Landscape Function Analysis: a means of monitoring soil productive potential

David Tongway,

Landscape Ecologist

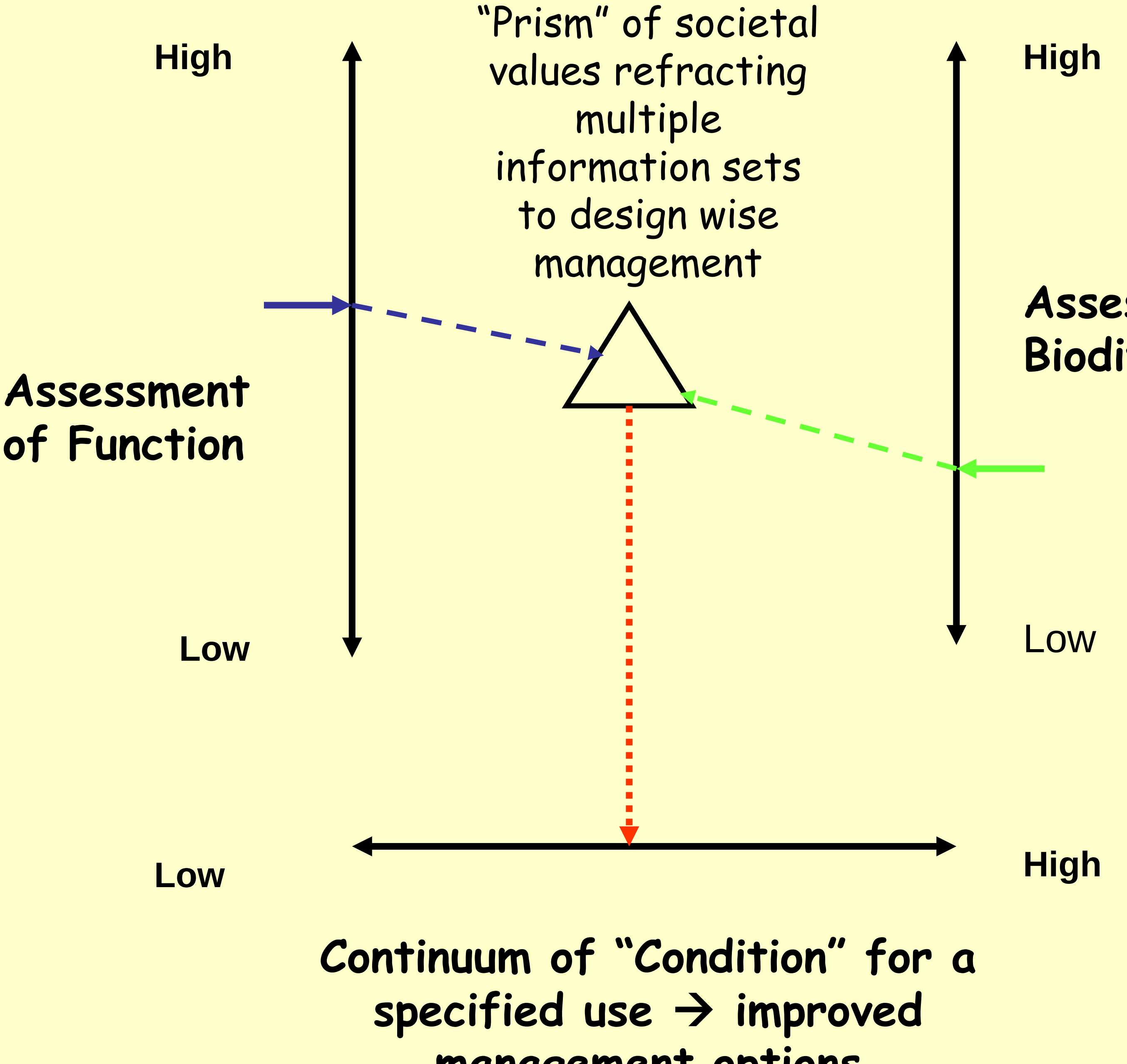
LFA is an indicator-based assessment procedure, based on evaluating soil surface processes, seeking to define how well a landscape is working as a biophysical system.

It is comprised of three modules:

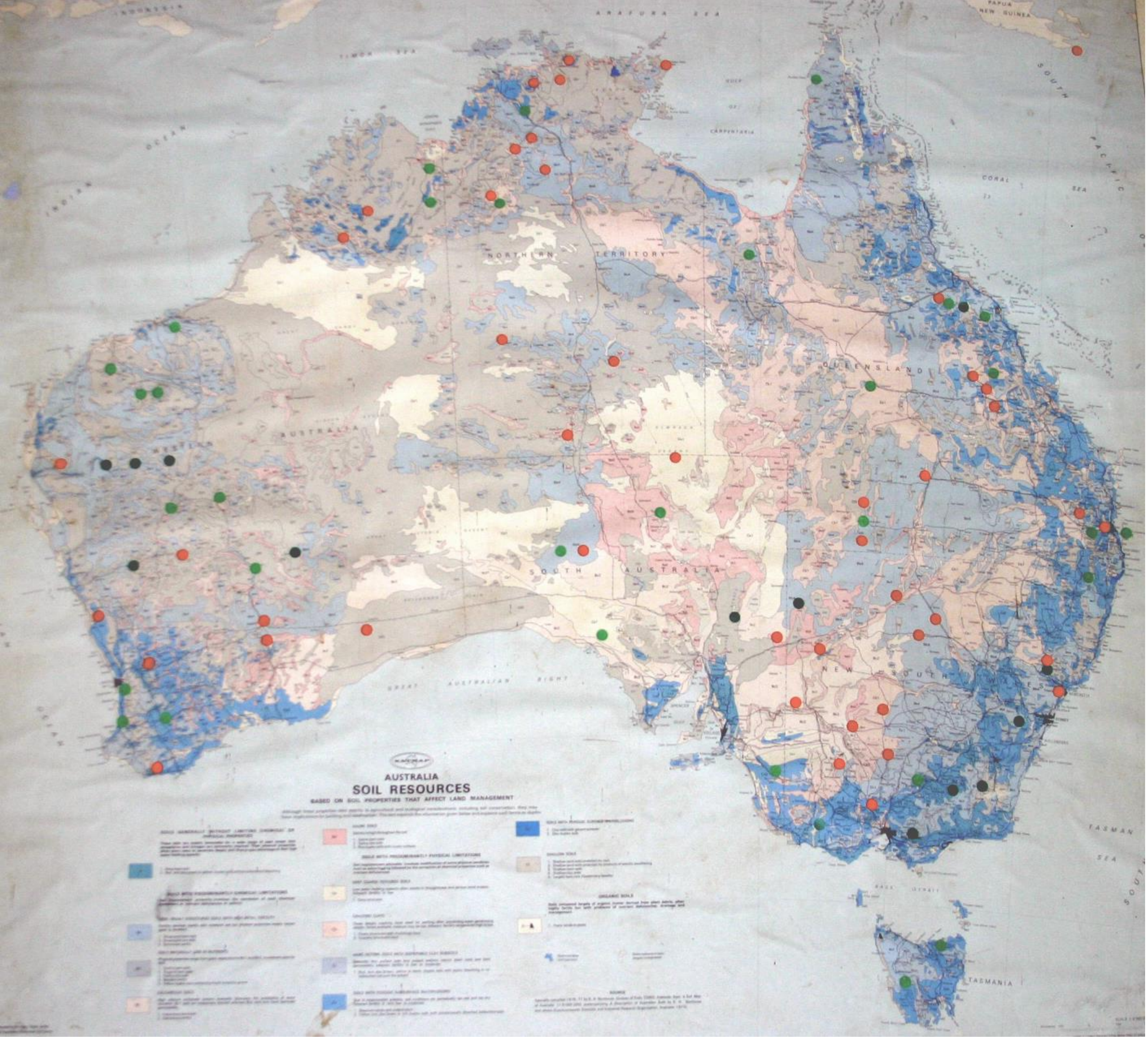
1 A conceptual framework representing the sequence of processes to be assessed

2. A field procedure collecting data at two spatial scales together with a spreadsheet that calculates indices of functionality. (coarser scales are being accommodated with tools like Google earth)

3. An interpretational framework to advice land managers about grazing strategy or landscape rehabilitation

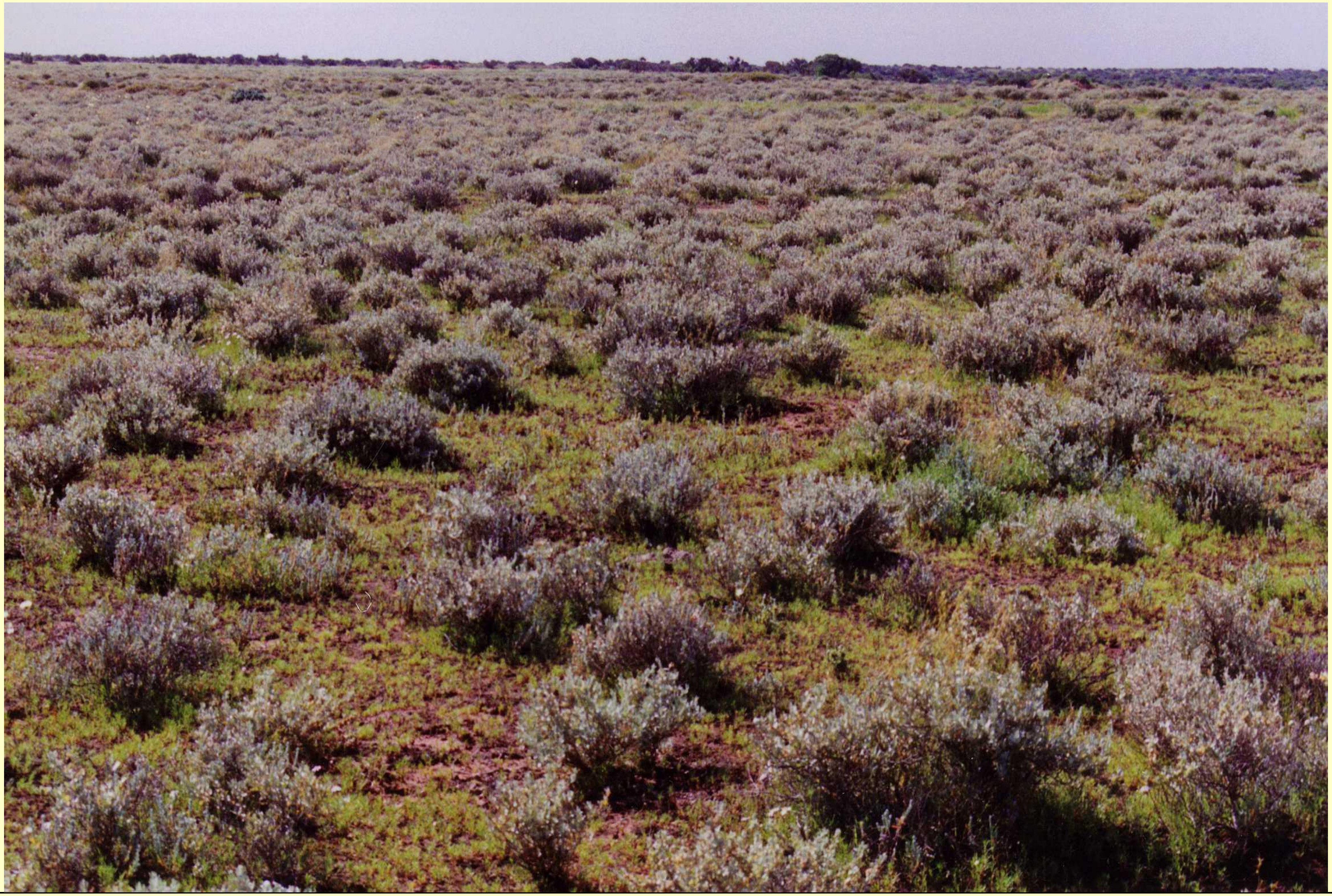


My personal experience has confirmed that B/D and Function are not necessarily locked together

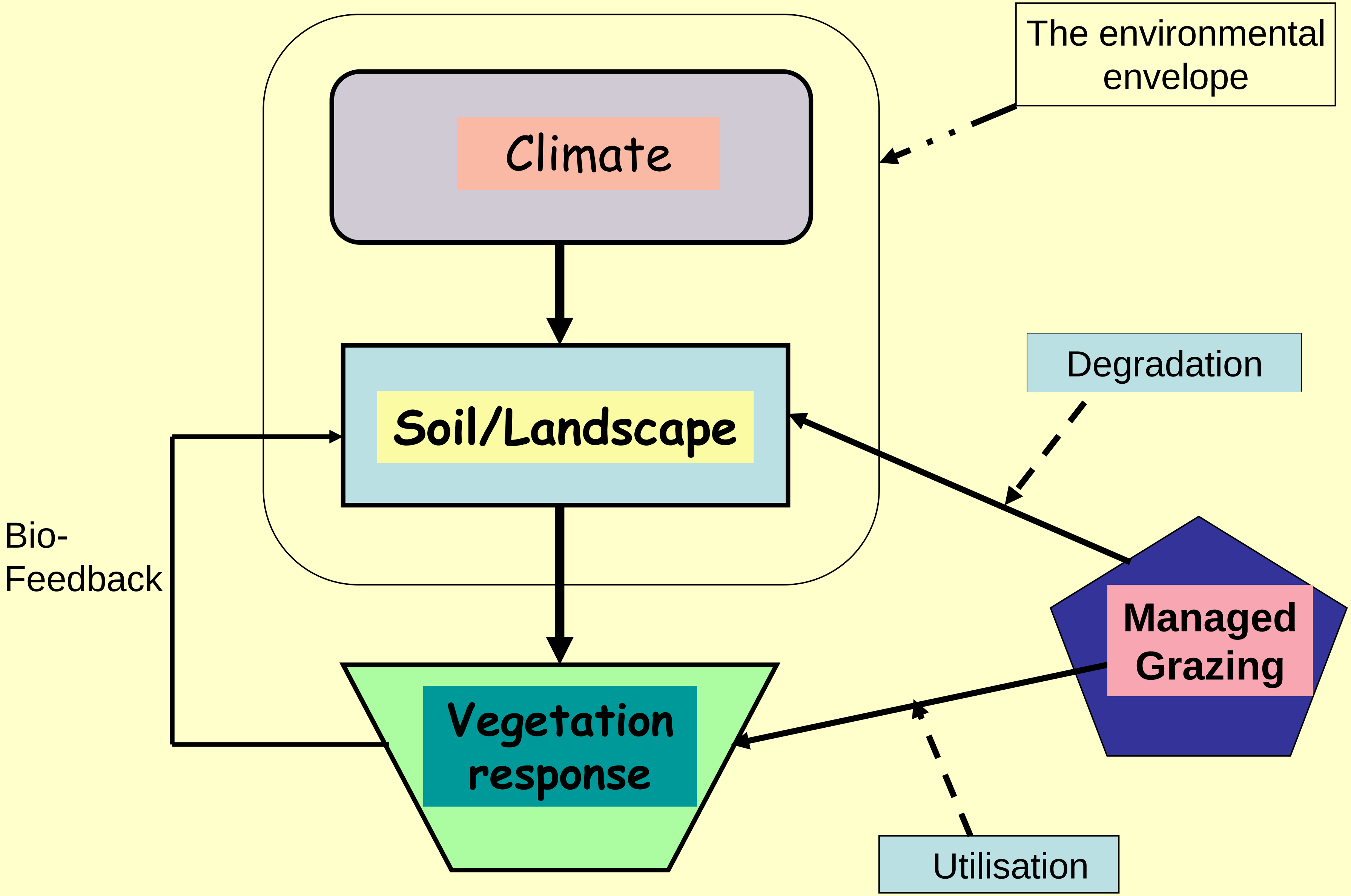


AUSTRALIA
SOIL RESOURCES
BASED ON SOIL PROPERTIES THAT AFFECT LAND MANAGEMENT
INDONESIA
ARAFURA SEA
TIMOR SEA
PAPUA NEW GUINEA
INDIAN OCEAN
CORAL SEA
SOUTH PACIFIC
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
GREAT AUSTRALIAN BIGHT
TASMAN SEA
TASMANIA

Monitoring Range Condition was traditionally based on assessment of vegetation variables, with judgements such as "good", "fair" and "poor" being the output.



