabilitated communities have vastly different environments and composition due to disturbance and cannot reflect the optimal state of an undisturbed ecosystem. There is,

nevertheless, value in setting benchmark areas so that climatic and seasonal influences that may impact on rehabilitation progression can be quantified (DITR, 2006).

In general, reference sites at Fortescue sites should be situated in close proximity to rehabilitated areas, in target vegetation community/broad vegetation formation or suitable domains that have the same or similar end land use to that of the rehabilitated areas. Existing site specific rehabilitation and revegetation plans and baseline flora and vegetation surveys should be reviewed prior to selecting and installing reference sites.

Legislative requirements should also be checked prior to installation of reference and rehabilitation monitoring sites. For example Condition 14 of Ministerial Statement 899 and EPBC Approval No. 2010/5696 states that reference sites be established in each of the identified broad vegetation formations identified in baseline mapping for the project.

In addition, reference sites should be installed in areas that can be accessed easily and safely (i.e. with minimal escorting requirements and close to navigable access tracks), as well in areas that will not be impacted by future mine development (as far as can be predicted).

### 3. MONITORING DESIGN

The following options should be used for monitoring of rehabilitated and revegetated areas (Table 1).

**Table 1: Monitoring options for rehabilitation sites**

Monitoring Option	Monitoring descriptions
Transect	<ul style="list-style-type: none"> <li>• A photographic record of transects (start and finish) should be taken parallel to each transect.</li> <li>• Used to collect soil and surface condition parameters (Landscape Function Analysis) as well as vegetation data (collected within 2m x 2m quadrats arranged along each transect).</li> <li>• Installed every 2 – 5 ha, or more, and should adequately represent the rehabilitation area.</li> <li>• Areas with a greater degree of variability (e.g. in topography or type of rehabilitation treatment) will require more transects (Figure 2).</li> <li>• Transects should be located on a homogeneous slope, with no marked changes in slope angle or rehabilitation treatment used, and never cross different vegetation communities, topographies or soil types. Transects on flat areas should be installed perpendicular to rip lines or follow the direction of water/resource flow.</li> <li>• When installed on a slope, transects should run down the slope and ideally be 50 m in length. In some cases, the physical nature of the rehabilitation area, e.g. slope length or the size of rehabilitated area, will constrain the maximum length of each transect, in which case transects may be less than 50 m in length (as a guide transects should not be less than 20 m). Paired transects may be used to increase sampling effort where extent is limited.</li> <li>• Transects should never extend from one batter on to another. Posts (steel posts or star pickets) should be used at the start (0 m) and end (50 m or more) points of each transect. Posts should be labelled with the transect name.</li> <li>• Erosion transects can collect data on rill and gully development. Two smaller pickets/posts are installed at the 10 and 30 m mark (approximately) of the main transect. These pickets/posts should sit on the 'bank' feature of the rip-line. Posts for the erosion transect are only usually installed on waste dumps or other sloped areas where large scale erosion is likely to occur. Installation of these on flat areas is only on an as-required basis where erosion is occurring.</li> <li>• Larger quadrats (50 x 50 m, or as appropriate for size of the area being assessed) should be positioned over the main transect, and used to capture the density and/or percentage cover of tree/mallee (upper storey) species.</li> </ul>

Monitoring Option	Monitoring descriptions
Photographic monitoring point	<ul style="list-style-type: none"><li data-bbox="568 286 1433 383">• A single star picket or steel post should be installed at the rehabilitation area and a photographic record of the site taken, including the post, in a consistent fashion each monitoring event.</li></ul>



**Figure 1:** Example positioning of transects (50 m) on a rehabilitated waste dump, red markers indicate start and end posts and yellow markers indicated erosion posts

## 4. MONITORING METHODOLOGY

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### 4.1.1 Monitoring parameters

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The selection of parameters to monitor, and how frequently, depends on what information the parameter provides, how sensitive its response, its correlation with known ecosystem processes and predictability, its ease and cost of measurement and repeatability or degree of subjectivity. The choice of monitoring parameters is quite extensive but should include those that are known or expected to be most limiting to rehabilitation success (DITR, 2006).

Typically, monitoring of rehabilitation can include:

- an assessment of surface and slope stability;
- the performance of constructed covers (where installed over mine or mineral processing wastes)
- properties of the soil or root zone media (chemistry, fertility and water relations)
- plant community structural attributes (such as cover, woody species density and height)
- plant community composition (such as presence of desired species, weeds)
- selected indicators of ecosystem functioning (such as soil microbial biomass)

Monitoring may also extend, where required, to monitoring of selected fauna groups to assess their colonisation (including mammals and avifauna) or as bioindicators of broader ecosystem trends (e.g. ants).

Monitoring of Fortescue rehabilitation sites should consist of the following parameters as a minimum (Table 2). Additional parameters can be added to the programme on a case by case basis depending on site specific requirements and upon consultation with Fortescue Environment Team.

**Table 2: Minimum monitoring parameters to be recorded for rehabilitation and revegetation monitoring**

Parameter	Method	Expected data outcomes
Species richness	2 x 2 m quadrats measured along a linear transect, up to 50 m in length	The total number of plant species present in the monitored section of the rehabilitation area.
Species diversity		The effective number of different species that are represented in a collection of individuals in a dataset and is measured using species richness and species evenness, where species richness is a count of total species, and species evenness quantifies how equal the abundances of the species are. The Shannon-Weiner Diversity index should be used, which is a measure of the relative abundance of species in a group.
Species Composition		The types of species present, including desirable species that are planned, as well as undesirable weed species.
Percentage cover and density		Total perennial percentage cover and density, calculated individually for native perennial species and weed species. Additionally cover values for <i>Triodia</i> , tussock grass and shrubs should also be recorded.
Upper storey species cover and density	All sites - 50 x 50 m quadrat TEC and PEC - 10 x 10 m quadrat	The number of upper storey individuals in a given area, as plants per hectare. Upper storey species are recorded at any lifeform stage.  Cover and density values should be recorded separately for each upper storey species, and separate counts and cover estimates to be made for plants <2m and ≥2m in height.
Erosion	Transect	Mean number of rills/gullies per 50 m and average rill/gully width and depth.
Landscape Function Analysis	Transect	Stability, nutrient cycling and infiltration indices.
Vegetation Condition	Qualitative assessment of whole rehabilitation area	A condition ranking from Excellent to Completely Degraded as per Trudgen (1991, cited in Department of Environmental Protection 2000), as well as a rehabilitation-specific condition (See Table 3).

## 4.1.2 Vegetation Monitoring

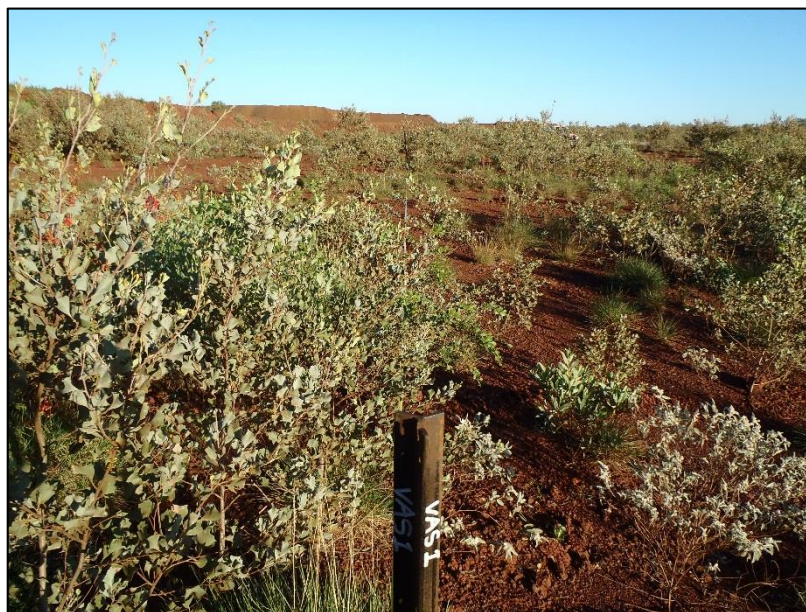
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At the installed transect, a series of quadrats will be monitored. The recommended required quadrat dimensions are 2 x 2 m at a spacing of 5 m (). Each transects should be aligned with the slope (downslope) and or surface water flow direction, and perpendicular to rip lines where areas are ripped and/or flat. The length of each transect should be 50 m but can be amended to accommodate the purpose of monitoring, size of rehabilitation area and local disturbances.

All transect posts should be clearly labelled with white paint pens or similar, with the transect name and distance (i.e. 0 m or 50 m) labelled on each post. A series of field sheets in excel and word format are available.

The monitoring methodology for vegetation monitoring includes:

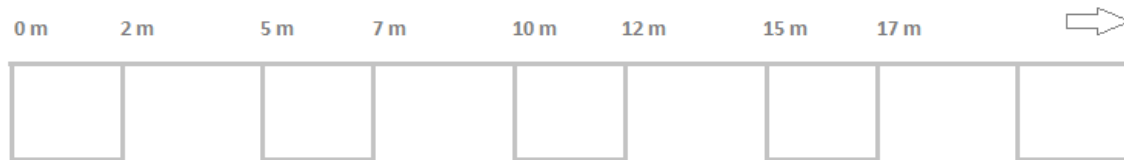
- In subsequent years of monitoring, the previous year's data sheets should be reviewed as a reference and form of calibration.
- A 50 m measuring tape should be run tautly with the 0 m end on the start picket (at the top of the slope) and 50 m end at the end picket (at the base of the slope). Coordinates at the start and end of each transect should be taken using a GPS and recorded on the *Revegetation monitoring field data sheet (2 x 2m quadrats) (M-TE-EN-0003)*.
- A photograph should be taken at the start and end point of the transect, with the picket aligned in the middle of the photograph, occupying no more than one third of the foreground. On subsequent visits, the photograph should be taken at the same spot and using the same focal length and settings as possible, to match previous photographs.



**Figure 2:** Example transect photograph showing picket and tape line in centre of photograph, with picket occupying less than one third of the foreground

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- Using a 2 x 2 m quadrat frame or hand held tape measure, align the quadrat on the ground (this is Quadrat 1) in front of the 0 m peg and align the left hand side of the quadrat on the right hand side of the transect.