An all too frequent post settlement scenario; Loss of perennial vegetation, soil erosion exposing dispersive sub-soil, but with continued, unremitting grazing pressure.



The environmental envelope
Climate
Soil/Landscape
Degradation
Bio-
Feedback
Managed Grazing
Vegetation response
Utilisation

1. Initial Proof of Concept

A paper presented to the first International Rangeland Congress in Denver in 1977 proposed that a wider set of landscape properties be assessed:--

"A Critical Evaluation of the Range Condition Concept"

By E. Lamar Smith

In particular, Dr Smith proposed:--

- That site condition should be primarily based on soil characteristics, and
- that a numerical scale based on assessments over time should measure trend.

This view clearly aimed to assess changes to soil properties due to weather and management interactions and anticipated being able to focus on changes rather than simply describing soil type as such.

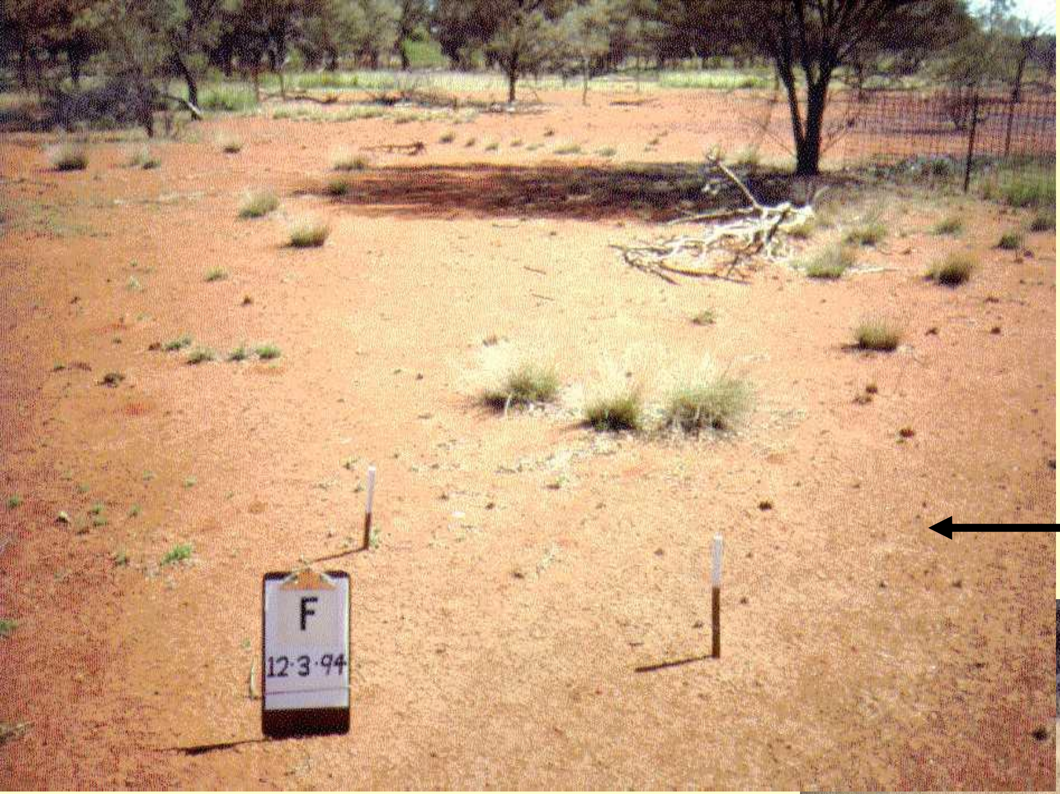
Previous proposals to use soil indicators had:

1. Concentrated on erosion as the only process assessed, or

2. Used pedological descriptions of soil profiles as the information source, which turned out to be not sensitive enough, and did not reflect **changes** to surface soil properties that affected "edaphic habitat" for pasture species.

The Challenge….

What sort of data collected from here in a drought….



Can predict this response to rainfall?

Clearly, the productive potential of the bare soil was substantial.

“Bare and productive vs bare but unproductive”

Initial soil surface Indicators

1. Biological soil crusts
2. Erosion features
3. Deposition of alluvium
4. Plant litter
5. Surface roughness
6. Surface physical crust character

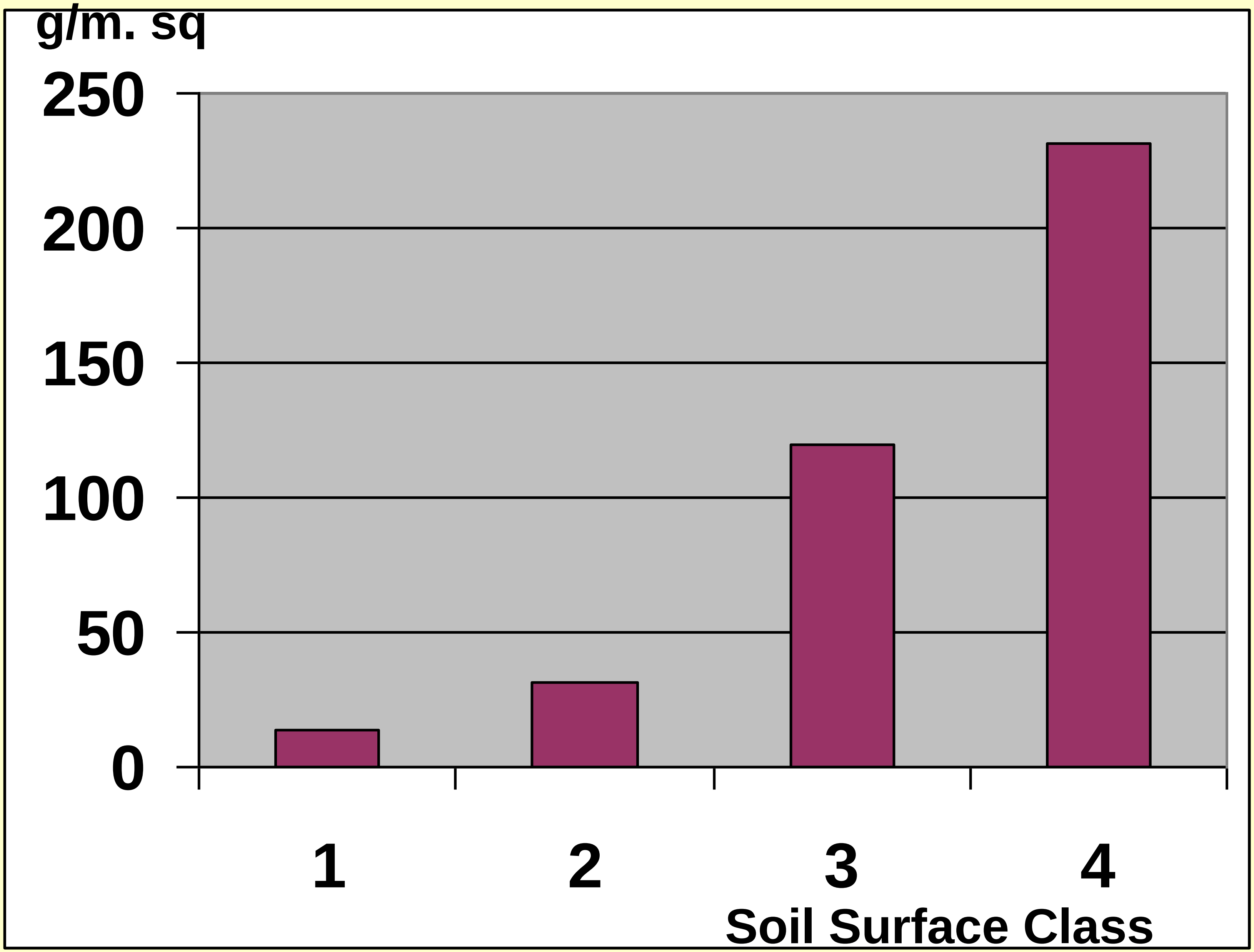
These were each rated from “nil” to “extensive”, *amalgamated mentally* and assigned to a class of soil stability.

The data were collected during a prolonged drought, in the near-complete absence of pasture plants, at 20m grid intersections: a total of 750, 0.5 x 0.5 m quadrats,

The data enabled the quadrats to be classified into 6 classes

1. Four classes of bare soil, characterised as "very unstable" (1) to "stable"(4)
2. On alluvium (very minor areas)
3. Under tree canopies (minor proportion)

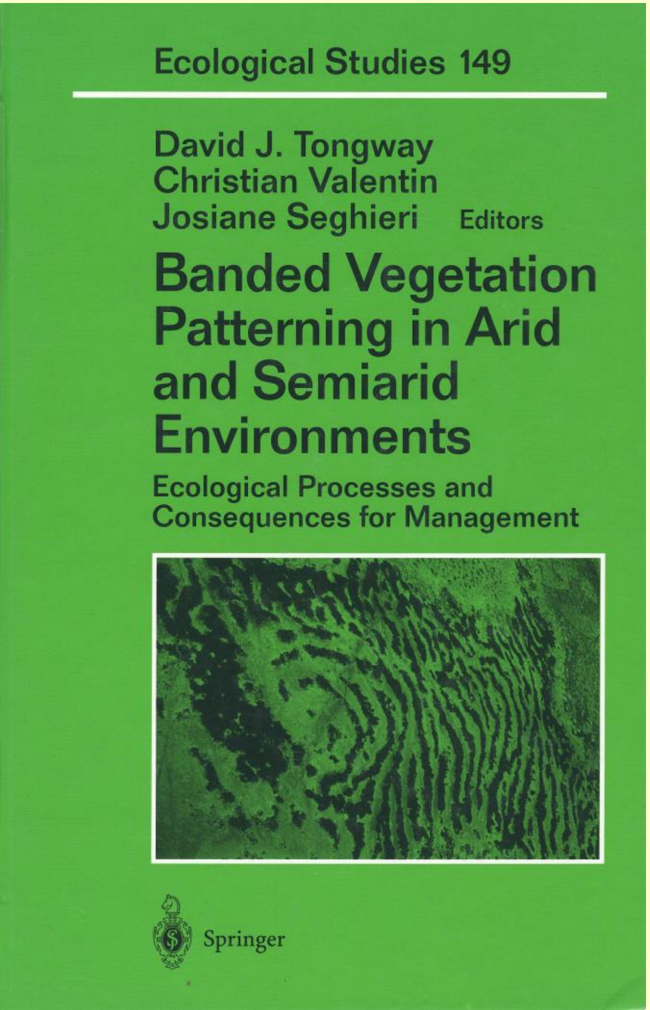
The drought broke with gentle but persistent rainfall extending over a long period, enabling vegetation to steadily grow according to the soil's potential.



Published: Australian Rangeland Journal 1989.

2. Recognition of landscape pattern

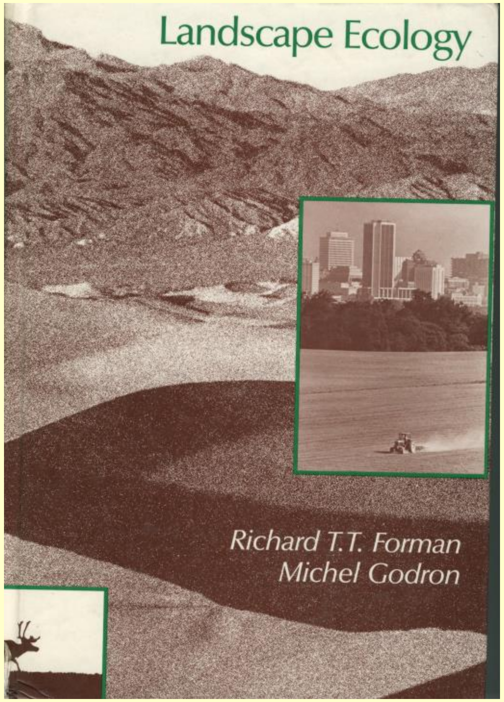
The use of grid-intersections as sampling sites worried us, as we could see a variety of locations not sampled as we traversed the sites. That is, agronomic sampling was seen as inadequate.

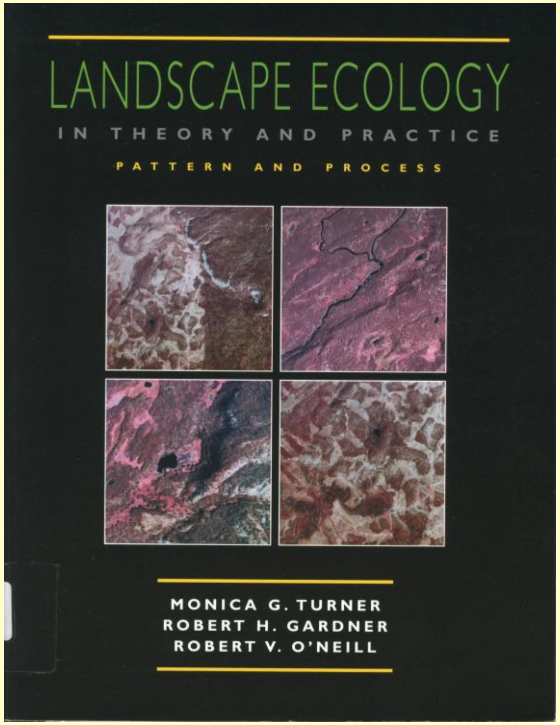


In other work at this stage, John Ludwig and I studied **vegetation patterning**, using **gradsects** (gradient-oriented transects) to explain how strongly patterned landscapes worked as runoff – run-on systems.

Making sense and use of heterogeneity: turning variability into information.

This turned out to be one of the global parallel developments of Landscape Ecology during the 1980s, as workers linked large to small spatial scales with landscape processes often previously only assessed at fine scale.