**Figure 3: Transect and quadrat layout for vegetation monitoring**

- Populate the *Revegetation Monitoring Field Data Sheet* (2 x 2 m quadrats) (M-TE-EN-003) with the following data for each quadrat:
  - the number of individual plants of each perennial species growing within the quadrat (e.g. the main stem of the plant must be inside the quadrat). The number is recorded on the field sheet under quadrat 1 in line with the recorded species name and in the column marked 'n'.
  - for each (perennial) species in the quadrat, estimate the percentage of cover inside the 2 x 2 metre quadrat and record this in the column marked 'c'. For example, there may be 4 *Senna artemisioides* subsp. *helmsii* with a total cover of 20% in the quadrat, and one *Triodia pungens* with 10% cover. Again, this measure only includes plants growing within the quadrat and excludes foliage overhanging over the quadrat. Where percentage cover is greater than 10%, estimates should be made in 5% increments so as to reduce observer subjectivity.
    - In order to reduce observer error, the 2 x 2 m quadrat can be divided into quarters (i.e. 25%) using hand held tapes. As a further guide, the size of an A4 page represents 1.5% cover within the 2 x 2 m quadrat.
    - Where plant cover is sparse, cover only includes living branches and foliage.
  - the same number and cover data should be recorded for each weed species, including both annual and perennial weeds.
  - the total native perennial cover of the entire quadrat (out of 100%). This also includes:
    - plants that are not growing within the quadrat but overhang into the area;

- plants >2 m or with the potential to grow >2 m (i.e. upper storey); but
    - does not include weeds or annuals.
  - the total percentage cover of spinifex, grass and shrubs. 'Shrubs' here are designated as any middle storey, multi-stemmed species (e.g. *Acacia*, *Senna* spp.) that are not tree (*Eucalyptus*, *Corymbia*, Mulga) species. Spinifex is defined as all species in the *Triodia* genus whereas grass includes all other species in the Poaceae family (e.g. other tussock and bunch grasses). Note that other vegetative forms, e.g. mistletoe, perennial herbs and creepers/vines, are excluded from this section of the data sheet. Weeds are also excluded.
  - Record litter cover, including litter under plants and litter on bare ground. This includes litter in contact with the ground only, and not suspended litter material (e.g. dead branches).
  - Record the presence of native annuals per quadrat, and list annual species in the row below. Annual species to be defined by FloraBase (DPAW) and where a species is defined as 'annual or perennial', additional information can be gained through specimens submitted to the herbarium.
  - Record the total number of logs and rocks for each quadrat, where logs are greater than 10 cm in diameter and 30 cm length and rocks are greater than 15 cm across any axis (i.e. large flat rocks are counted). Although not part of the compulsory parameters, this information can give an indication of available habitat for future fauna colonisation of rehabilitated areas.
  - For each quadrat, record whether the vegetation has been burnt since it was last monitored. Previous photos can help with this section if a recent fire is evident, to determine if the fire occurred before or after the previous monitoring.
  - Record dust presence on plant canopies (yes/no).
- For the remaining quadrats on the transect, shift the quadrat frame/hand held tapes onto the 5 m mark so that the left hand side is aligned against the 5 – 7 m section of the measuring tape. A standard transect (50 m) should have a minimum of ten quadrats.
  - At the bottom of the *Revegetation Monitoring Field Data Sheet* (2 x 2 m quadrats) (M-TE-EN-003):
    - Record the Vegetation Condition as per Table 3. The Trudgen 1991 scale is best suited to reference sites only, however this scale has been used in completion criteria for rehabilitation areas. For this reason, the Trudgen scale

must also be applied to the assessment, as best as practicable given the descriptions. An additional scale has also been developed to better reflect rehabilitation outcomes, and may be used to update completion criteria in the future (thus both scales must be used for each rehabilitation area).

- Record extent and intensity of grazing, if present. Scat and track counts are useful measures.
- List species flowering and fruiting.
- List any sightings of fauna, tracks, scats or burrows (feral and native).
- Upper storey, including all tree and mallee species as defined by FloraBase (DPAW) recorded within a quadrat (generally 50 x 50 m, or 10 x 10 m in the TEC/PEC) and recorded in the *Revegetation Monitoring Field Data Sheet (Upper Storey)* (M-TE-EN-0003). If the transect has been limited by the length of slope, the upper storey quadrat should be 50 m x ‘the length of the transect’.
- Specimens of plant species not immediately or readily identified in the field should be tagged, labelled and collected in a field press for identification by a qualified taxonomist.

**Table 3: Vegetation condition scales**

Vegetation Condition	Trudgen 1991 criteria	Rehabilitation-specific criteria
Excellent	Pristine or nearly so, no obvious sign of damage caused by European man.	Rehabilitation blends into surrounding vegetation such that it is almost indistinguishable from surrounding vegetation. Erosion is minimal or very stable. Very low or no weeds.
Very good	Some relatively slight signs of damage caused by the activities of European man e.g. damage to tree trunks by repeated fires, the presence of some relatively non-aggressive weeds or occasional vehicle tracks.	Native perennial vegetation cover is similar to reference sites (but vegetation community still easily distinguished from or different to surrounding vegetation) or vegetation community developing towards reference sites (but cover/density lower than control sites). Low or no weeds, low or no erosion.
Good	More obvious signs of damage caused by the activities of European man, including some obvious impact to vegetation structure such as caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive species.	Appears to be developing towards ‘very good’, but with lower perennial vegetation cover or perennial vegetation species very different to reference sites. Higher weeds than reference sites or erosion moderate to high (but not severe).

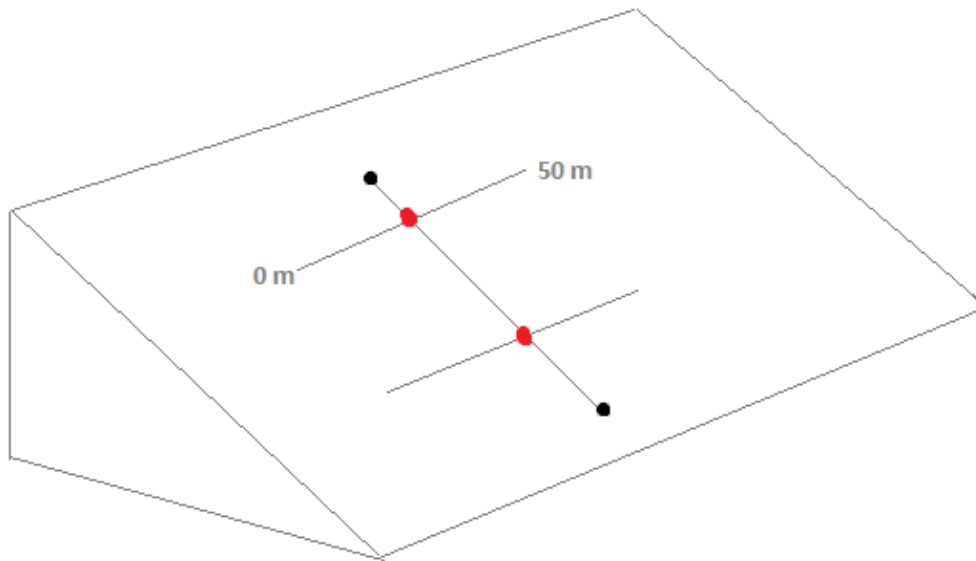
Vegetation Condition	Trudgen 1991 criteria	Rehabilitation-specific criteria
Poor	More obvious signs of damage caused by the activities of European man, including some obvious impact to vegetation structure such as caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive species.	Low native vegetation cover compared to reference sites and/ or high weed cover and/ or high/severe erosion.
Very poor	Severely impacted by grazing, fire, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weeds species including aggressive species.	Very sparse native vegetation, such that management action may be required to improve native vegetation, and/or  Severe erosion, with multiple deep gullies which will require management action and/or dominated by aggressive weed species which are out-competing native species.
Completely degraded	Areas that are completely or almost completely without native vegetation e.g. areas that are cleared or parkland cleared with their flora comprising weed or crop species with isolated native trees or shrubs.	N/A

### 4.1.3 Erosion Monitoring

Transect design can be used to monitor erosion monitoring parameters. This monitoring can be conducted on sloped areas, or flat areas exhibiting signs of significant erosion (e.g. extensive rilling and gullying).

The monitoring methodology for erosion may include:

- Place a 50 m tape flat on the ground perpendicular to the main transect using the 10 m and 30 m erosion markers as the middle point (e.g. 25 m on the tape) as a reference. The 0 m end of the tape should be on the right side of the transect (facing downslope) **(Error! Reference source not found.)**.
- Starting from the 0 m end of the tape, walk along the transect and record any rills or gullies that intersect the tape (gullies are >30 cm deep) on the 'Start' and 'End' columns in the *Erosion Monitoring Sheet* (M-TE-EN-005). Measure the depth of rills and gullies at the deepest point
- Where determined significant (e.g. a gully, or a rill that has recently developed into a gully), photograph the feature and record its photo number. Two photos should be taken, one facing up and one facing down the slope, with the erosion gully running through the centre of the photo.



**Figure 4:** Erosion monitoring transect, as indicated by lines running parallel to the slope and perpendicular to the main transect. Red dots are erosion peg markers.

#### 4.1.4 Landscape Function Analysis

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Landscape Function Analysis (LFA) consists of two main components: landscape organisation and soil surface assessment. LFA is conducted using the standard transect, on all rehabilitated and reference monitoring sites, with field data recorded on the *Soil surface assessment and landscape organisation data sheet* (M-TE-EN-006). The full method is detailed in Appendix 1.

Using transects (facing downslope), the landscape is divided into zones, designated as patches or interpatches. Patches are zones of resource accumulation, for example, troughs which accumulate litter. Patches should be assigned a brief but descriptive name according to their nature and function. Interpatches are areas that shed/freely mobilise resources such as water, soil and litter and should be similarly named.

The entire transect is to be classified and divided up into zones, using the initials of each zone. 3 – 5 replicates of each zone are selected and eleven parameters (soil surface condition indicators), are measured.

The eleven parameters are:

- Rainsplash protection: The objective is to assess the degree to which the physical surface cover and plant cover ameliorates the erosive effect of rain on the soil surface.
- Perennial Vegetation Cover: The objective is to assess the contribution of below ground biological activity as provided by perennial plants.
- Litter: The objective is to assess the amount, origin and degree of decomposition of plant litter, to assess nutrient cycling.