In many Australian landscapes, the combination of:

(i) Highly weathered soils

(ii) Rainfall highly variable in amount, intensity and temporal distribution

(iii) A range of disturbance regimes initiated by pastoralism, farming and mining

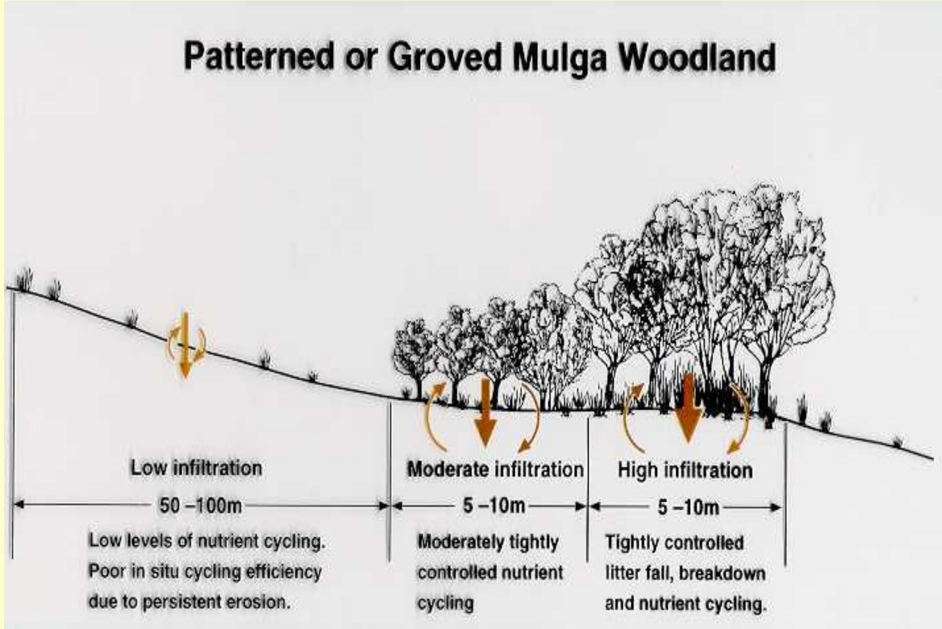
have made analysis complex in a scientific context and confronting in socio-economic situations

However, by viewing landscapes as <u>bio-physical systems</u>, instead of associations of species, a less emotive and more rational analysis was possible:-examining the fate of rainfall and run-off was a key step.

Undisturbed banded landscapes have clearly heterogeneous water run-off.

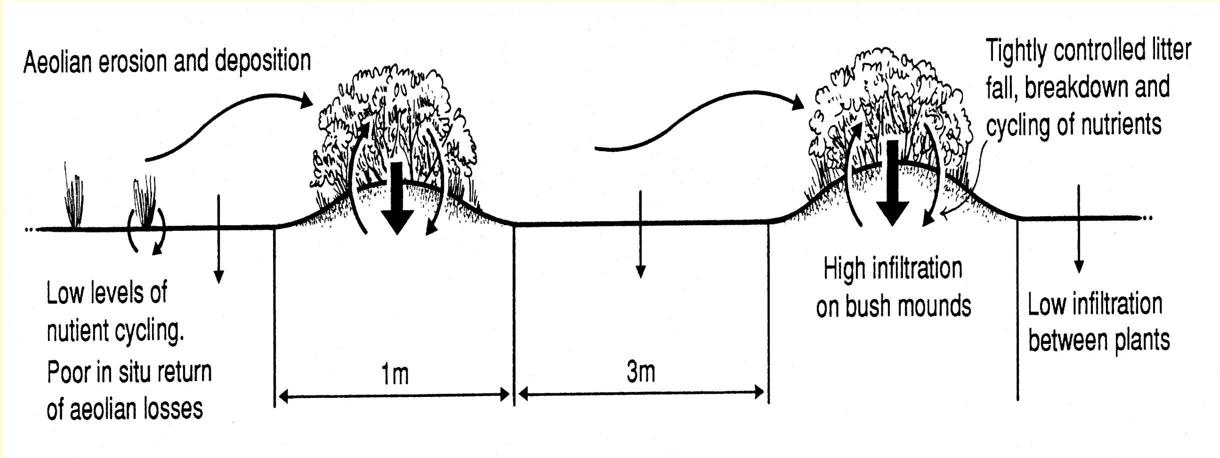
Chenopod shrublands are superficially homogeneous, but are functionally patchy at fine scale

Coming to grips with the scale at which functional heterogeneity is expressed is a crucial step in assessing landscape function. (Data in IRC 1991 paper)



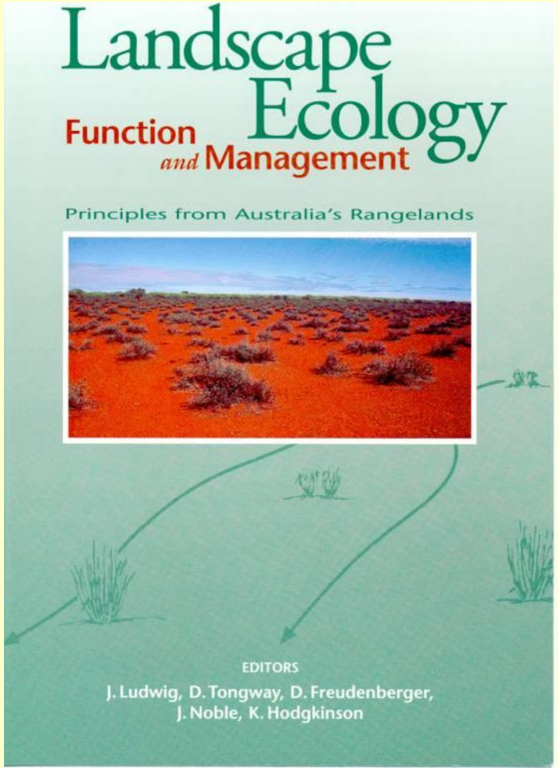
Woodland functioning is expressed at the scale of tens of metres

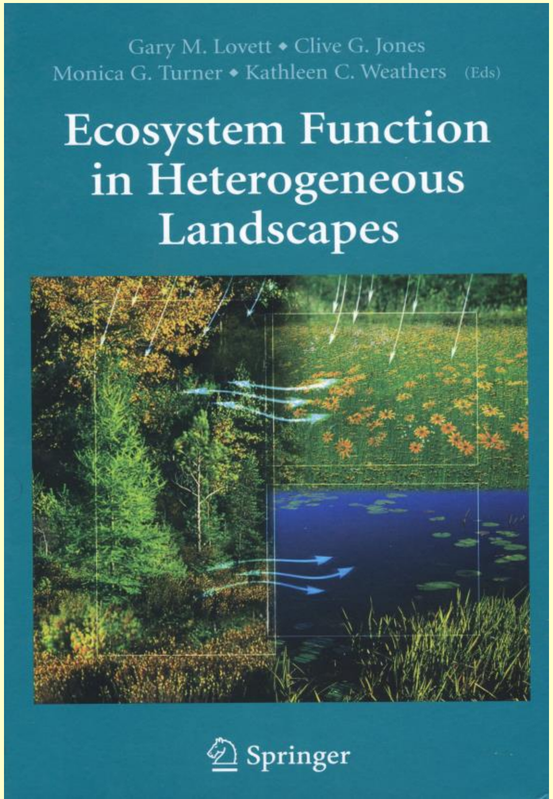
Shrubland functioning is expressed at the scale of metres



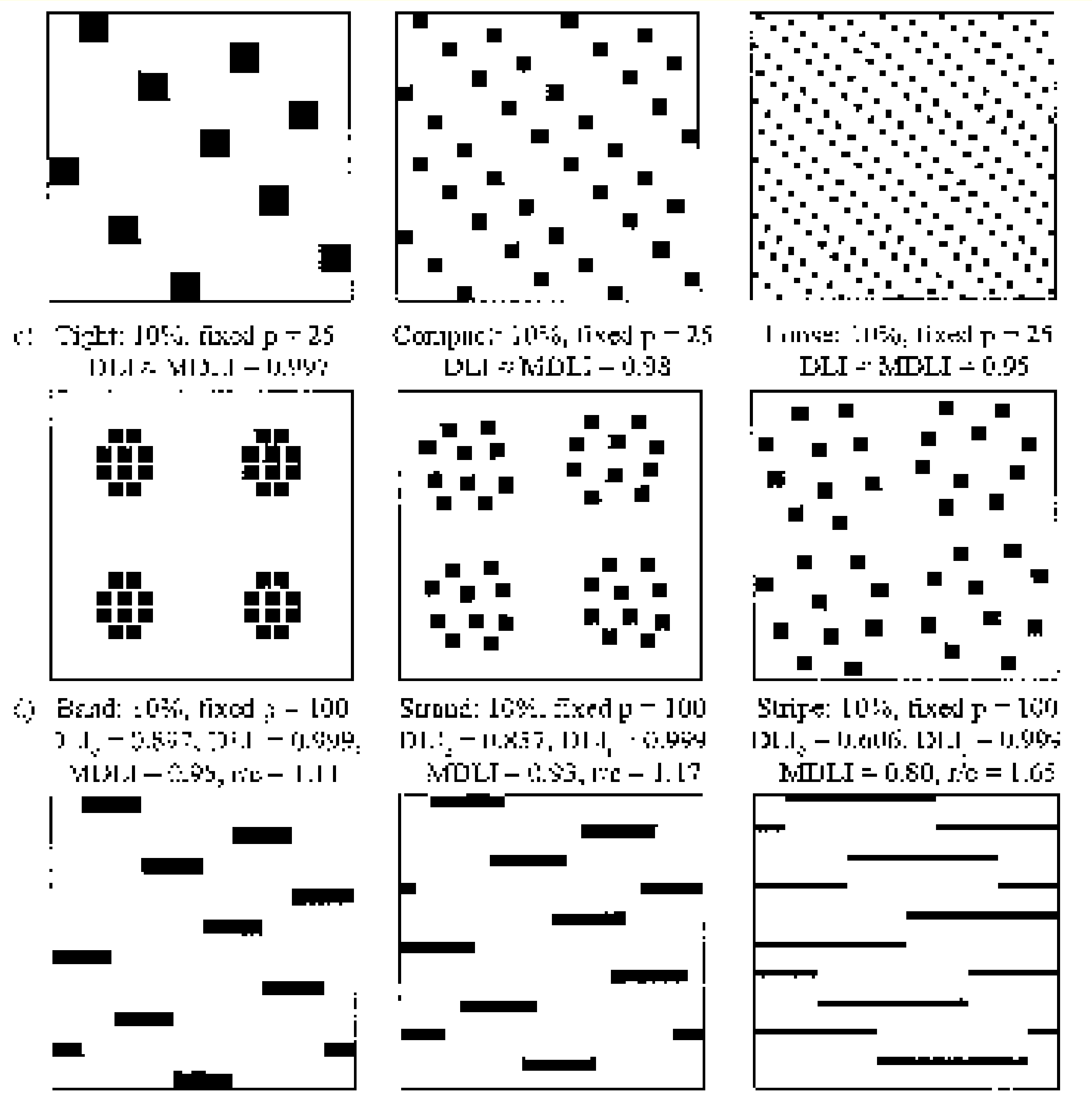
By studying the processes underlying heterogeneity in landscapes, we eventually proposed a sequence of information-processing steps:-

Pattern → Properties → Processes → Function





This lead to a simple concept of <u>"landscape leakiness</u>" as a "selling point" to new observers, but also facilitated modelling of landscape function and then "dysfunction" as an induced landscape circumstance.



Spatial Pattern is more important than crude measures of cover in assessing resource leakage.

Landscape ecology now uses field metrics that detect, characterise, measure and interpret the meaning of spatial pattern

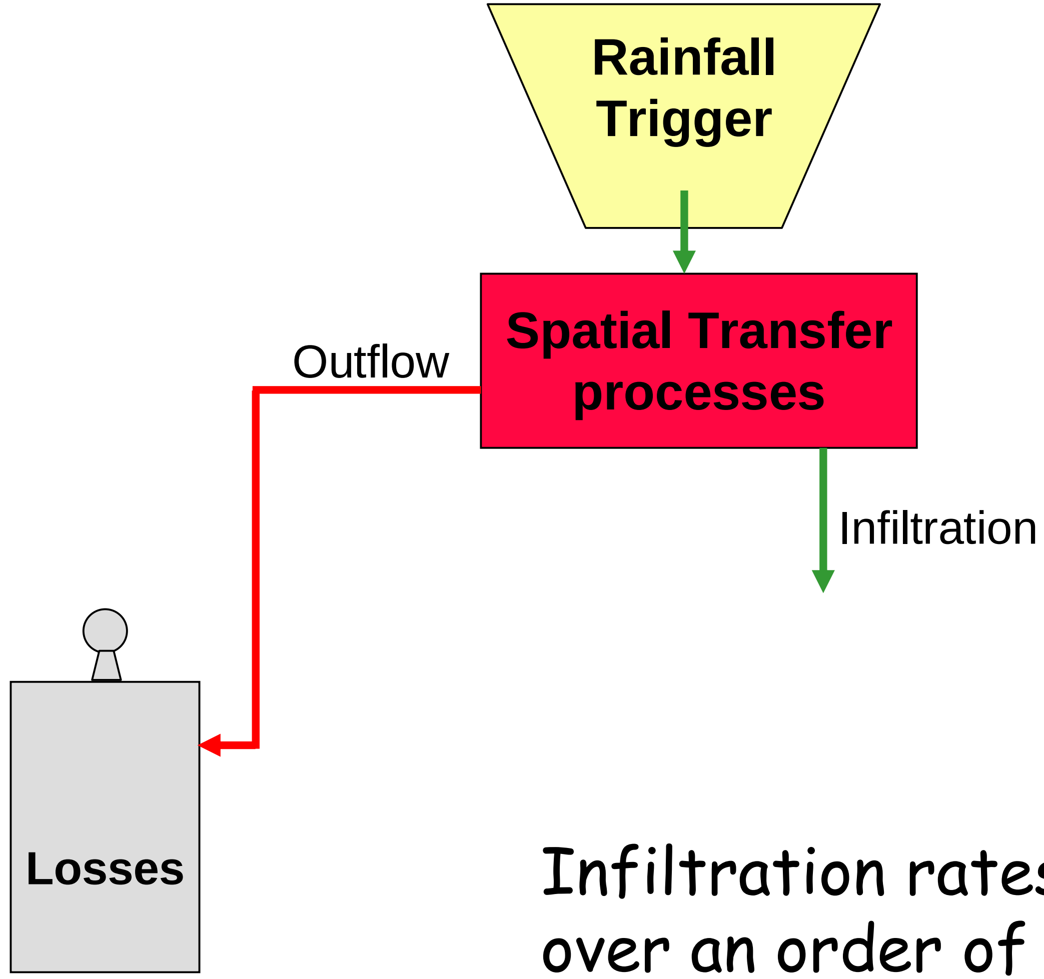
We needed to make our data collection procedures recognise the scale at which surface processes were expressed and to make them "spatially referenced" – to look at the effect of processes over time: identifying cause and effect.

We wanted to use an information gathering sequence to create a generic monitoring procedure, able to be used without modification across a range of landscape types.