- **Biological Soil Crust Cover:** The objective is to assess the cover of biological soil crusts visible on the soil surface. These crusts include cyano-bacteria, algae, fungi, lichens, mosses, liverworts, bryophytes and fruiting bodies of fungi.
- **Physical Crust Brokenness:** The objective is to assess to what extent the surface crust is broken, which the extent to which loosely attached soil material is available for erosion.
- **Soil erosion type and severity:** The objective is to assess the type and severity of recent or current soil erosion
- **Deposited Materials:** The objective is to assess the nature and amount of alluvium recently transported to and deposited within the query zone.
- **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 dry coherence (resistance to physical 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.
- **Slake Test (Surface coherence when wet):** The objective of this test is to assess the stability of natural soil fragments when rapidly wetted.
- **Soil Surface Texture:** The objectives of this test are to assess the texture class of the surface soil as it impacts directly on infiltration.

#### 4.1.5 Bio-indicator monitoring

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In rehabilitation and reference sites that require bio-indicator monitoring, ants may be utilised as a bio-indicator for ecosystem health. A qualified myrmecologist or entomologist and invertebrate taxonomist should be consulted for an adequate monitoring method appropriate for the specific site (especially as there may be topographical and other physical constraints in most of the rehabilitation areas which are only of a limited size) and to conduct the monitoring, species identification and data analysis.

In general, ant monitoring will involve the installation of 10 x 10 m quadrats, spaced evenly or centred along existing transects within each of the reference and revegetation monitoring sites. One ant pitfall trap will be set in the centre of a quadrat within each monitoring site, with any collections subsequently identified.

#### 4.1.6 Photographic Monitoring

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Areas with a high number of representative and predominantly homogeneous examples and less than 1 ha in size may not require comprehensive monitoring. The aim of this monitoring is

to establish fixed photo points for medium to long term observational monitoring of the rehabilitated and revegetated area. These areas include:

- Borrow pits <1 ha
- Long, narrow tracks
- Other flat areas and linear infrastructure <1 ha

To undertake photo monitoring:

- Place a star picket or small post at the point at which the photo will be taken, in some cases this may be the middle of the rehabilitation area or a suitable vantage point providing an adequate, representative view of the area.
- Install the star picket using a sledge hammer or star picket driver. Identify the star picket using a unique code with aluminium tags and soft wire to attach to the star picket.
- Take a photo at eye level, with the star picket occupying no more than one third of the field of view, with minimal sky in the foreground.

Using the *Photo Monitoring Data Sheet for Rehabilitation Areas* (M-TE-EN-0007), record the following information:

- Date
- Observers
- Photo point name
- Rehabilitation area
- Coordinates (take a reading with a GPS)
- Photo number/s
- Age of rehabilitation area
- Overall condition
- Vegetation cover (estimated percentage)
- Surface treatment (topsoil, ripping, cover, mulch, rehabilitation trials)
- Dominant perennial species
- Erosion

- Surface water management
- Weeds
- Other issues (grazing, rubbish, contamination, safety, access, visual amenity)

## 4.2 Data Management and Analysis

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All monitoring data sheet templates should be stored in Fortescue's document management system.

Where work is undertaken by consultants, all photos and completed data sheets are to be provided to the Fortescue Environmental team.

Geographical Information Systems (GIS) spatial data and raw data must be provided in a format that meets Fortescue's *Geographic Information Systems and Raw Data Guidelines* (100-GU-EN-0009).

The data collected during the monitoring activities should be documented in the corresponding Monitoring Data Sheets. Separate workbooks should be used for each operational site and labelled appropriately with the site name and date and should be provided in the following formats:

- Vegetation data in the *Revegetation Monitoring Field Data Sheet* (M-TE-EN-0003).
- Erosion monitoring data in the *Erosion Monitoring Data Sheet* (M-TE-EN-005). Values should be calculated for average gully width, average gully depth, average rill width, average rill depth, total number of rills and total number of gullies. An average result should also be provided for number of rills and gullies for each transect which will be the mean of the 10 m and 30 m erosion transects.
- Landscape Function Analysis data in the *Soil Surface Assessment and Landscape Organisation Data Sheet* (M-TE-EN-0006) into an LFA data entry workbook. One workbook must be completed per transect. The workbook is the standard as provided (publically available) by Tongway (2003). The workbook should be labelled with the site name and date.

Where bio-indicator monitoring is required, data and results should be provided in accordance with Fortescue's *Geographic Information Systems and Raw Data Guidelines* (100-GU-EN-0009).

All raw data collected in the monitoring data sheets, must be entered into the *Data management workbook* (M-TE-EN-004). The graphs and tables are provided as a reference, with some modification required depending on the site specific outcomes or data being considered for analysis.

Statistical analysis of data should be undertaken, with a focus on comparison of rehabilitated sites with reference sites, and where appropriate, the impact of individual treatments on rehabilitation outcomes.

## 4.3 Reporting

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Monitoring results that have been interpreted and subject to quality assurance processes will generally be required to meet Fortescue's reporting obligations. This could include:

- Internal reporting to inform management planning and future monitoring program designs.
- A summary of findings relating to the monitoring program objectives/results in relevant company Environmental Reports.
- Reporting against legislative and compliance requirements.

The communication of monitoring findings to other stakeholders should be identified and undertaken where required.

The monitoring report should include the following as a minimum:

- Introduction, project background, purpose of the monitoring
- Background on biophysical climate (climate: average and at time of study, rainfall: average and at time of study, soils and geology, vegetation, land systems, biogeographical systems)
- Methodology (monitoring timing, site selection, site descriptions, taxonomy and nomenclature, monitoring team, any constraints and limitations)
- Results, including raw data, are to be provided in the following formats, with raw data and transect start and end photos included as appendices to the report:
  - The table and graph formats shown in the *Data management workbook* (M-TE-EN-004)
  - *Geographic Information Systems and Raw Data Guidelines* (100-GU-EN-0009)
- Figures and graphs are to be used throughout the results section. Photos may also be used in the results section to further illustrate a specific point.
- Discussion addressing the results, statistical significance where adequate, comparison of rehabilitation sites to reference sites and performance in relation to revegetation completion criteria.
- Any recommendations for future work (monitoring improvements, remedial actions) and discussion of results which may assist in informing future revegetation and rehabilitation programs should be provided in a separate letter.
- Where photographic monitoring only has taken place, the data is to be entered and saved in the data entry tab of the *Photo monitoring data sheet for rehabilitation areas*

(M-TE-EN-0007). Where a combination of photographic monitoring and transect monitoring has taken place for a site, the photographic monitoring data should be provided as an appendix.

## 5. MONITORING FREQUENCY AND SCHEDULING

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The monitoring program is implemented so as to determine the effectiveness of site rehabilitation management actions, and whether site specific objectives and completion milestones have been or will likely be achieved.

Rehabilitated areas within the monitoring program should be monitored on an annual basis for the first three years to determine initial establishment, then on a biennial basis to determine trajectory towards reference sites and established completion criteria. Areas should be monitored as soon as possible in the right season following completion of earthworks, spread of topsoil and any seeding/planting. Monitoring should be conducted between April-June each year.

Depending on the outcomes of specific areas, the frequency may need to be increased or decreased. The justification for this should be discussed in the monitoring report. Cessation of monitoring should only take place when:

- a) the rehabilitation area has achieved the completion criteria; or
- b) the area requires re-working and monitoring is discontinued.

An annual review of rehabilitated and revegetated areas should be conducted and include existing monitoring sites, new areas requiring monitoring, and areas that may be available for rehabilitation in the short to medium term.

The planning forecast for new areas requiring monitoring should take place in conjunction with the Site Environment and Mine Planning Teams.

## 6. ALTERNATIVE MONITORING TECHNIQUES AND INNOVATION

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Fortescue should continue to develop monitoring techniques and implement innovative and technologies to increase the efficiency of rehabilitation monitoring.

If aerial imagery and data is available, remote sensing may be an additional tool for monitoring rehabilitation at Fortescue. Specialised computer programs and users are required to extract meaningful information from imagery and data, with minimum data requirements being:

- four band multi-spectral imagery (including near-infrared band); and
- digital elevation model (DEM).

Specialist advice will be required in relation to minimum requirements (i.e. pixel size) for imagery and DEM data.

Once suitable data is obtained, vegetation cover values and erosion values could be extracted, and changes assessed from year to year. Remote sensing can be an effective tool to monitoring erosion and broad trends in vegetation cover, which can potentially be used to reduce the frequency of on-ground monitoring. However, some level of ground validation is required to confirm results. In addition, some level of on-ground monitoring will likely to be required to determine species level information and address all completion criteria.

## 7. CORRECTIVE ACTIONS

Rehabilitation monitoring data are used to inform the development of completion criteria, to monitor the progress of rehabilitation towards the reference site values and established completion criteria, and in turn are used to determine priority areas for remedial works.

Where rehabilitation progress is deemed below standard (i.e. has not met completion criteria requirements or is not in a trajectory towards reference site values), it may be necessary to reassess the area and conduct remedial actions to mitigate the problem. Some of these activities may include ripping or re-ripping of existing areas, application of soil treatments or growth media, seeding with local provenance seed, erosion control works and weed management. The need for corrective actions (Table 4) will be triggered following a review of rehabilitation monitoring results against completion criteria.