This implied the need for a robust conceptual framework involving all relevant scales and processes (Water, the master input -Noy-Meir 1973)

We subsequently found that this framework had great utility in identifying the effects of disturbance upon landscape functioning – the assessment of dysfunction.

L/F Conceptual Framework. Step 1. Infiltration vs outflow

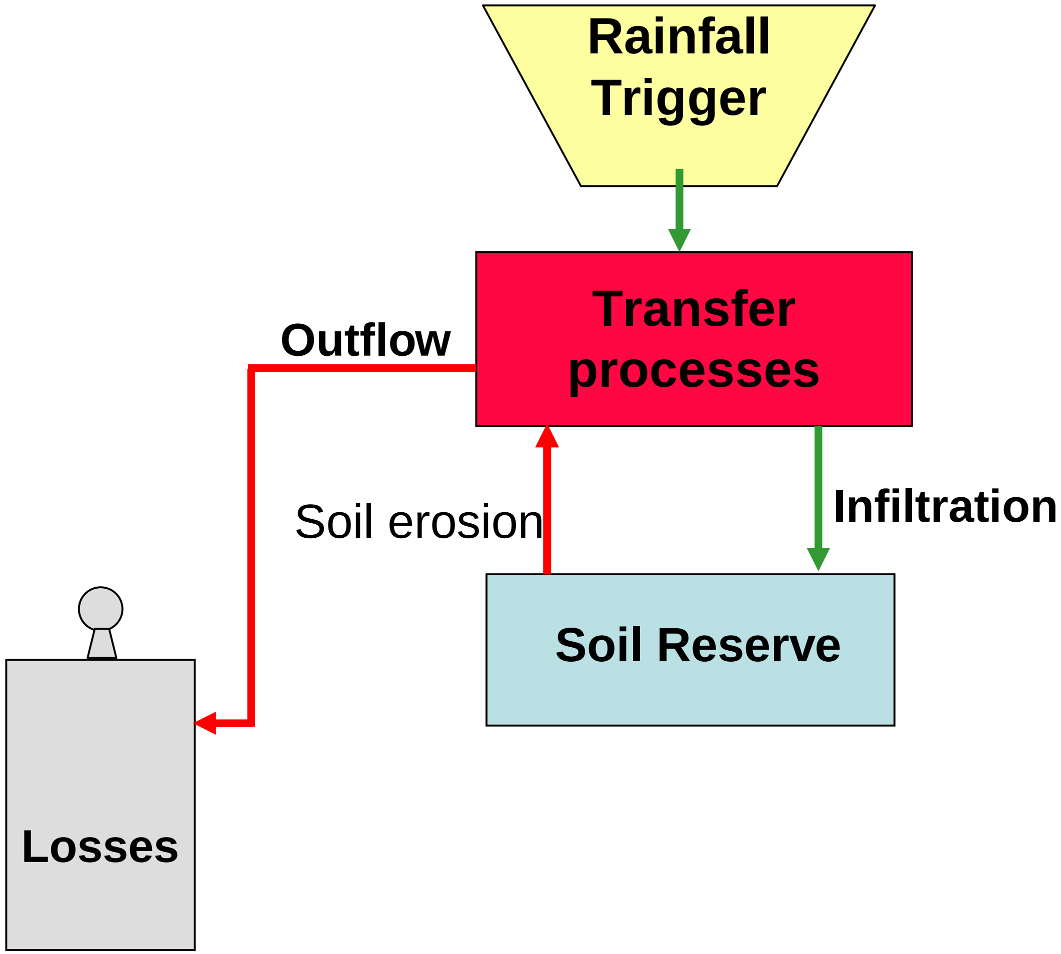


Infiltration rates may vary by well over an order of magnitude, in a given soil, depending on management.

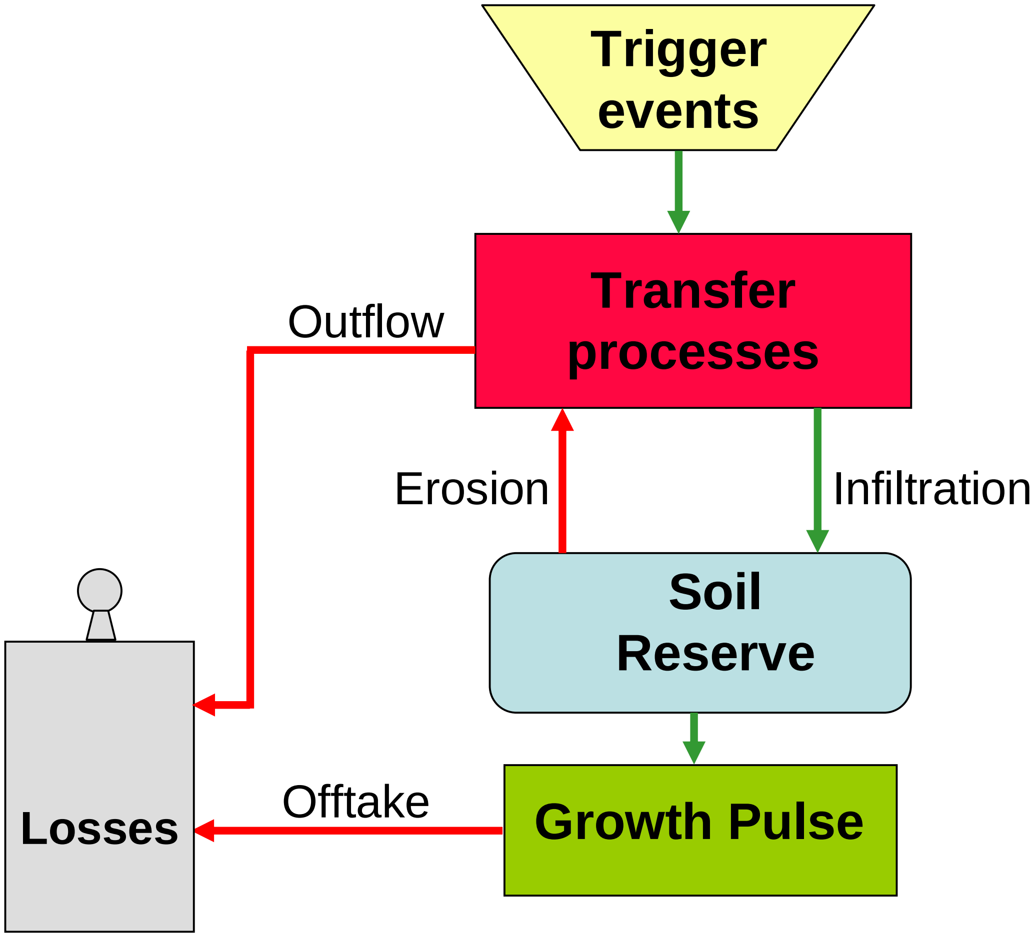
Runoff volume and rate regulated by numerous small grass plants

The same landscape type where grass has been eliminated by mis-management, and the increased shrub population does not control overland flow

L/F Conceptual Framework Step2. Outflow → Erosion losses

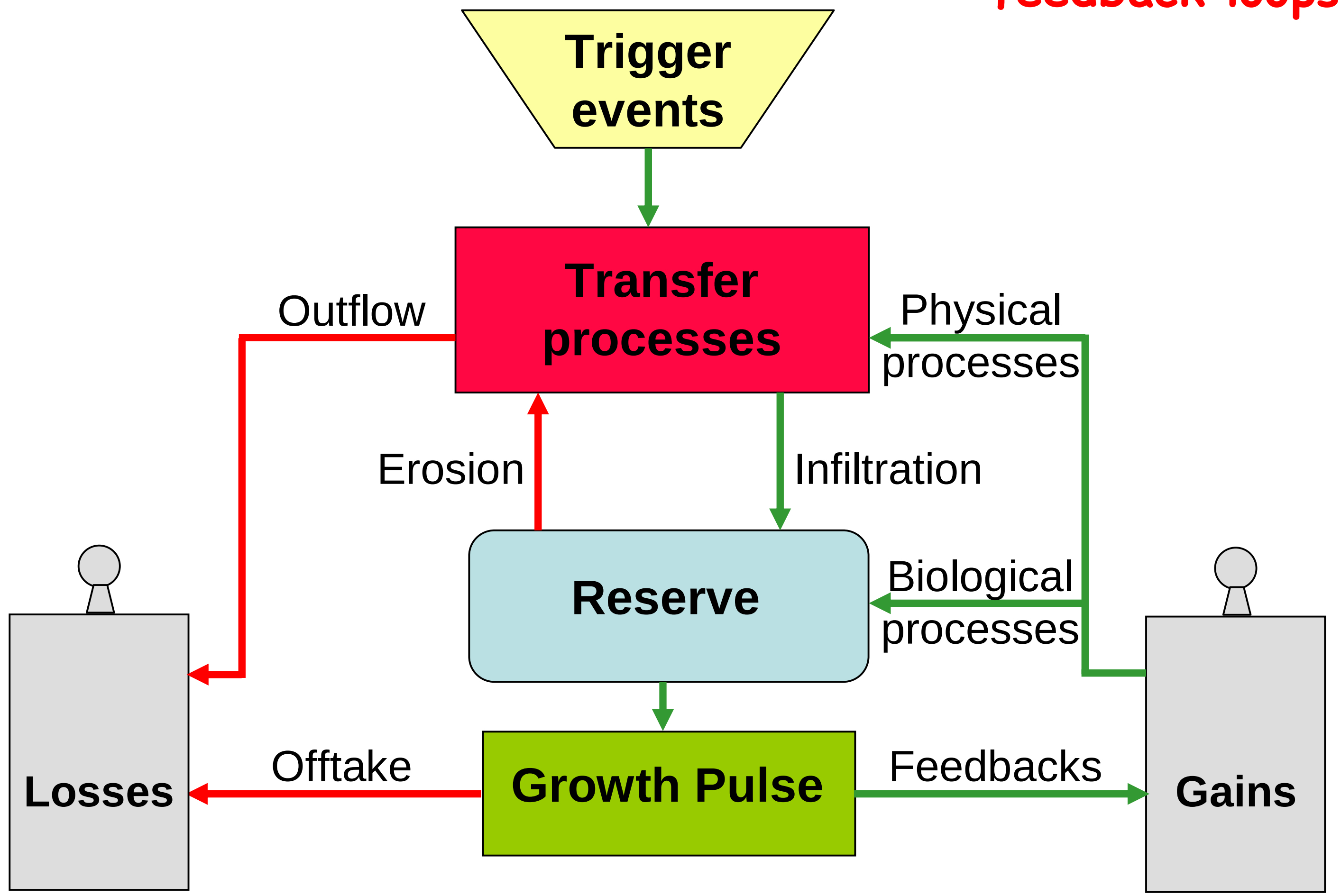


L/F Conceptual Framework Step 3. pulses of growth and modes of offtake



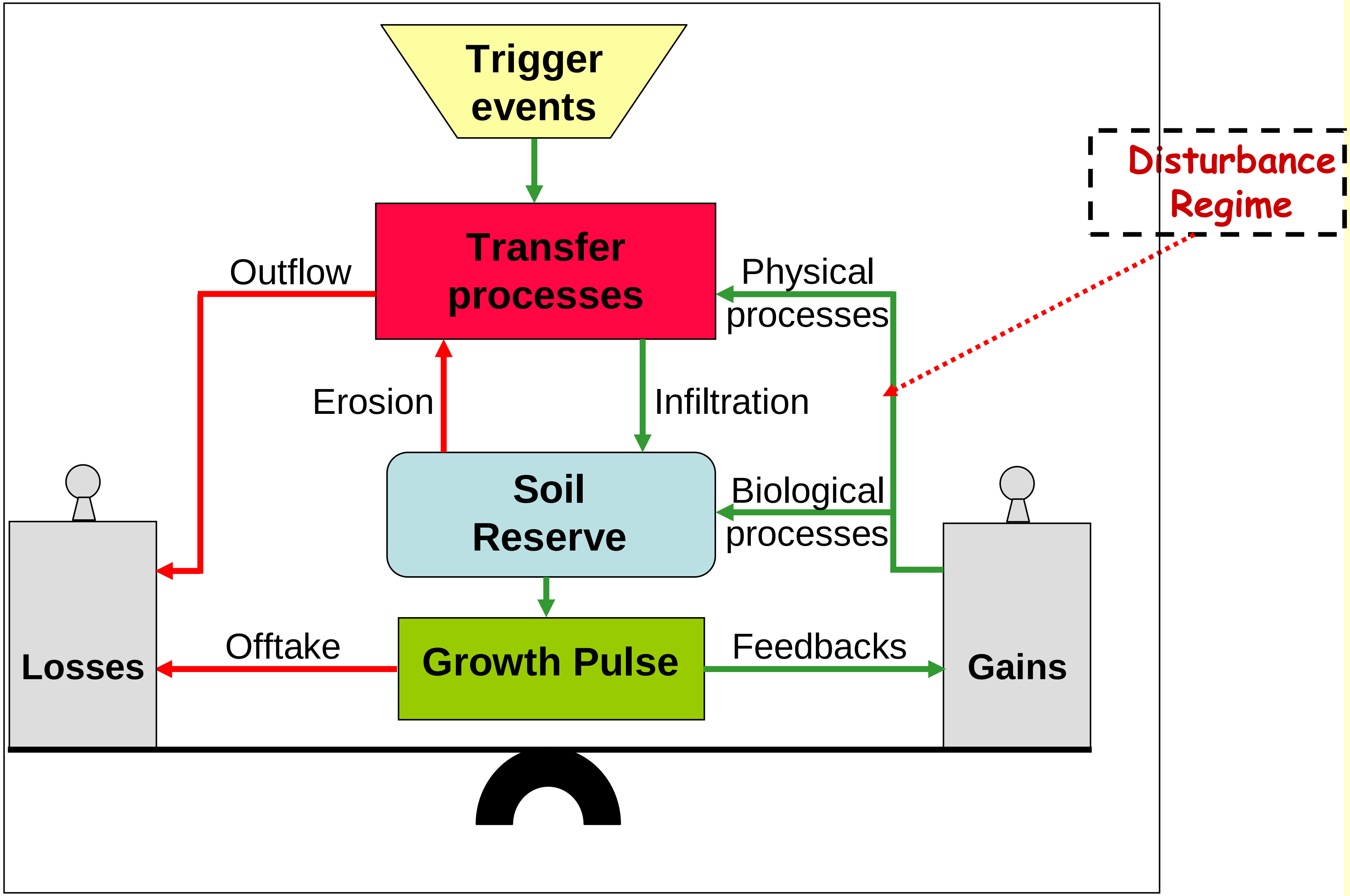
Off take: grazing, fire.

L/F Conceptual Framework **Step 4. Goods and services provided by vegetation growth: crucial feedback loops**



L/F is assessed as "the economy of vital resources"

LFA is designed to address the effects of a disturbances that affect landscape function



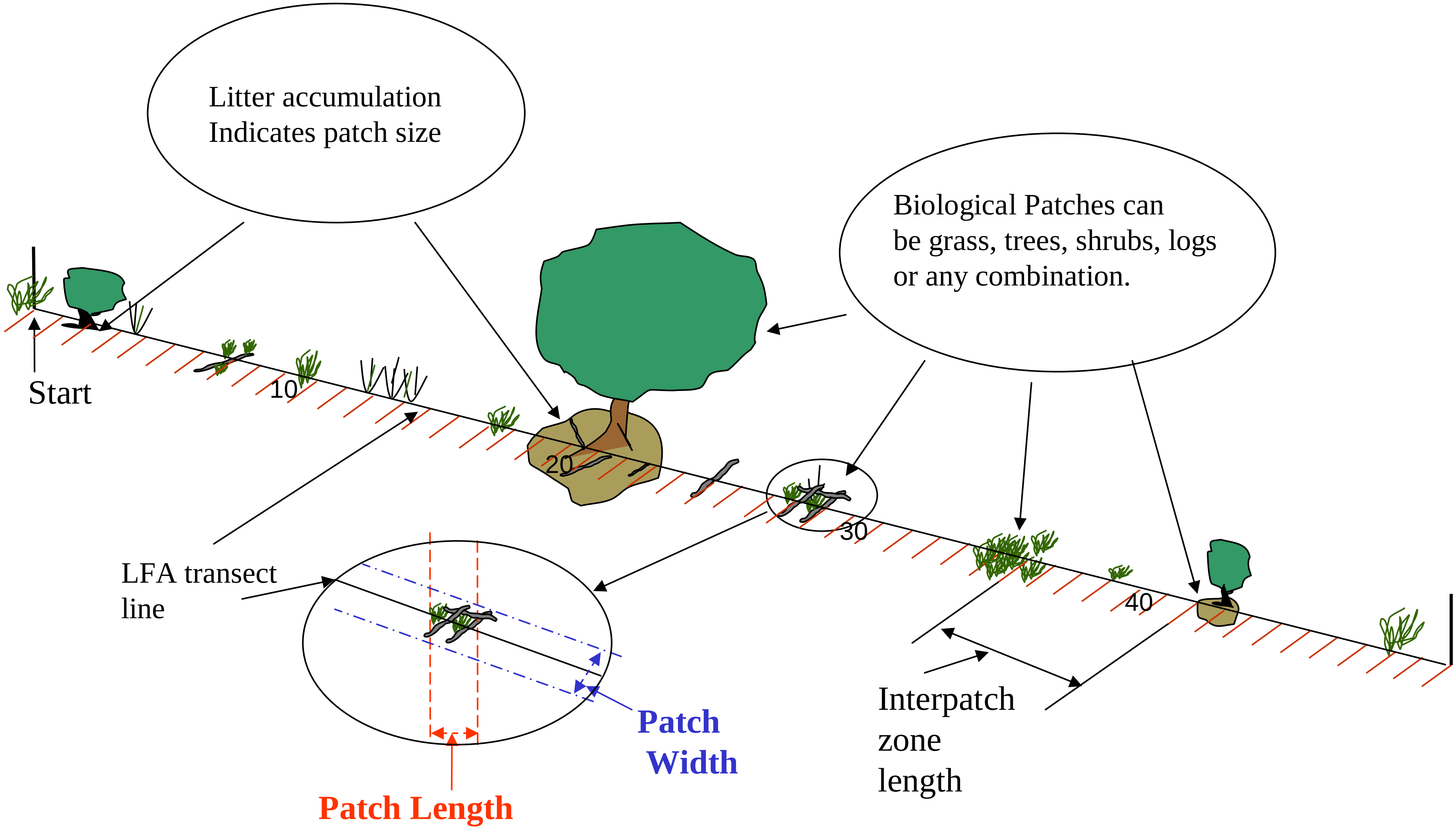
Examples of surface processes:

- Infiltration
- Runoff
- Erosion/sediment mobilization
- Saltation
- Deposition
- Crust formation
- Aggregate Slaking
- Clay Dispersion
- Nutrient cycling
- Organic matter decomposition

All of these processes can be assessed visually in the field in terms of their activity or rate

- Each landscape type has a characteristic scale of self-organisation which explains the pattern and processes by which vital resources are retained and used.
- So, when disturbed, each landscape responds in a characteristic way dependent on the soil properties, slope and the scale of resource regulation.
- The field procedure for monitoring needs to be able to capture this information by a combination of measurements and indicators.

Landscape Organisation: continuous data recording from a gradient-oriented transect (Gradsect)



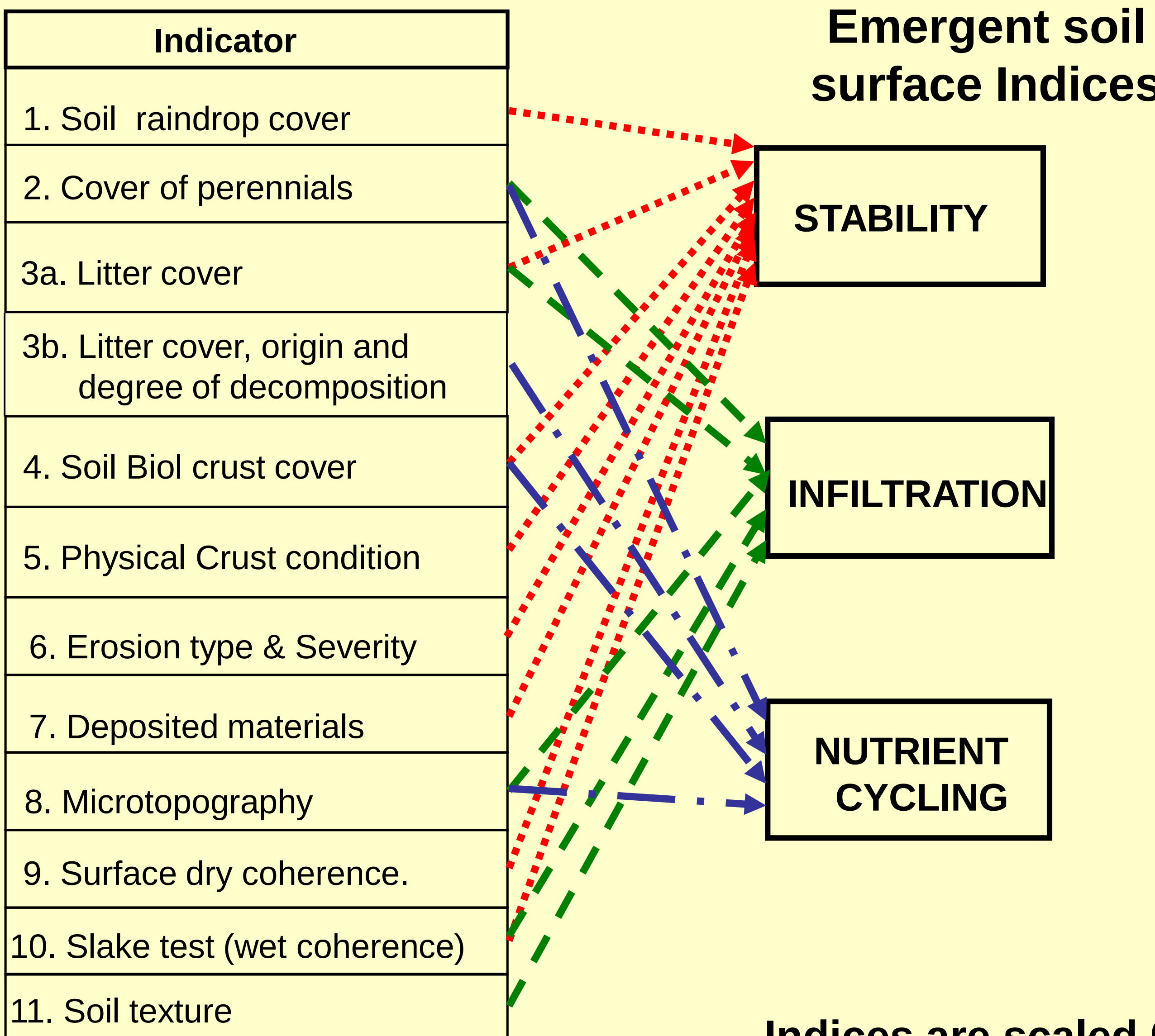
LFA provides patch/inter-patch metrics to assess differences in resource regulation ("resource leakiness") at hillslope scale.

"Gradsects" were tools by which this sort of information could be acquired, with a number of emergent indices reflecting function <u>at the hillslope scale.</u> (already demonstrated as efficient ways to measure differences in biodiversity)

This advance enabled the **original soil surface indicators** to be applied to the full range of heterogeneous pattern elements in a landscape

Those original soil surface indicators were then more carefully defined and assessed one at a time; a spreadsheet being used to compute the final classification, reflecting soil stability, infiltration rate and effectiveness of nutrient cycling

Each indicator is assigned a class value.



Indices are scaled 0-100

Each indicator refers to a <u>process</u> depicted in the C/F and a spreadsheet calculates the synthetic indices

Stab.= 69.1

Infil. = 39.8

N/C = 31.7

Friable, open-fabric soil a perennial grassland A horizon:

Stab.= 43.3

Infil.= 24.0

N/C= 11.5

Bare, crusted, compacted A horizon: no visible biopores

A highly functional grassy landscape subject to a light disturbance regime

- competent regulation of overland out-flow **rate and volume**
- Effective nutrient cycling

Features	Max score	Rep1
Soil Cover	5	3
Per. basal / canopy cover	4	3
Litter cover, orig & incorp.	10	5ls
Cryptogam cover	4	0
Crust broken-ness	4	0
Erosion type & severity	4	4
Deposited materials	4	4
Soil surface roughness	5	3
Surface resist. to disturb.	5	3
Slake test	4	4
Texture	4	3

Stability:-	71.9
Infiltration:-	46.1
Nutrient Cycling:-	41.0

Over-grazing by kangaroo has resulted in a 2-phase landscape with high "leakiness"

Bare, inter-tussock soil with a robust physical crust

Features	Max score	Rep1
Soil Cover	5	1
Per. basal / canopy cover	4	1
Litter cover, orig & incorp.	10	1
Cryptogam cover	4	2
Crust broken-ness	4	4
Erosion type & severity	4	2
Deposited materials	4	3
Soil surface roughness	5	1
Surface resist. to disturb.	5	3
Slake test	4	4
		3

Stability:- 50.0

Infiltration:- 23.3

Nutrient Cycling:- 11.6

Pedestalled Grass Tussocks

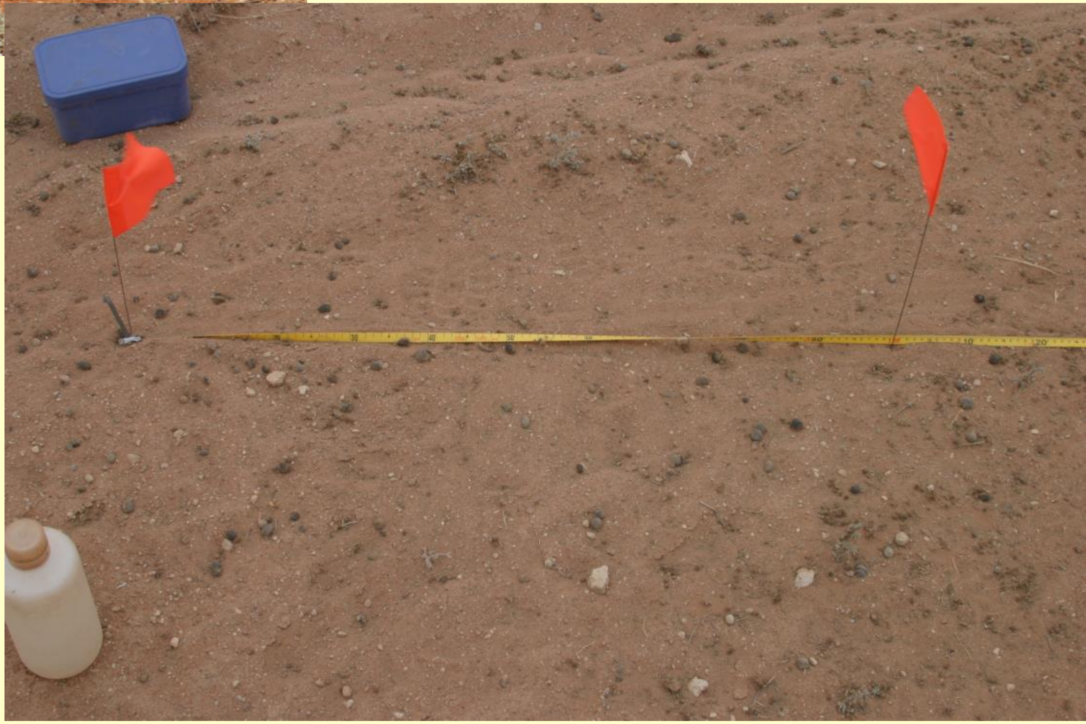
Features	Max score	Rep1
Soil Cover	5	4
Per. basal / canopy cover	4	4
Litter cover, orig & incorp.	10	2ls
Cryptogam cover	4	0
Crust broken-ness	4	0
Erosion type & severity	4	2
Deposited materials	4	3
Soil surface roughness	5	2
Surface resist. to disturb.	5	3
Slake test	4	4
Texture	4	3

Stability:- 56.3

Infiltration:- 35.6

Nutrient Cycling:- 25.6

Seeking an interpretational framework: how to make use of the numbers



1.Function/dysfunction along a landscape use gradient. Rangelands.