**Table 4: Trigger for corrective actions**

Trigger	Corrective actions
<p>Monitoring results show levels of erosion occurring beyond natural geomorphic processes and has impact on rehabilitated landform e.g. compromising geotechnical stability</p>	<ul style="list-style-type: none"> <li>• Review the revegetation process (e.g. timing, techniques) in context of other parameters measured during the monitoring process.</li> <li>• Implement maintenance repairs</li> <li>• Review and amend rehabilitation methods to address identified faults in the landform design</li> <li>• Adjust monitoring frequency and methods to determine if revised rehabilitation methods are effective and to identify any future structural changes</li> </ul>
<p>Unsuccessful planting, seeding or germination rates, or a decline/undesirable level in species diversity, structural complexity and percentage cover</p>	<ul style="list-style-type: none"> <li>• Review the revegetation process (e.g. timing, techniques) in context of other parameters measured during the monitoring process.</li> <li>• Implement supplementary revegetation efforts</li> <li>• Amend revegetation methods to address identified faults in the revegetation process</li> <li>• Adjust monitoring frequency and methods to determine if revised revegetation methods are effective and to identify any future revegetation issues as soon as possible</li> </ul>

Trigger	Corrective actions
Ant group populations not progressing towards those in Reference monitoring sites (where applicable)	<ul style="list-style-type: none"><li>• Review the revegetation process (e.g. timing, techniques) in context of other parameters measured during the monitoring process.</li><li>• Implement supplementary revegetation efforts</li></ul>

## 8. REVIEW AND REVISION

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This Guideline will be reviewed three-yearly as a minimum in accordance with Fortescue's *Document Governance Standard* (100-ST-DC-0002), and may be updated to reflect new methodologies or improvements to existing methods.

## 9. RESPONSIBILITIES

All Fortescue employees and contractors involved in rehabilitation monitoring activities need to be aware of and comply with the requirements of this guideline.

The RASCI framework below is used to delegate roles, responsibilities, and review and approval levels (Table 5):

- R-Responsible** Those who do the work to achieve the task.
- A-Accountable** Those who are ultimately accountable for the completion of the deliverable or task and the one to whom the Responsible person is accountable.
- S-Supportive** Resources allocated to the Responsible person and who will also assist in completing the task.
- C-Consulted** Those whose opinions are sought, two-way communication.
- I-Informed** Those whom are kept informed, one-way communication.

**Table 5: Task, timing and RASCI**

Task	Timing	RASCI
Monitoring	During the field monitoring season (April-June)	R: Consulting company A: Environment Governance and Sustainability Team S: HSE Manager (or equivalent) C: Principal Mine Closure, Mine Closure I: Environment Team
Data Management, Analysis, Reporting	After return from field trip	R: Consulting company A: Environment Governance and Sustainability Team S: HSE Manager (or equivalent) I: Environment Team
Communication of results to stakeholders	As required by conditions and commitments	R: Environment Governance and Sustainability Team



Task	Timing	RASCI
		A: Environment Governance and Sustainability Team  S: Corporate Affairs
Monitoring scheduling	At the end of each year in preparation for the following year's monitoring season	R: Environment Governance and Sustainability Team  A: Environment Governance and Sustainability Team  S: HSE Manager (or equivalent)  C: Principal Mine Closure, Mine Closure  I: Environment Team
Identification of corrective actions	Following results from monitoring	R: Environment Governance and Sustainability Team  A: Environment Governance and Sustainability Team  C: HSE Manager (or equivalent) and Principal Mine Closure, Mine Closure
Implementation of corrective actions	Where required, based on results from monitoring	R: HSE Manager (or equivalent)  A: HSE Manager (or equivalent)  S: Manager Mining  C: Principle Mine Closure, Mine Closure
Review and revision of guidelines	Three-yearly	R: Environment Governance and Sustainability Team  A: Manager Environment Governance and Sustainability  C: Principle Mine Closure, Mine Closure

## 10. REFERENCES

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Department of Environmental Protection (2000) Bush Forever vol.2: Directory of Bush Forever Sites. Western Australia, Department of Environmental Protection, Perth

Department of Industry, Tourism and Resources (2006) Leading Practice Sustainable Development Programme for the Mining Industry – Mine Rehabilitation

Fortescue Metals Group (2013) Rehabilitation and Revegetation Management Plan (100-PL-EN-0023). Unpublished document

McCord, A.K. and Payne, R.A. (2010) Monitoring trends in wind and water erosion in South Australia – Rationale and Methodology.

McDonald, R.C. (1990) Australian soil and land survey field handbook. CSIRO

Tongway, D. (2008) *LFA Methodology* Accessed 14<sup>th</sup> November 2013, available at: <http://www.csiro.au/services/EcosystemFunctionAnalysis>

Tongway, D.J. and Hindley, N.L. (2005) Landscape Function Analysis: Procedures for Monitoring and Assessing Landscapes with special reference to Minesites and Rangelands. CSIRO Australia

Zar, J.H. (1984) Biostatistical Analysis. Prentice Hall, New Jersey

## 11. APPENDICES

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## Appendix 1: Landscape Function Analysis procedure

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# LFA METHODOLOGY

## 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 Chapter 2 in “Restoring Landscapes”, rather than being dependent on specific organisms.

There are 3 principal steps in this process.

1. Describing the geographic setting of the site, including delineation of different areas of impact or of fundamental differences in landscape type across a large area requiring monitoring (different Landscape Functional Types or LFTs) .
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.

\*\*\*\*\*

### 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.

In sites where high-resolution remote imagery is available, maps of landscape features may be prepared digitally at a range of scales. This may well assist in steps A and B, below.

#### 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 topographic position, GPS coordinates, compass bearing of the transect, slope, aspect, underlying geology, soils, vegetation type and its current or projected landuse. These data can be used to both group similar sites and make sure that different site types are not inadvertently compared.

#### 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:

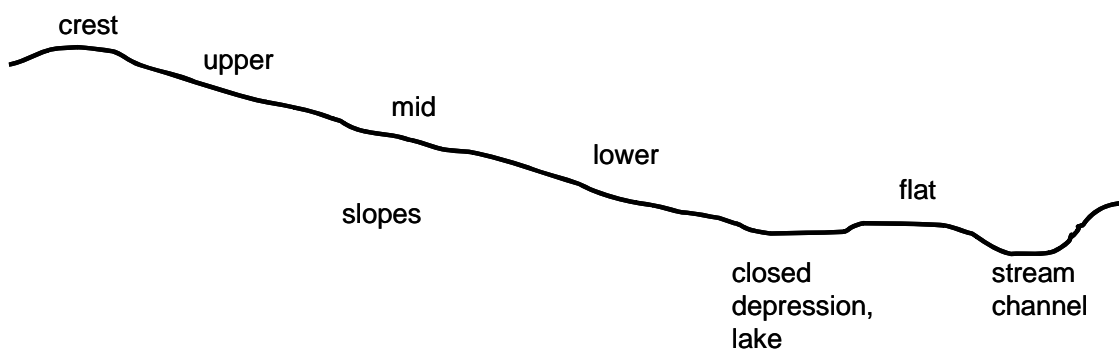


Figure 1. The identification of topographic position in the landscape for monitoring sites.

\*\*\*\*\*

## 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 zones 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 on hillslopes with complex shape.
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 each end of the transect, 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, and no especial means need to be deployed to make this exact. Sometimes beds of transported litter can be used to determine the transect orientation. Such litter beds will be aligned on the contour, and the LFA transect will be normal to the litter bed. 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 the 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 or large area. 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. On minesites, the foot of constructed slopes should be inspected for sediment fans: whether they are present, whether they coalesce or are isolated, whether they are fed by rills or gullies or by sheet overland flow.

Study of aerial photographs or digital images is important to be sure to be aware of all the variation present and to pinpoint particular disturbance types, such as erosion gullies or in mapping LFTs. On sites with a range of success, both “typical” and eroding locations should be assessed. Desk-top initial studies will be increasingly possible with emerging products and technologies.

### How to set up transects

Start the transect at the upslope edge of the local watershed, at the boundary between a patch and an inter-patch. Each patch and inter-patch type should be given a descriptive name reflecting the nature of the surface in functional terms; eg bare crusted soil inter-patch, grassy sward patch. Do not be tempted to invent too many types, and take photos of each type to ensure consistency across sites and over time.

### How many Transects?

In most sites, from experience, two or three transects per LFT are sufficient to represent “typical” conditions. However, to test this, compare the means and variances for the stability, infiltration and nutrient cycling indices for each patch and inter-patch type (see p 28 and 29 for a formal procedure). Additional sites may well have been identified from remote sensing to examine small but dignificant erosion areas, for example. Whole-of-site values are not appropriate for this analysis (see example of Summary page on p ). **Note: Five replicates of each patch/inter-patch type are usually essential for statistical reliability**, but see the section on p 28. 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 are defined as areas of land which tend to accumulate resources** by intercepting 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 land-forming processes, or biological features such as plants or fallen or placed 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. Inter-patches are areas of land where resources tend to be mobilized and transported away. “Reading the landscape” in this manner is an acquired skill, and the principles in Chapter 2 of “Restoring Landscapes” should be used as a constant guide to correct classification.

**The processes identified at this scale are extremely informative about rangeland health and function, and forms the backbone of the assessment and can develop the capacity to “read the landscape” at the hillslope scale. Computed data at this scale is important to monitor over time, as it reflects what casual observers see when they look at the landscape as a whole.**

In functional grasslands, much of the regulation of vital 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: an impact which changes grass plant spacing from 20 cm 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 2 and 3 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.

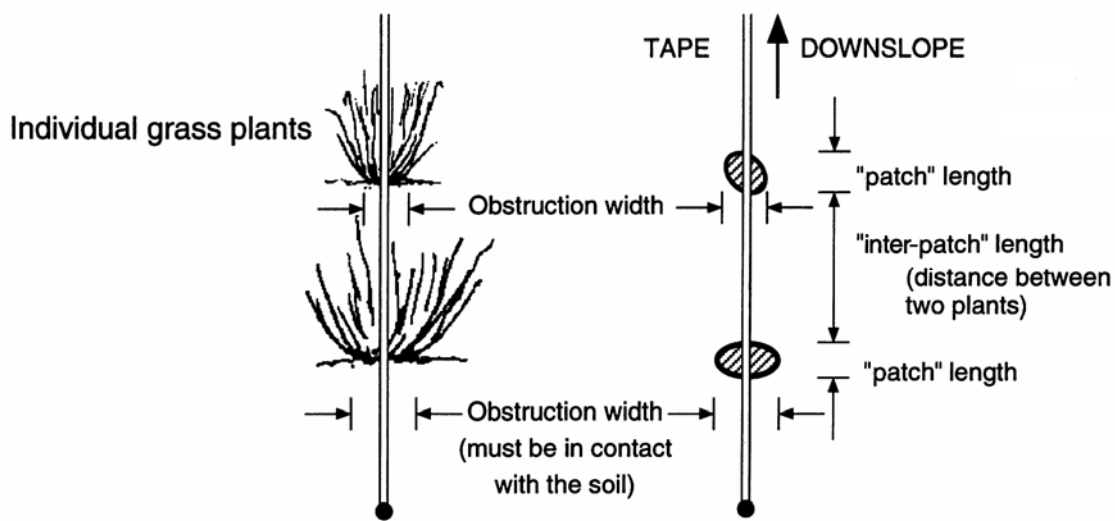


Figure 2. Illustrates the measurements of individual grasses when they form the patches on a monitoring transect.