(i) 20 m from water. All plants are short-lived annuals

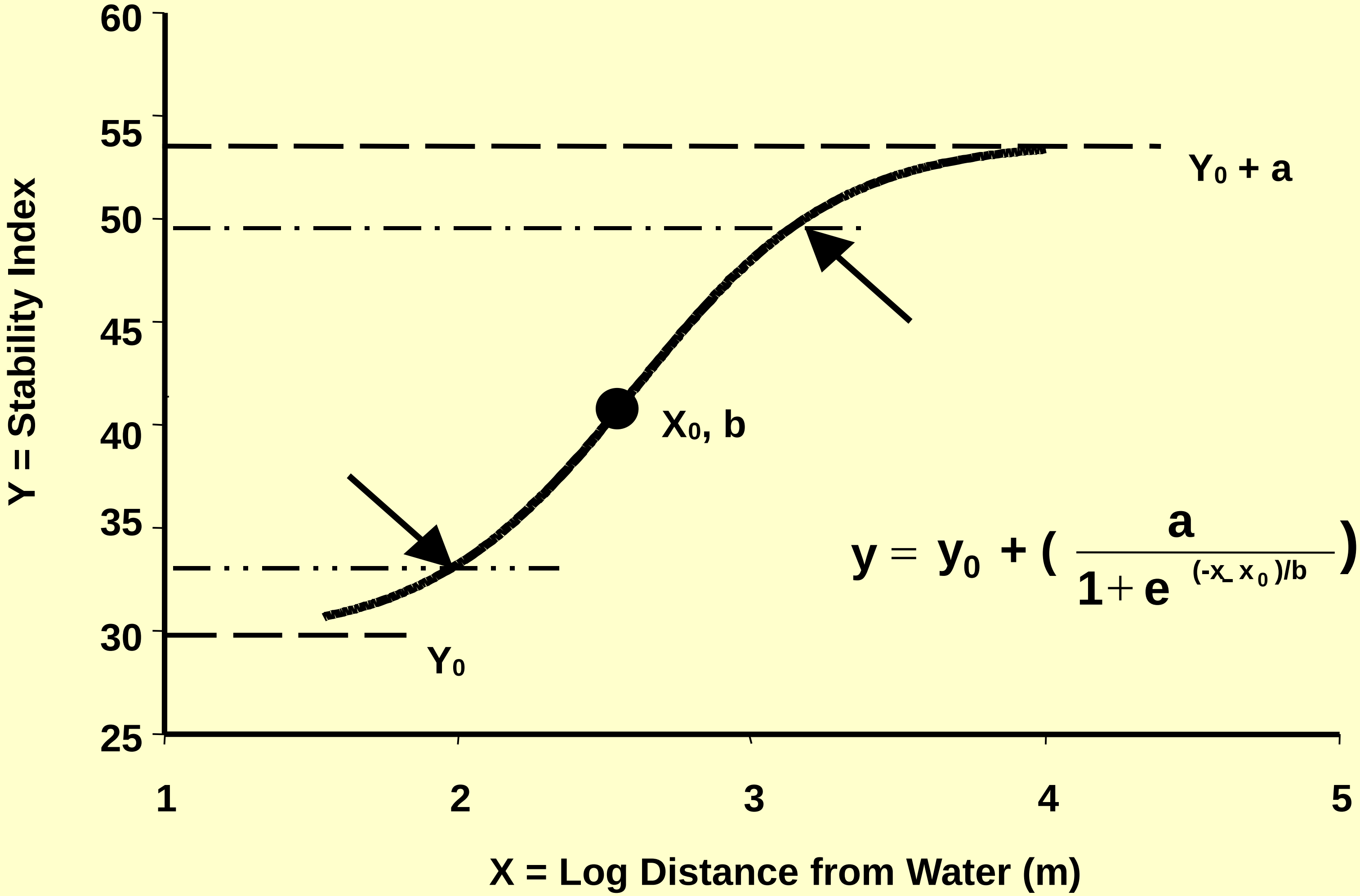
150 m from water

1 km from water

4 km from water

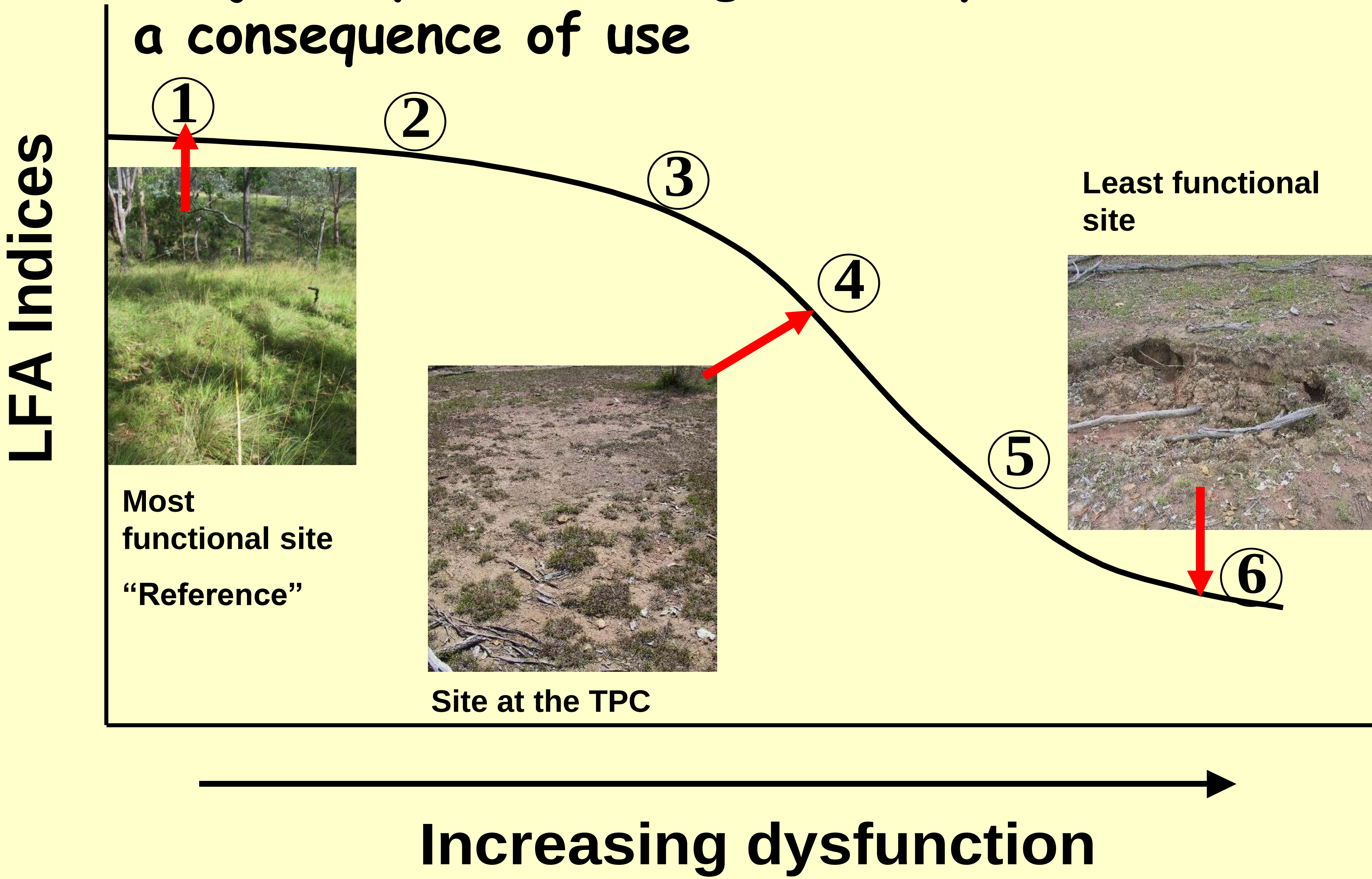
10 km from water

Interpretational framework



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

Trajectory of declining landscape function, as a consequence of use



Interim Summary: LFA:-

- Facilitates assessment of functional status of a landscape across the full functional spectrum
- Consistent with recently articulated principles emerging from Landscape Ecology and contributing disciplines
- Indicators are rapidly assessed and the output presented as numbers. Numbers are well-related to measured variables
- Contains an explicit interpretation module to advise managers.
- Can provide early warning because of the diversity of independent indicators creates a smooth curve
- Self-scaling: the procedure has been used from the driest deserts to tropical rain forest without modification

Minesites have extreme disturbance regimes, compared to farm and rangelands, but are still amenable to LFA.

- Hard rock – gold, nickel
- Mineral sands
- Bauxite
- Iron
- Diamonds
- Coal
- Uranium

56 sites

Australia
PNG
South Africa
Tanzania
Mali
Indonesia
Brazil
Namibia

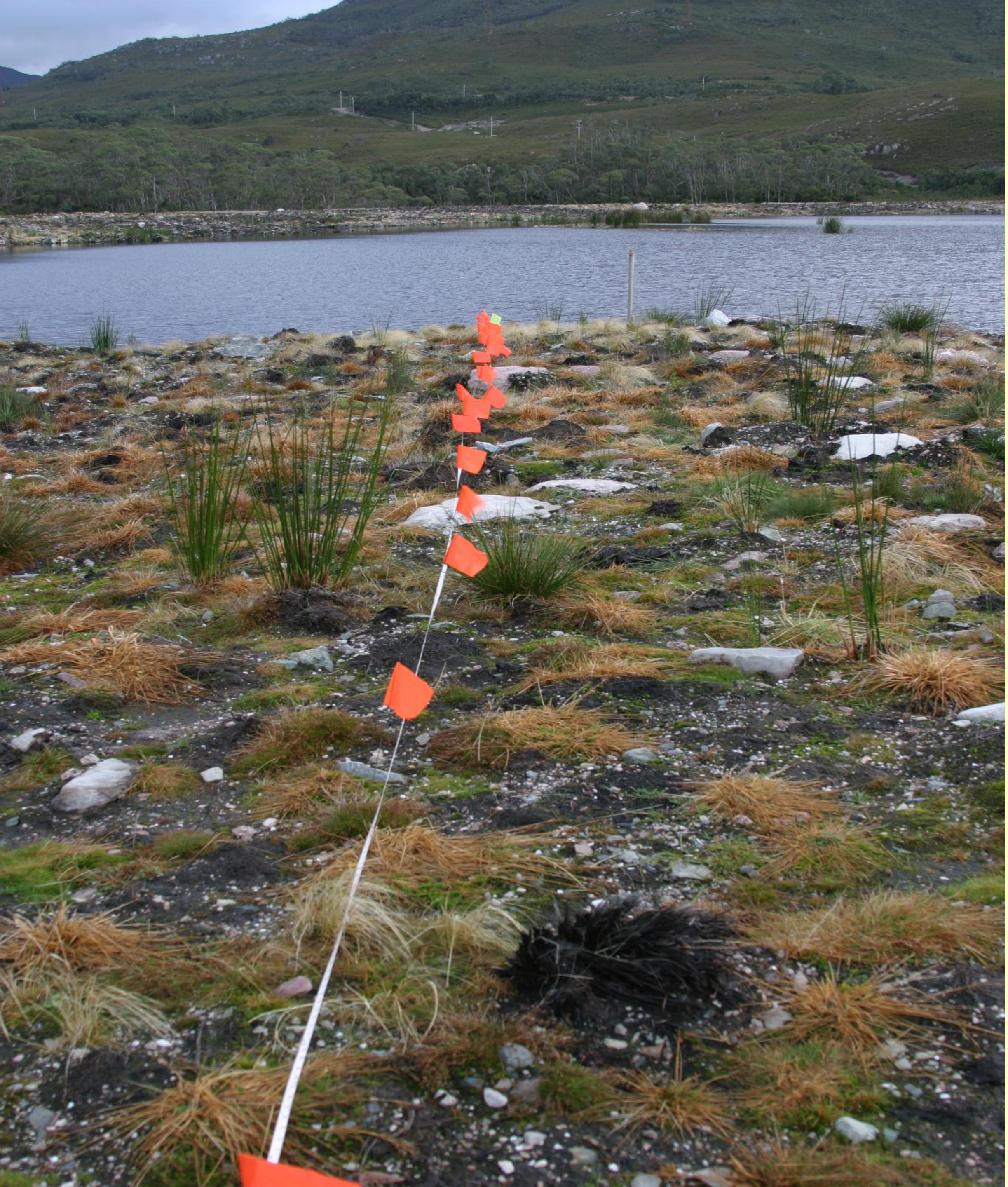
Gold: northern Eucalypt savannas

Mineral Sands: semi-arid heathlands

Bauxite, northern Eucalypt savannas.

Gold: Tropical rain forest

Uranium: Northern Eucalypt savanna



Gold: Henty, Tasmania

Iron: Mt Whaleback, Pilbara

Minesites have to make good the lands affected by mining according to legal agreements made through State Regulatory bodies.

These vary according to when the agreements were made and stakeholder involvement.

In many cases, especially in the past, making information available in a form that permits bond return and lease relinquishment was difficult.

In 2000, the ANZMEC composed a statement of intended standards.

Objectives and Principles in Mine Closure

(Australia New Zealand Minerals Extraction Commission, 2000)

What Mining companies need to do: a framework

1. Stakeholder Involvement
2. Planning closure in a timely and cost-effective manner
3. Financial provision for closure in company accounts
4. Implementation of the plan with adequate resources
5. **Standards**
6. Relinquishment on meeting completion criteria

- **An agreed set of Environmental Indicators that demonstrate successful rehabilitation**

Environmental Indicators

(ANZMEC 2000)

"A set of specific performance **indicators** should be developed to measure progress in meeting **completion criteria**. Correctly chosen, the environmental indicators will show whether the **ecological processes** which will lead to successful rehabilitation are **trending** in the right direction."

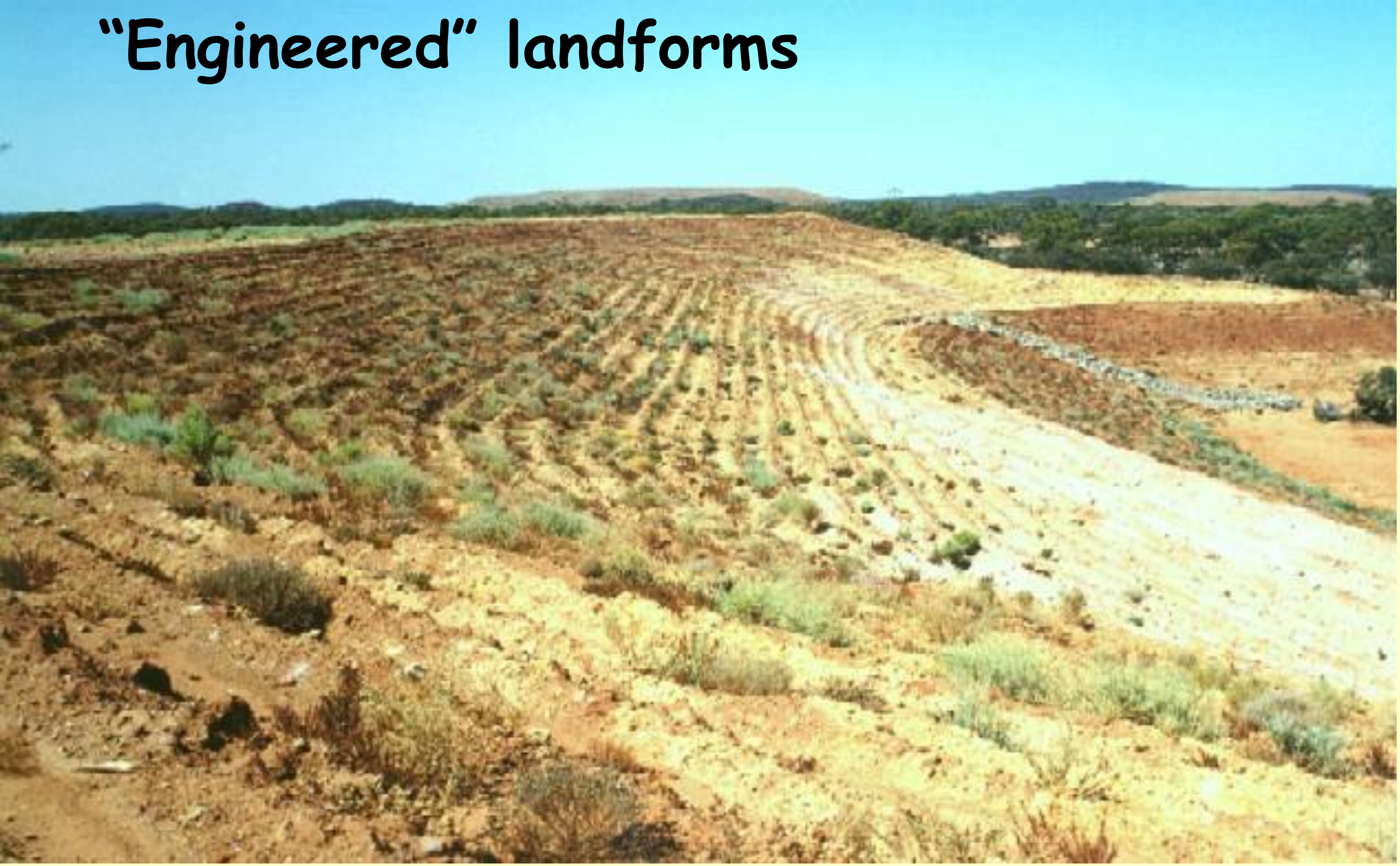
Minesite rehabilitation requires attention to:-

- environmental contaminants
- selection of rock and soil resources
- design and construction of appropriate landforms
- matching vegetation species selection to the above
- monitoring to ensure that the site becomes self-sustaining, and eventually meets completion criteria

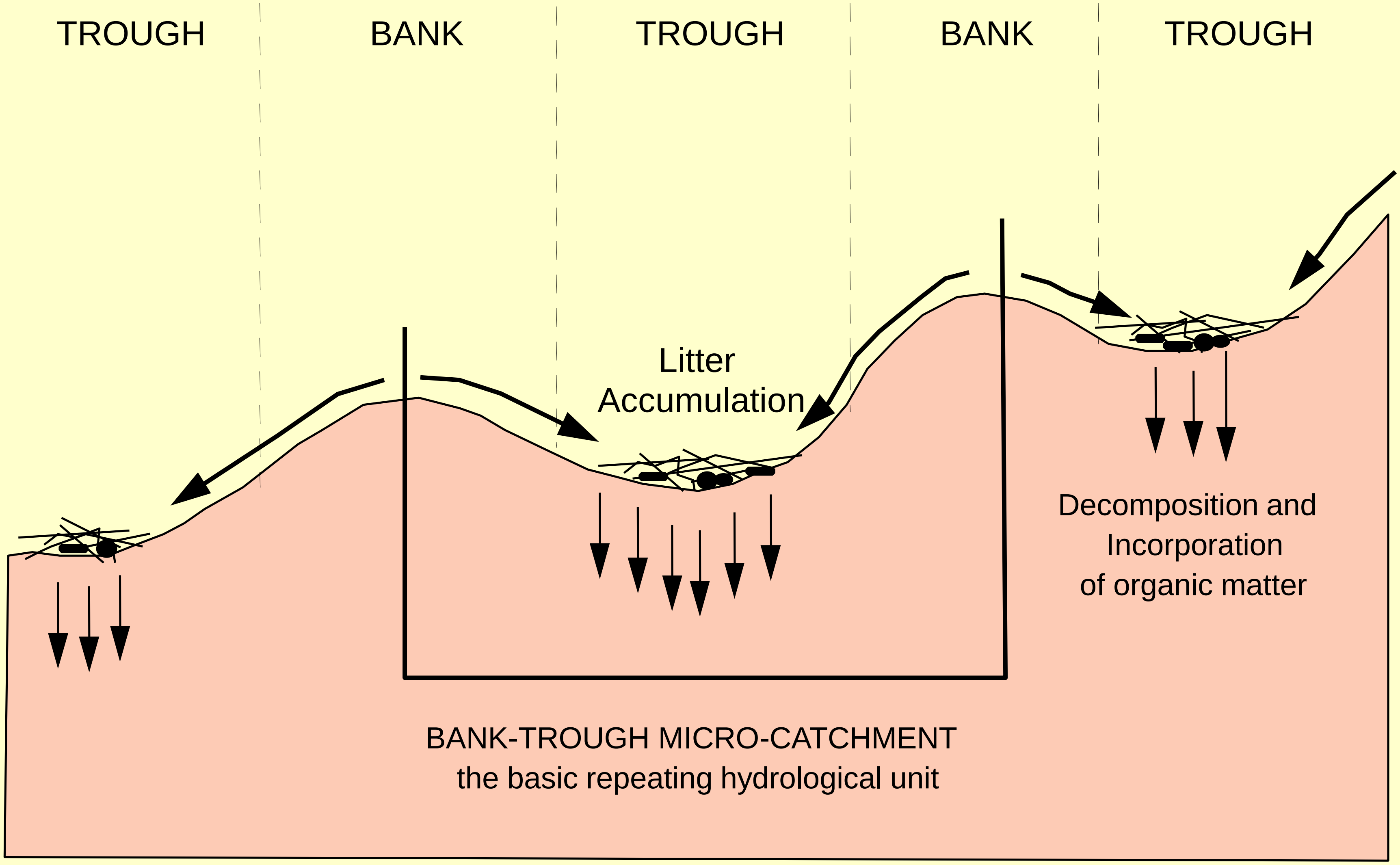
Coalmine dragline spoil

Is this rehab adequate?

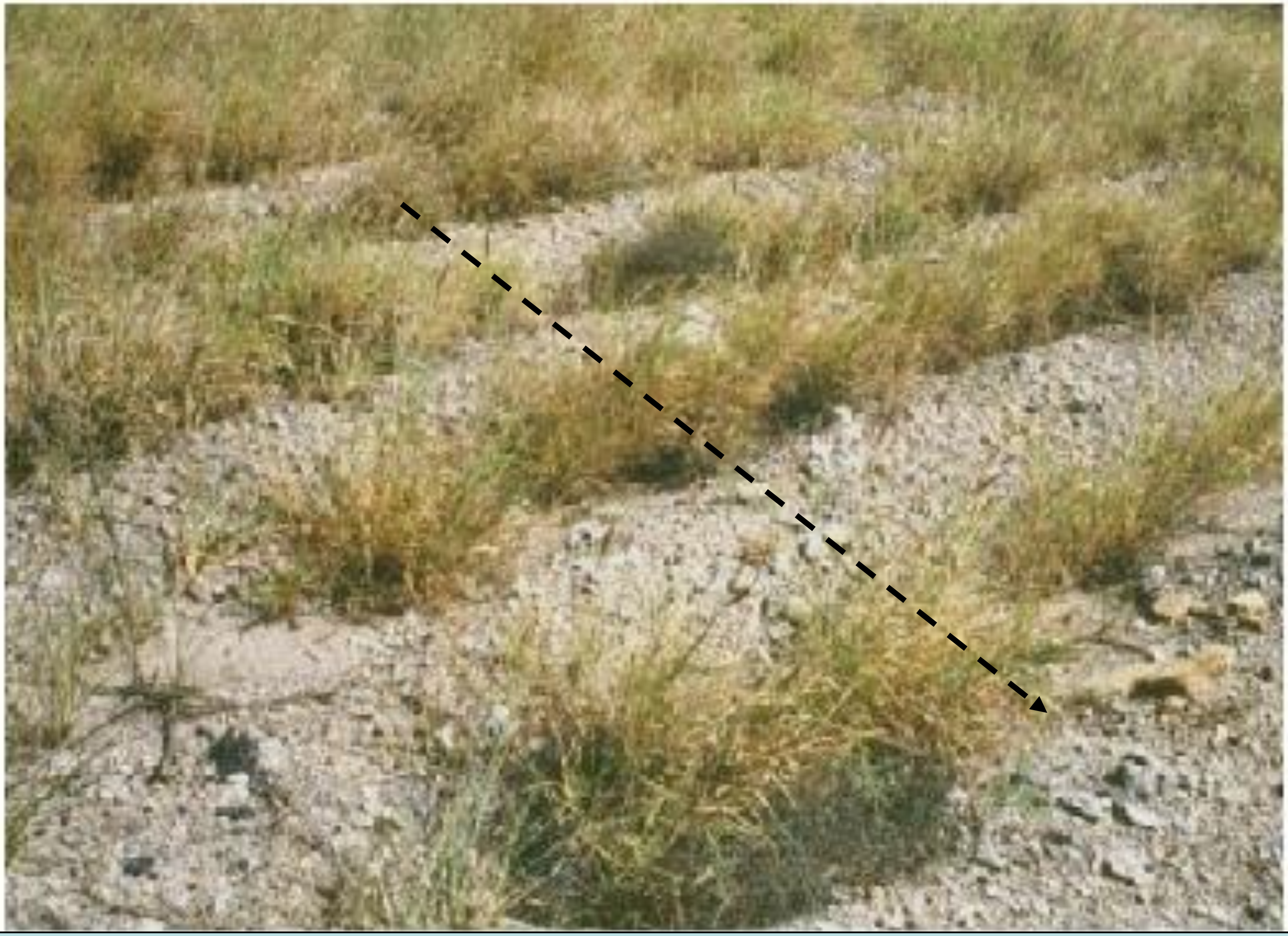
“Engineered” landforms



Many mines use **contour ripping** to eliminate compaction, but this also form banks and troughs: which are effective patch/inter-patch systems at fine scale, when well implemented.



Engineered patchiness: often important on mines



A competently ripped mine slope with grassy vegetation well established in "trough" patch locations. This shows landscape has well-retained engineered structures and now in the process of adding biological "control".

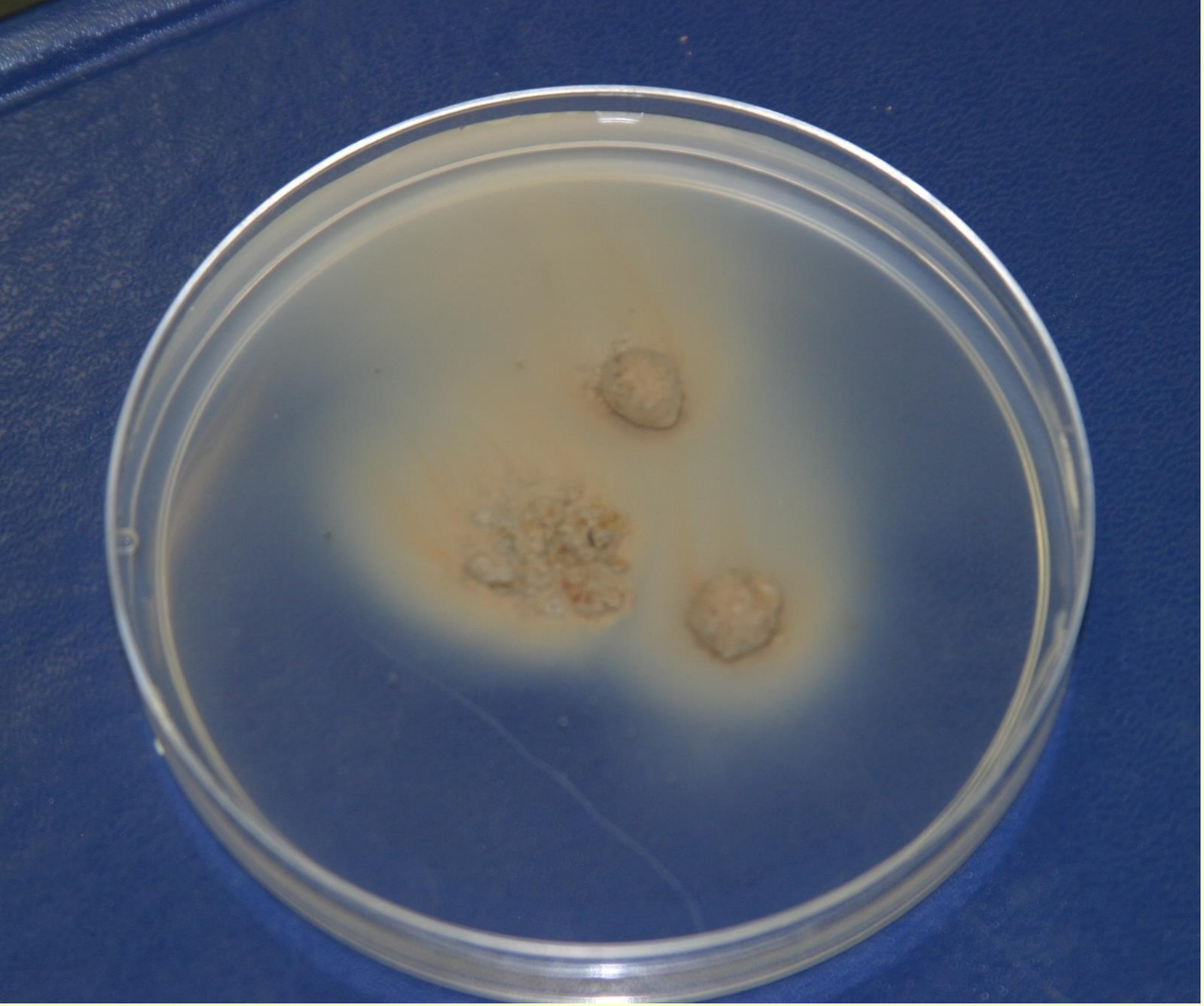
However, when a slope has been inadequately prepared (not planar), and the rip lines are not on the contour, ripping has facilitated lateral water flow which has initiated gully formation within months of land forming. The soil used tested moderately non-cohesive.

In addition, the stone cover is inadequate to prevent soil crusting and thus increases runoff speed.

Stage 2, 3. A mixture of “waste” materials: what adverse and beneficial properties do each of these spoil types have? Can long-term dis-benefits be avoided by early, accurate characterisation and handling?

Early stage monitoring: Spoil aggregation in the rhizosphere produced by a well-selected initial species in initially unstable spoil. The soil aggregates are stabilised by root exudates. This early monitoring evidence confirms that plants have commenced providing “goods and services” to the ecosystem.