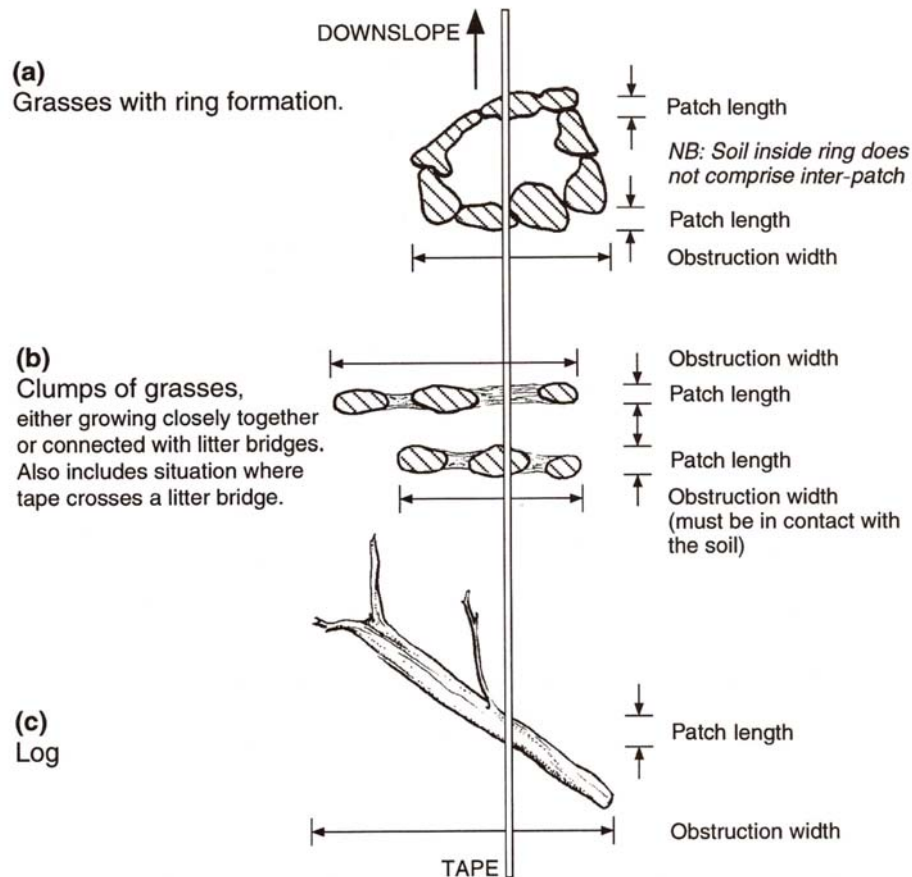


Figure 3. A diagrammatic illustration showing how to measure the length (along the transect) and the width of patches (right angles to the transect).

## 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.

Patches may change their nature over time when landscape restoration occurs: for example, there may be a progression from “grass plant” to “grassy patch” to shrub-grass complex” over time. The explicitly spatial nature of LFA data acquisition enables this progression to be properly acknowledged in the trend analysis.

The decision to include, or exclude, biennial plants should be made with available local biological 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. 2).
- 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. 4), or **complex** (Figure 5).

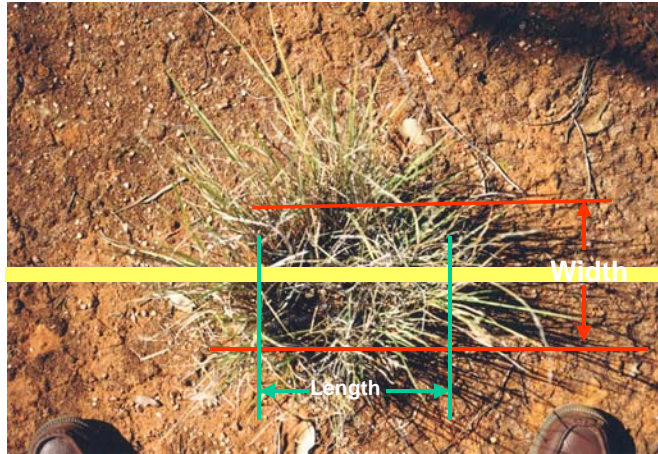


Figure 4. Illustrates a simple patch that captures some resources that are flowing down the transect.

### 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 characterized as 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. 5d).
- 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 5a - single “grass plant” patch



Figure 5b - several grass plants combine into a “grassy patch”



Figure 5c - grass plants acting as a sward



Figure 5d - dense sward. Note the capture of plant litter within the sward.

Figure 5. Showing (5a) a landscape where the only resource control is by single grass plants, and patches of grass plants (5b). 5c shows the litter being retained by the grasses in a sward, and 5d 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. 6).



Figure 6. Section of a monitoring transect showing the patch/inter-patch boundaries. The inter-patch name was "Bare, crusted stony inter-patch" and the patches were "Shrub patch".

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 2 and 23).
- Measure with a precision of  $\pm 2$  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. 6a) or “bare sandy” (Fig. 6b) or “bare + gravel” (Fig.6c).



Figure 6. Showing three examples of bare classification for inter-patch zones.

### Worked Example

Figure 7 and Table 4 demonstrate a typical LFA landscape organization data set.

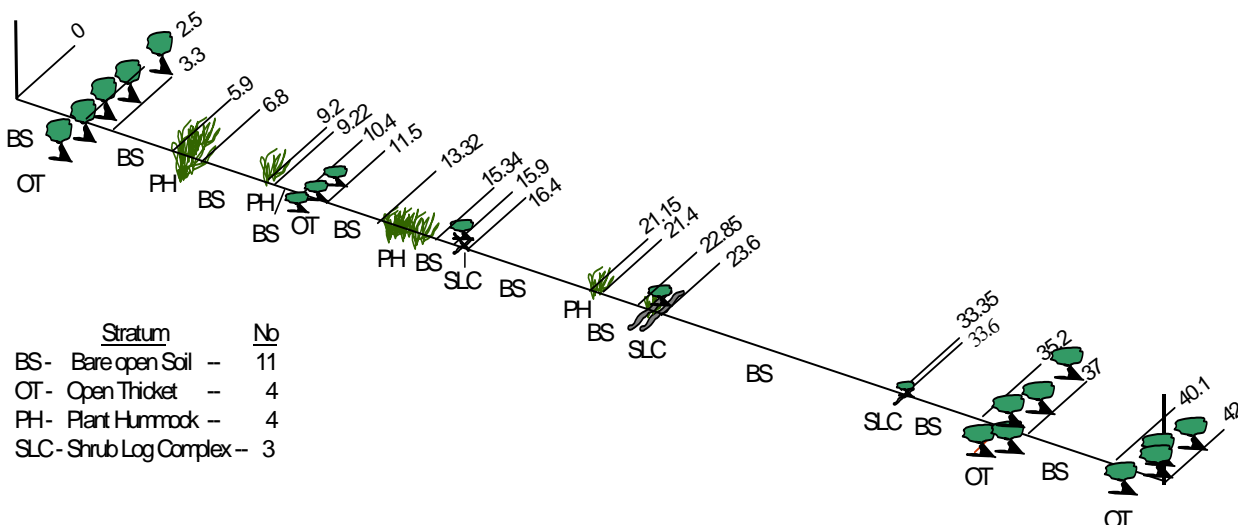


Figure 7. A diagrammatic representation of a monitoring transect showing the "logging of the line" into its inter-patch (bare open soil) and 3 types of patches (open thicket, plant hummock and shrub log complex).

Table 1. 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 1. The landscape organization index is the proportion of the length of patch to the total length of the transect. *ie*, 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 1.00.

Table 2. Summarises the landscape organisation data from Table 1.

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

\* length of patches/length of transect

### Major Erosion Features

The location of erosion features such as terracettes and rills (Table 3) 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 3. 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, I recommend surveying their number, location and cross-section by the following procedure, using the data sheet supplied in the “Field Data Sheets” file .

Using the LFA transect as a reference, establish transverse transects  $\pm 25$ m. (total = 50m) on the contour. Locate these at 25, 50, 75 and 100% of the LFA transect. Map the location of each rill on the contour transect by recording the “left and right” hand bank edges and measure the 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 4 and 5)

Table 4. 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	Rock	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 5. 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 in this case as biological control was established.

Years since rehabilitation	No of rills per 200 m	Mean rill cross section (cm <sup>-2</sup> )
2	66	341
5	10	102
9	0	0
15	0	0
unmined	0	0

\*\*\*\*\*

## 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.

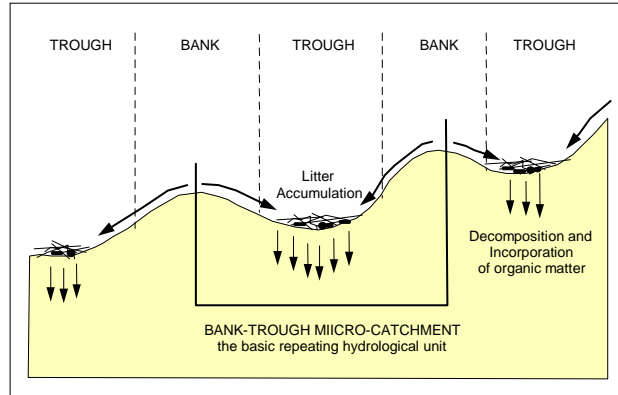
Typically on mines, deep contour ripping of rehabilitated lands produces a “bank and trough” structure that forms the primary means of resource regulation from the earliest stages and often lasting many years (Fig. 8). In this system the trough is the patch (traps resources) and the bank the inter-patch (sheds resources).

Figure 9 is diagrammatic illustration of this process.



Figure 8. 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 9. 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 6. 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 7. Summary tables generated from the data shown in Table 6 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 10 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.

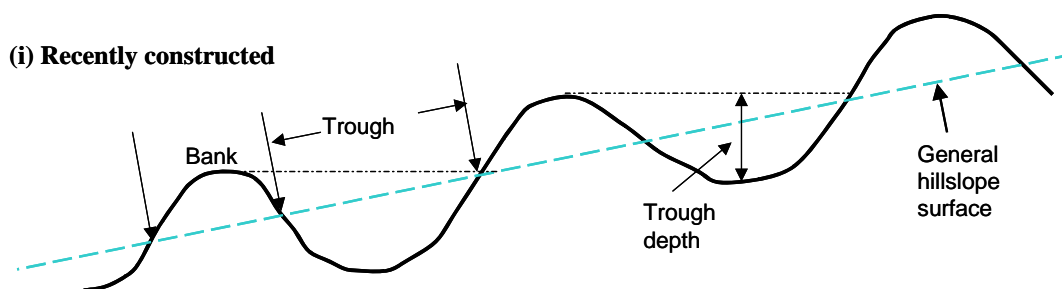


Figure 10. A diagrammatic representation of a bank/trough slope showing the measurements of patch (trough) and inter-patch (bank), and the trough depth used in the surface roughness assessment in SSA.

### 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. Rehabilitated sites may have

quite different plant species; the purpose of the analogue site is to set the functional values that would signify “self-sustainability” in landscape function terms.

The field procedure for data collection on analogue sites is exactly the same as for the monitored sites. Figure 11 illustrates the range of patch and inter-patch zone types typically found in natural landscapes.

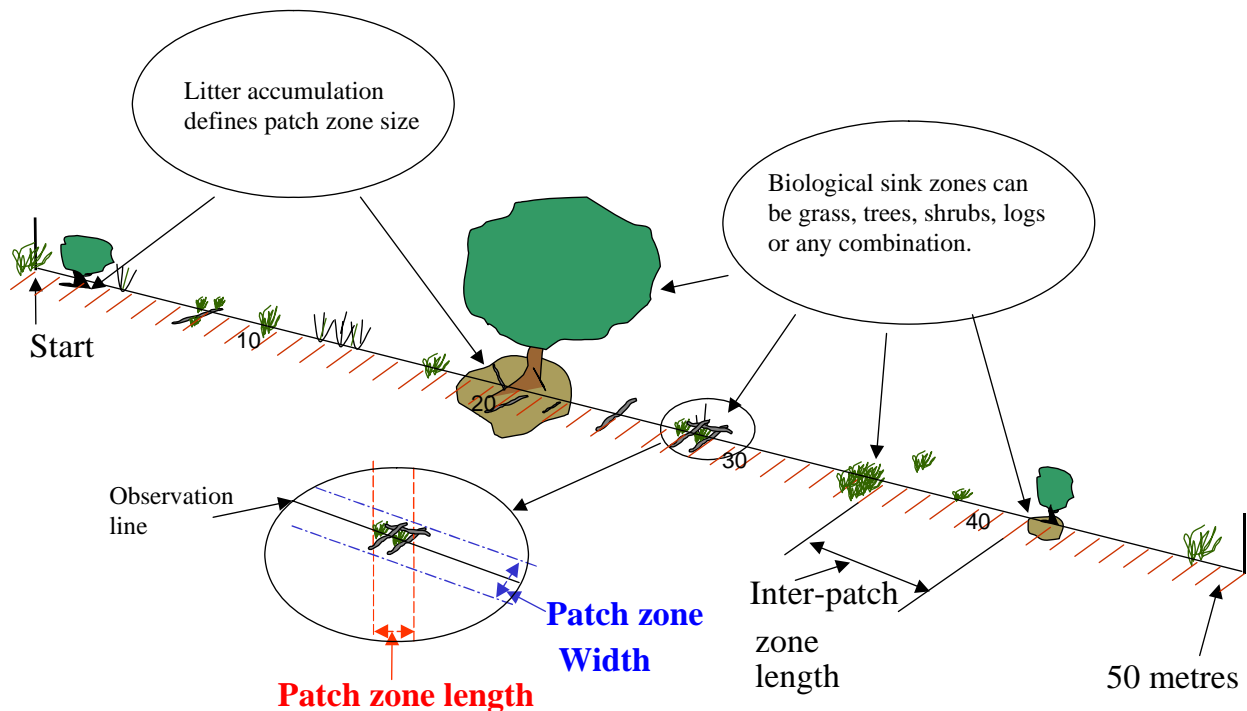


Figure 11. Illustration of an analogue monitoring transect. The short lines indicate metres. The assessment time should not exceed 20 minutes.

An analogue site is one that has the functional attributes of the desired final rehabilitated landscape and is self-sustaining, particularly in respect to stress and disturbance and serves to provide a goal or target values for rehabilitation. The objective is to define a variety of functional 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. 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).

Rehabilitated sites identical in every way to reference sites would be an impossible requirement, and probably subject to interminable disagreement.

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### STEP 3. SOIL SURFACE ASSESSMENT

Each patch/inter-patch type identified in the landscape organisation assessment must have its soil surface conditions classified according to the Soil Surface Assessment Method detailed below. Together, these data assess the “functional quality” of each patch and inter-patch type. 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 LFA 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 about 5 replicates of each patch/inter-patch type for statistical reliability (see p ). 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. Typically, a 1-m mini-transect is used to collect SSA data. For landscape zones greater than 1-m in length, the query zone should be located in about the middle of the available space.
4. 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).
5. 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 8):-

Table 8. The query zones for the transect in figure 11.

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:-** OT, PH and SLC were insufficient in total length to have 5 query zones for each of these type so the replication represents the space available.

6. 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.
7. 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.
8. The boundary between two zones should be avoided if 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 than 10 cm, in this case assess the whole patch.

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## SOIL SURFACE ASSESSMENT CRITERIA

The nature, meaning and scope of each surface feature, together with a classification procedure are 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 by splashing particles or form dense “physical crusts”, which reduce infiltration markedly.**

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, immovable 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, physically 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 in order to assess below-ground biological activity.**

This indicator assesses the contribution of the below-ground biological activity to nutrient cycling and infiltration processes through aboveground observations. 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. However, 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 LFA 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 all other species plus animal dung.

This indicator is strongly related to the cycling of carbon, nitrogen and other elements 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. This provides an opportunity to examine “site resilience” by looking at the shape of the “recovery of function” curve: resilient sites responding rapidly and less resilient sites recovering more slowly.

**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 by 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

<b>100, 21-70 mm thick</b>	<b>7</b>
<b>100, 70-120 mm thick</b>	<b>8</b>
<b>100, 120-170 mm thick</b>	<b>9</b>
<b>100, &gt; 170 mm thick</b>	<b>10</b>

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

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

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:

<b>Litter Decomposition Criteria</b>	<b>Class</b>
<b>Nil decomposition (n)</b> : the litter is loosely spread on the surface with few, if any, signs of decomposition and incorporation.	<b>n</b>
<b>Slight decomposition (s)</b> : litter is broken down into small fragments and intimately in contact with soil; some fragments may be partially buried.	<b>s</b>
<b>Moderate decomposition (m)</b> : 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.	<b>m</b>
<b>Extensive decomposition (e)</b> : 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.	<b>e</b>

#### 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

This is the only indicator which has an alpha-numeric data entry. Write the full alpha-numeric coding into the SSA data-recording sheet and also type into the Excel SSA template.

#### 4. Biological Soil Crust Cover

**The objective is to assess the cover of biological soil crusts (BSCs) visible on the soil surface.**

For the purpose of this assessment, BSC is a generic term that includes cyano-bacteria, algae, fungi, lichens, mosses, liverworts, bryophytes 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, transparent 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 BSCs 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 (Indicator 5) has been assessed as “zero” (not applicable) then BSC 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.

<b>BSC Cover</b>	<b>Class</b>	<b>Interpretation</b>
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. Physical Crust (PC) 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 physical 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 PCs 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 physical 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

<b>Crust Brokenness</b>	<b>Class</b>
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. soil 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). Sheet erosion has values of either 3 or 4.

**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. Pedestal erosion is either class 2 or 1, as it signifies serious erosion

**Rills and gullies (R)** are channels cut by flowing water. Rills are less than 300 mm deep and gullies are greater than 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. Rills and gullies are either class 2 or 1 as they signify rapid runoff and serious erosion.

**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. Erosion scarps have a similar appearance, but are caused by erosive forces from down slope, for example wave action, rather than down-slope water flow. Terracettes are either class 2 or 1, as significant soil is lost

**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. Scalding is classified as class 1 as it is a very serious erosion type.

<b>Erosion Severity</b>	<b>Insignificant</b>	<b>Slight</b>	<b>Moderate</b>	<b>Severe</b>
<b>Erosion Type</b>	<b>Class</b>	<b>Class</b>	<b>Class</b>	<b>Class</b>
<b>Sheeting (E)</b>	<b>4</b>	<b>3</b>	n/a	n/a
<b>Pedestal (P)</b>	n/a	n/a	<b>2</b>	<b>1</b>
<b>Terracette (T)</b>	n/a	n/a	<b>2</b>	<b>1</b>
<b>Rill (R)</b>	n/a	n/a	<b>2</b>	<b>1</b>
<b>Scalding (S)</b>	n/a	n/a	n/a	<b>1</b>

\*\*\*\*\*

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 mobilized 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. This should be noted, as this represents ecological development. The amount or volume of deposited material is more important than the simple cover.

**Hummocking** is an indication of the deposition of large quantities of materials by wind around surface obstructions. 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 may be widely dispersed during windy phases and are lost to the system. It is rare in the tropical grasslands.

<b>Deposited Material</b>	<b>Class</b>
Extensive amount present. Greater than 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

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#### 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)

<b>Surface roughness</b>	<b>Class</b>
<3 mm relief in soil surface. Smooth: little or no detained materials	1
Shallow depressions or above-grade obstructions: 3-8 mm relief. Low but visible detention of mobile resources	2
Deeper depressions 8-25 mm or grass plant tussocks growing close together. Moderate visible detention	3
Deep depressions that have a visible base or very large tussock grasses. Considerable mass of visible accumulated resources	4
Very deep depressions, >100mm. Gilgai depressions. Extremely high visible retention of mobile resources. No plant mediated roughness at this scale	5

#### 9. Surface Dry Coherence (resistance to physical 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. This test must be done in the field as disturbed samples may lose their coherence in sampling and returning to the lab.
- 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, a high value: the spreadsheet deals with this apparent anomaly with appropriate re-scaling based on known stability and infiltration implications of very hard impermeable surfaces.

Surface Nature	Class	Interpretation
<b>Non -brittle</b>	5	Shows some “springiness” when pressed with finger, typically with a conspicuous A <sub>0</sub> layer; <b>or</b>  Surface is a self-mulching clay (significant surface “crumb” present); <b>or</b>  Surface has no physical crust and is under a dense perennial vegetation of considerable cover: trees, grass swards (i.e. not just an isolated plant).
<b>Crust is very hard and brittle</b>	4	Needs a metal implement to break the surface, forming amorphous fragments or powder. The sub-crust is also very hard, coherent and brittle.
<b>Moderately hard</b>	3	Surface is moderately hard, may have a physical crust, needing a tool such as the blunt end of a pencil to pierce, breaking into amorphous fragments or powder; the sub-crust is coherent.
<b>Easily broken</b>	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.
<b>Loose sandy surface</b>	1	Surface is not crusted, easily penetrated by finger pressure to about second knuckle joint. Sub-surface soil is non-coherent.

\*\*\*\*\*

#### 10. Slake Test (Surface coherence when wet)

**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, due to organic matter bonding of inorganic particles. 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 the soil is moist, samples can be collected and returned to the office or lab 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 in the field. Take a sample home, allow it to air-dry, then test

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

## 11. Soil Surface Texture

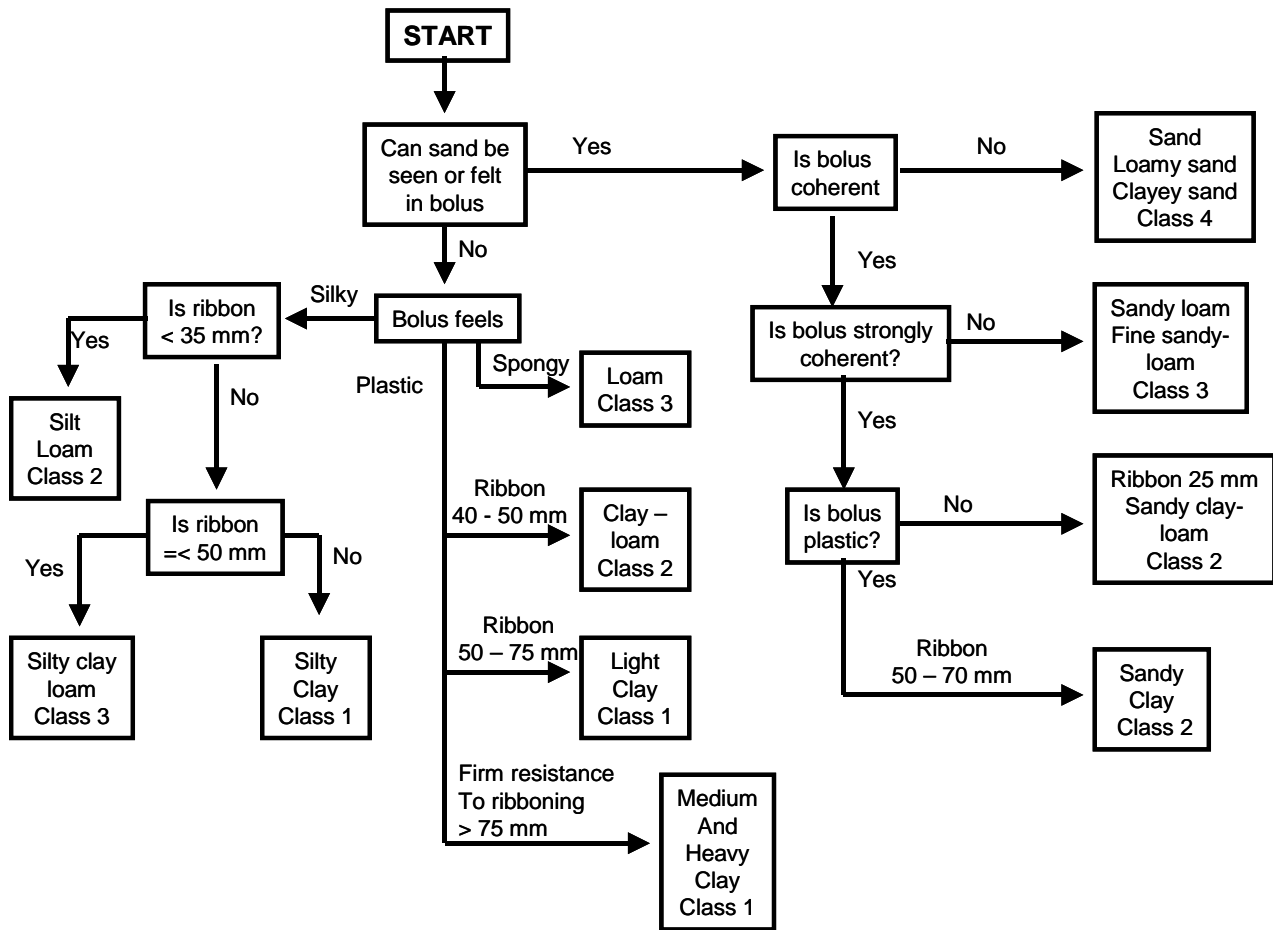
**The objectives of this test are to assess the texture class of the surface soil as it affects infiltration.**

This procedure is an initial measurement at the establishment of the site, and does not require being repeated at each monitoring event, unless there is clear evidence of recent deposition. 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



## Appendix 1.

### PROCEDURE FOR CALCULATING SAMPLE SIZE: A GENERALISED DISCUSSION.

The number of transects and number of replicates for assessment are the most frequently asked questions with the implementation of LFA. This has no unequivocal answer in terms of numbers, as the actual number depends on the heterogeneity of the sites and of their patch and inter-patch variation. Below, we have provided a methodology for observers to test their data after they have carefully considered what precision is needed for their task.

#### 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.

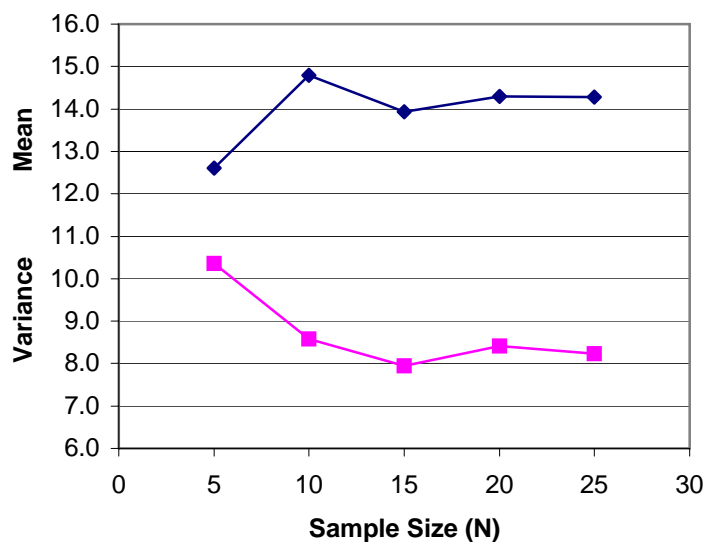
#### Background

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 let’s plot an example of mean and variance as they relate to N. For this example, let’s assume we have made 25 observations for soil surface nutrient cycling 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 let’s plot the ‘travelling’ or ‘running’ means and variances after every 5 observations for this set of 25 observations (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 nutrient cycling. 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,  $N = \text{Variance}/(\text{Standard Deviation of the Sample Mean})^2$

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:

$$\text{Standard Deviation of the Sample Mean} = 0.10 \text{ times } Xbar$$

### 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:

$$\text{Standard Deviation of the Sample Mean} = 0.10 \times 14.3 = 1.43$$

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

$$N = \text{Variance}/(\text{Standard Deviation of the Sample Mean})^2$$

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

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

$$N = 4.0 \text{ for a } 10 \% \text{ error about the sample mean}$$

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

$$N = 820 / 204.5 = 4.0 \text{ for a } 10 \% \text{ error about the sample mean}$$

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

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

## 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 erodible 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.

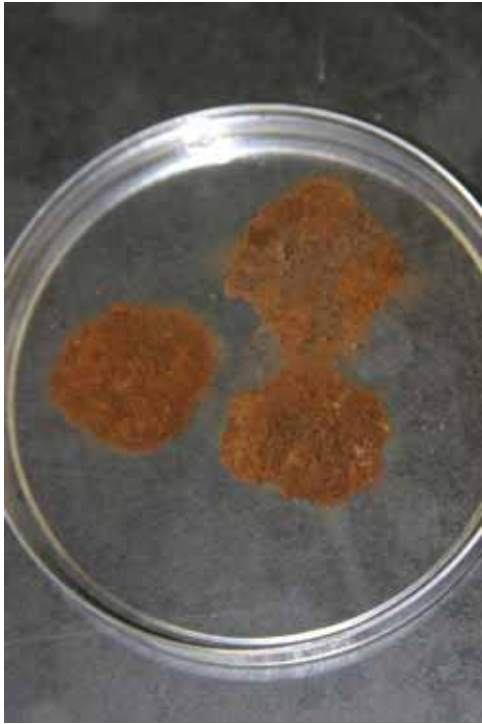
## The ASWAT soil stability test

From Field, McKenzie and Koppi 1997 (AJSR 35, pp 843-52)

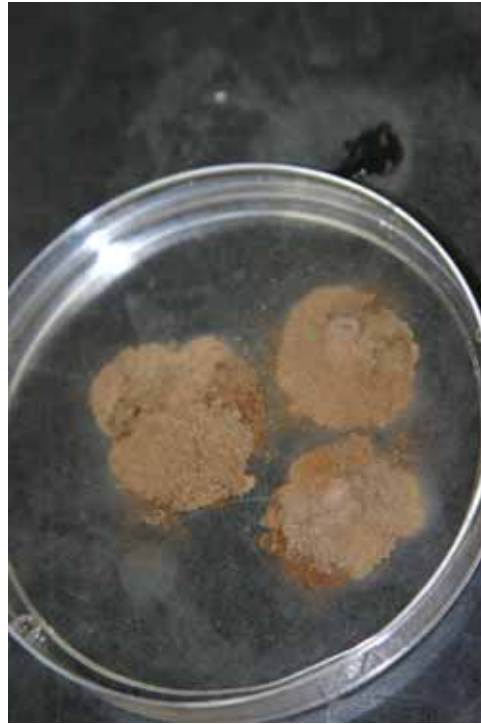
ASWAT = Aggregate Stability in WATer

**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  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  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.



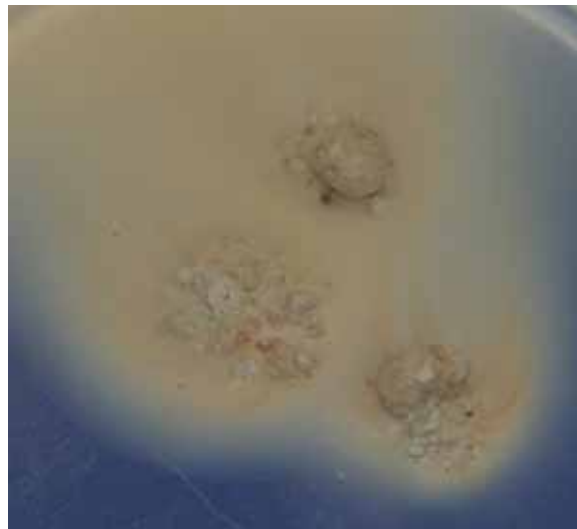
Slaked soil, no dispersion



Slaking plus Slight dispersion



Re-moulded soil: Moderate dispersion at 2 minutes



Re-moulded soil: 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” to compare the same site over time. The data 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. These data would be used to see if patches had become wider or narrower over time

**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. These data would be used to compare patch and inter-patch types over

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

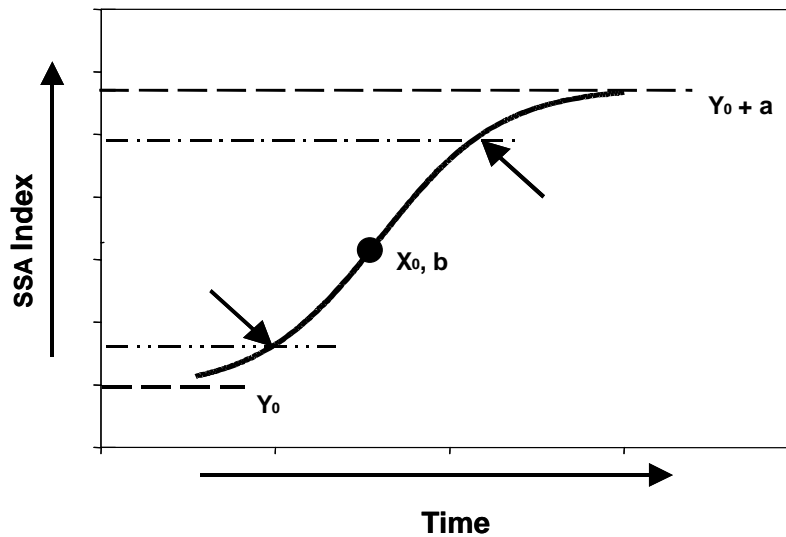
Zone	Stability	Std err	Infiltration	Std err	Nutrients	Std err
Bare soil	8.2	0.1	2.6	0.4	2.5	0.3
vegetation Pa	39.0	0.9	16.8	1.0	15.9	1.1
Tree Patch	22.9	0.8	13.2	0.6	12.6	0.5
Total	70.1	1.9	32.6	2.1	31.0	2.0

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 for each Index are the bottom line on this table, together with the site standard error of the means. These data would be used to compare sites at the same time or over monitoring periods.

## The Sigmoidal curve shape as a basis for interpretation

There needs to be ways of interpreting monitoring data so that practical values emerge that are useful in following progress and predicting ultimate 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.

### Interpretational Framework



**Sigmoidal curves** have been proposed for resource limited landscapes (Noy-Meir 1981), so there is at least a *prima facie* case to use 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 resistance and resilience in response to stress and disturbance. 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. This curve form could also represent rehabilitation progress over time. In the reverse direction, it might represent desertification under specified circumstances. The figure below depicts a fitted sigmoid relationship of the form

$$y = y_0 + a / 1 + e^{-(x-x_0)/b}$$

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

$(y_0+a)$  represents the value of the upper asymptote,  
 $y_0$  the computed value of the lower asymptote,  
 $x_0$  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.

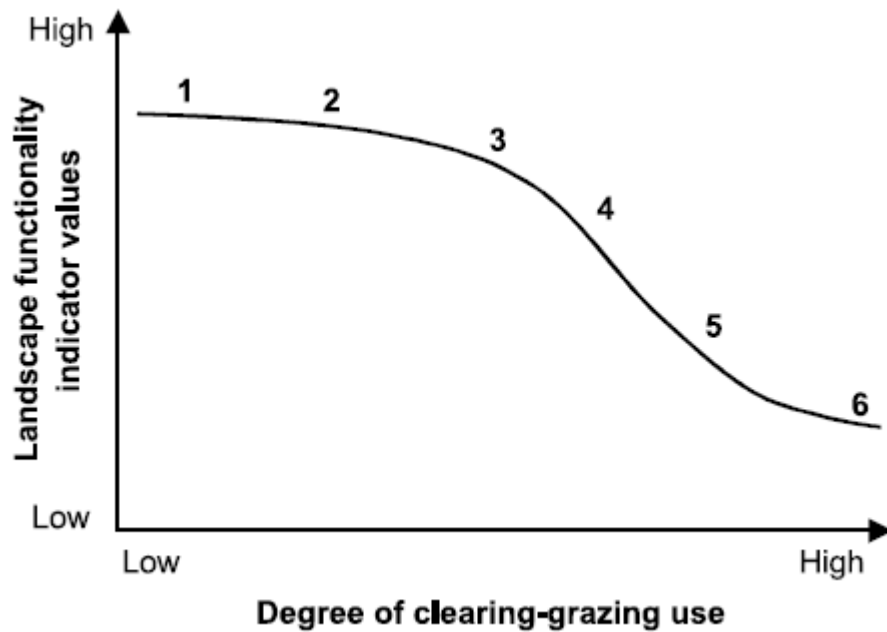
The curve parameters represent values related to functional behaviour of the landscape: how stable it can be when fully functional and how unstable when severely stressed. The dynamics of “functional” response in this case are due to the nature of the soil type and its moderate capacity to resist erosion. There are many other equations that describe sigmoidal curves, but the coefficients to the equations do not have the neat biophysical interpretation that the above equation has.

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, using empirical data and values for each of the curve parameters calculated by commercial software packages.

### **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 properties of the sigmoidal curve, estimates of important milestones and important thresholds or milestones for each LFA index can be derived. The curve selected is deemed to be symmetrical around the point  $x_0, b$ , the inflexion point of the curve, 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 “typical” 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. This point is best called a “threshold of potential concern (TPC), as it can be used in both rehabilitating and degrading circumstances. If the search for examples of the most and least functional landscape is successful, then simple calculations can be made to determine this threshold. If, however, the examples available do not cover the full dynamic range of landscape function data, then the process becomes reliant on curve-fitting with software packages, so that the extreme values are derived from the curve-fitting . This is likely to be less reliable than real field data. I strongly recommend seeking the extreme values in the field sites.



This diagram facilitates the rapid calculation of critical threshold values for each of the LFA indices:  $C/T = (\text{top value} - \text{lowest value})/2 + \text{lowest value}$ .

This procedure does not permit the rate of change to be assessed, until a genuine time sequence of data is available. In rangelands, this is largely restricted to “distance from water” situations, unless deliberate rehabilitation procedures (eg water ponding) 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 fit a full sigmoidal curve with a curve-fitting package, but enables an early estimate of “indicative” critical values to be calculated. Over time, this value will become more and more reliable as data accumulates.

Year to year fluctuations of the analogue site, due to weather variations may well arise. I suggest that the analogue value be updated as a “grand mean” at each sampling period, so that both the variance over time and the mean can be specified.

## Data Entry Instructions for LFA data

1. On the CD, open the folder: “LFA\_Manual\_ver31”
2. Then open the folder “Data Entry”.
3. Then open the file; “lfa\_ssa\_data\_entry-V3.0.xls”
4. On the bottom left horizontal bar, click on “Start”. This opens the page you must begin the data entry.
5. Fill in all the upper white-background boxes with information uniquely defining the site.
6. In the **bottom left-hand box**, type in the names and abbreviations for **all the patch and inter-patch types** identified on the gradsect field data sheet.
7. In the **bottom right hand box**, type in the names and abbreviations of **only the patch types** on the gradsect. You can copy and paste the patches.
8. Then click on the **LFA page** tab, which will open a file which is a near exact replica of your landscape organisation field data sheet. Type in the field data, making sure that your use identical abbreviations for the patches and inter-patches in your data. *I prefer to type the data in rows, rather than columns, as if typing errors occur, they are easier to chase down and fix.*
9. On completion of the landscape organization data entry, you may visit the **Summary** page and inspect the top three tables to see if any errors have crept in. If so, over-type the errors on the LFA page with the correct values’
10. Then click on the **SSA1 tab**. The name of the patch or inter-patch whose data is required will be on the upper right hand side of the page. Over-type the zero values in the table with a white background with your field values. **Do not use the back-space or delete button when typing errors occur. Move the cursor to another cell, then return to the cell with the error and over-type the error.**
11. Type in the data for all the replicate data sets for the first patch or inter-patch type. You can examine the computed indices for each replicate by paging down. The data used for the Stability, Infiltration and Nutrient Cycling indices successively are revealed. This is an opportunity to check for keying errors and concordance between replicates. If there is substantial non-agreement, check the main data field for errors.
12. When the checks are complete, click on the SSA2 tab and type in the data for the relevant patch or inter-patch type required. Repeat until all the patch types, with replicates, are all keyed in, checking by paging down again.
13. Now return to the **Summary** page, where all the landscape organization and soil surface assessment computed data will be presented. Refer to page 35 in the Field Procedures Manual where a full explanation of the content of the five computed values tables that appear on the Summary page. The Charts tab also allows some of the data to be expressed as box and whisker plots.