LFA provides simple, unequivocal tests: Soil or spoil with this degree of self-coherence when rapidly wetted would make a good seed-bed and topsoil



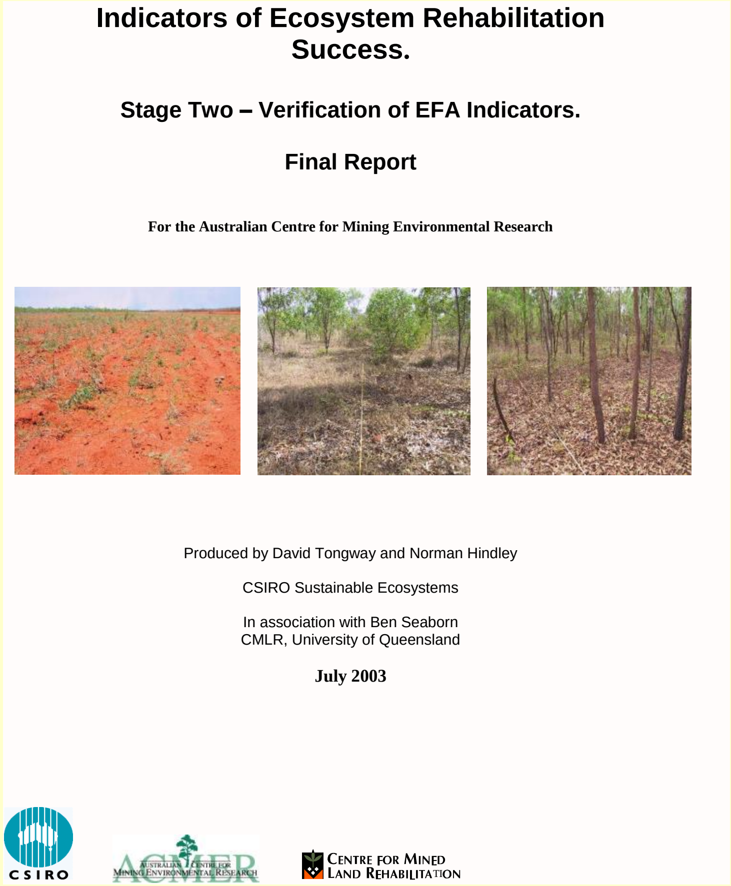
Preliminary testing of spoil with this degree of dispersivity could have prevented the outcome in the next image…

Tunnel and gully erosion formed not long after land-form construction after using overtly dispersive (sodic) materials

A verification study was undertaken on 9 mines around Australia and Indonesia in 2000-2002

Mine	Stability	Infiltration	Soil Respiration.	Nutrient Pool Size
Brocks Creek (Gold)	nv	nv	√√√	nv
Carnilya Hill (Nickel)	√√√	√√	√√√	√√√
Eneabba (Min. sands)	np	√√	√√√	√√√
Gove (Bauxite)	√√√	√√	√√√	√√√
The Granites (Gold)	√√	nv	√√√	√√√
Gregory (Coal)	√√√	nv	√√√	√√
Kelian (Gold)	√√	√√√	nv	√√√
Nabarlek (Uranium)	√√	nv	nv	nv
New Celebration (Gold)	np	√√	√√	√

Whenever reliable soil measurements were made on mines, the LFA indicators were verified


Indicators of Ecosystem Rehabilitation Success.

Stage Two – Verification of EFA Indicators.

Final Report

For the Australian Centre for Mining Environmental Research

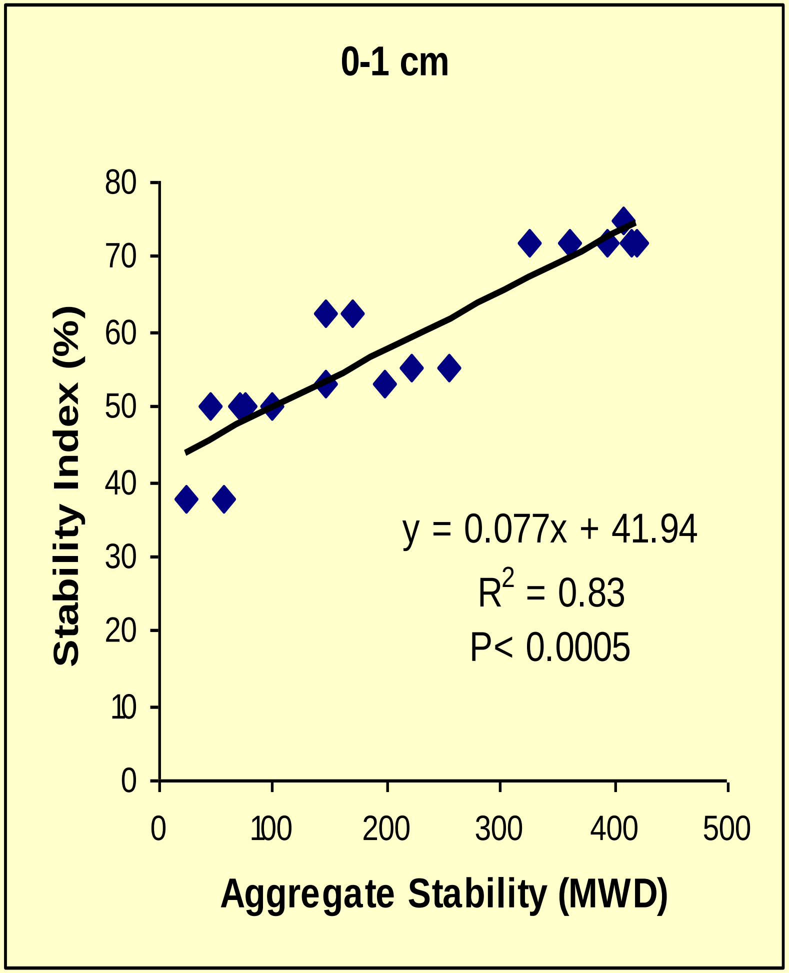
Produced by David Tongway and Norman Hindley

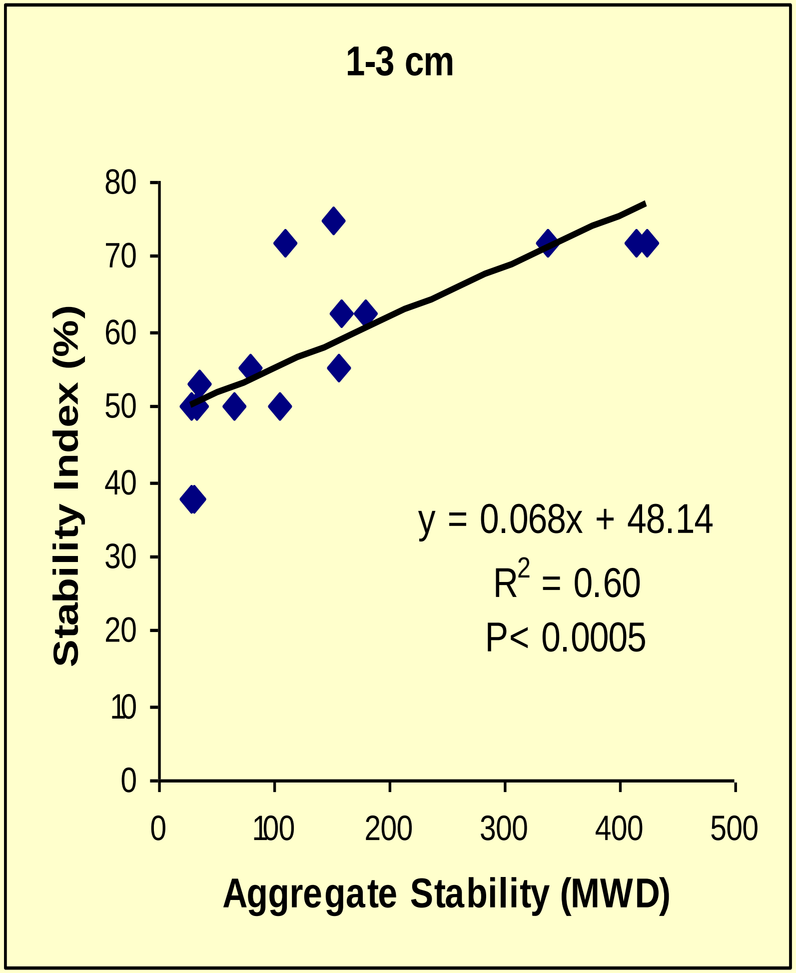
CSIRO Sustainable Ecosystems

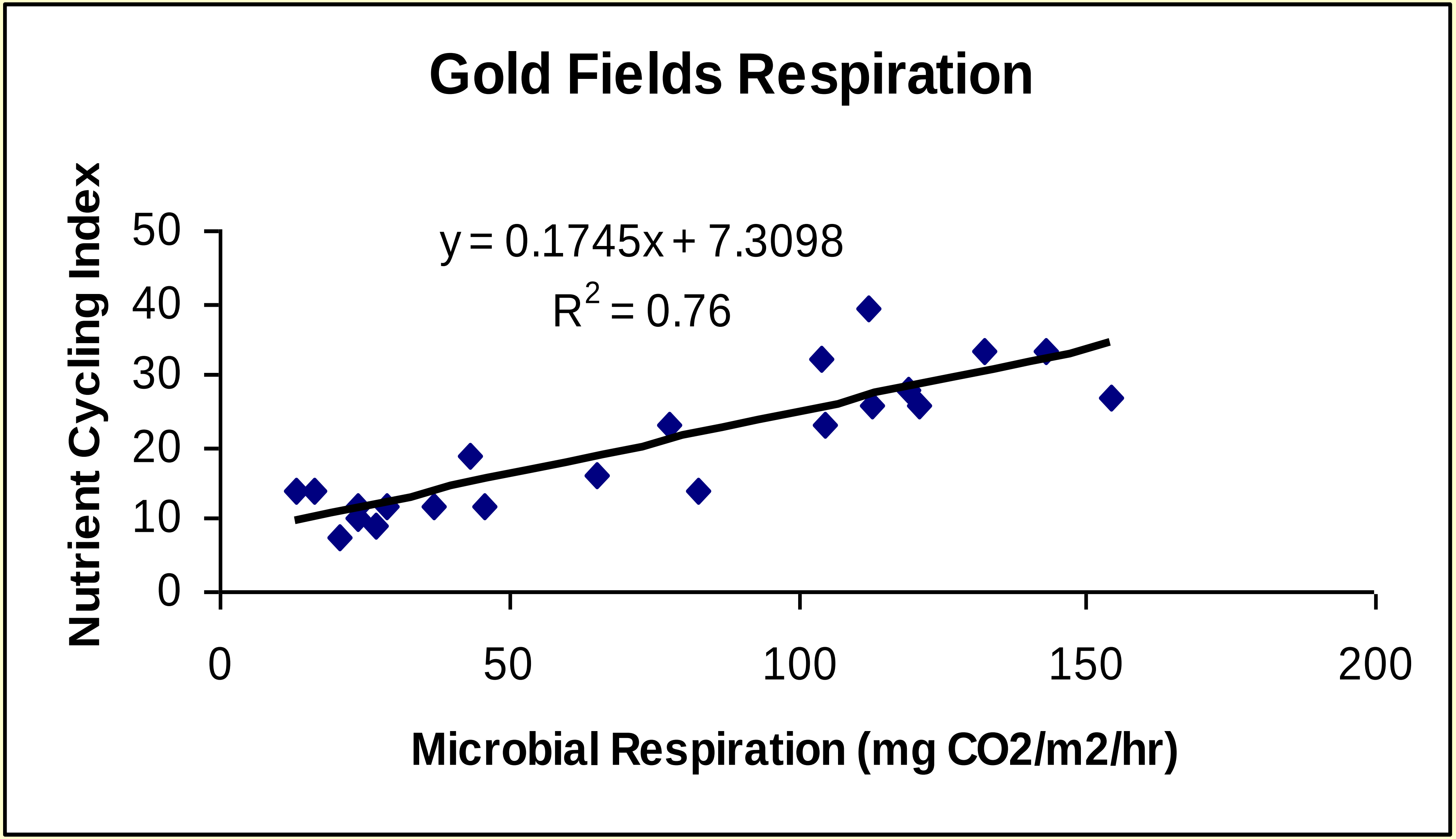
In association with Ben Seaborn
CMLR, University of Queensland

July 2003

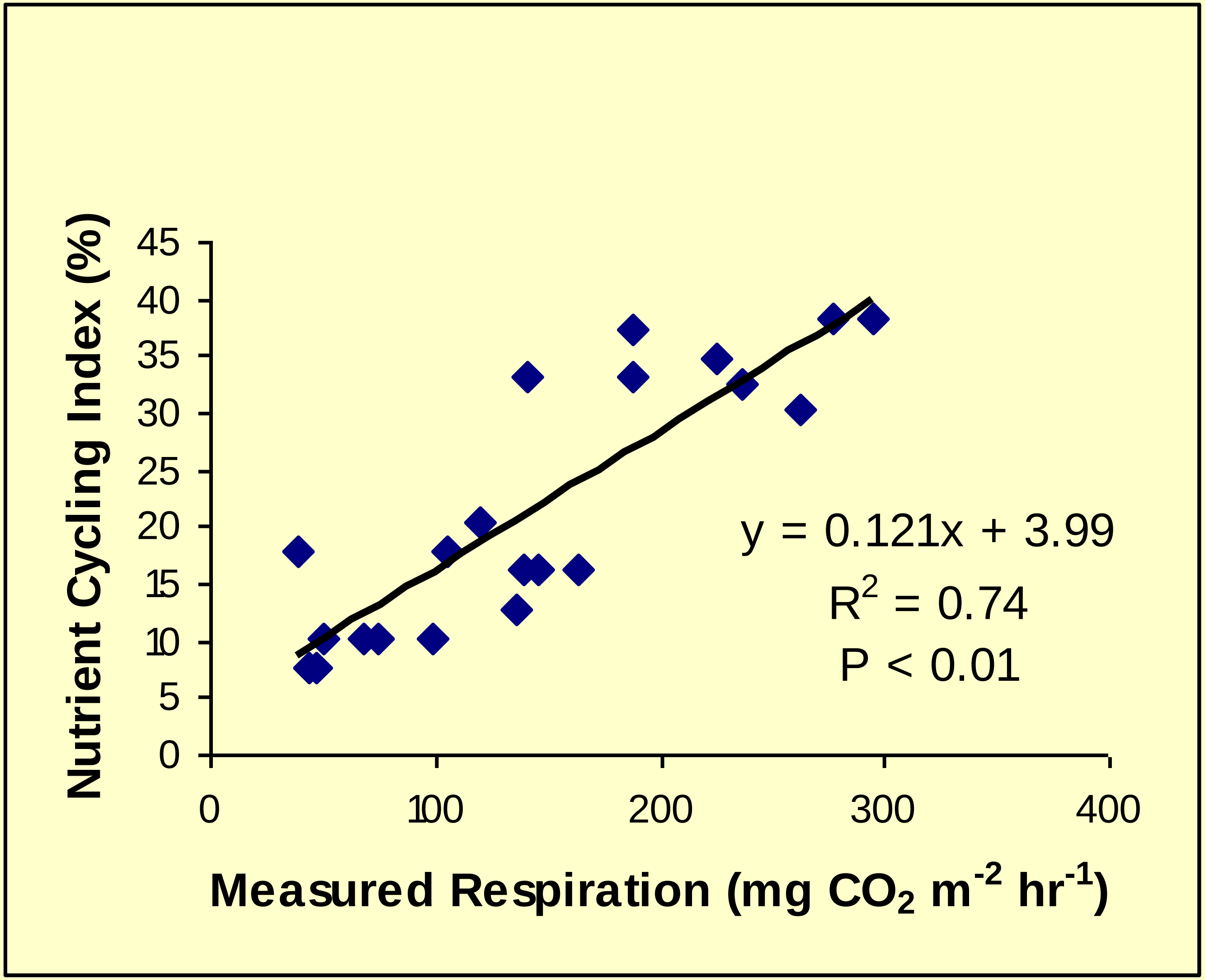
Stability Index, Carnilya Hill.






Gold Fields Respiration
y = 0.1745x + 7.3098
R2 = 0.76
Nutrient Cycling Index
0
10
20
30
40
50
0
50
100
150
200
Microbial Respiration (mg CO2/m2/hr)

Nutrient cycling index assessed as soil respiration rate – arid shrubby *grassland*



Land managers need to make prompt use of monitoring information: LFA's integral **interpretational framework**, facilitates:

- **Trend analysis**
- **Identification of threshold values**

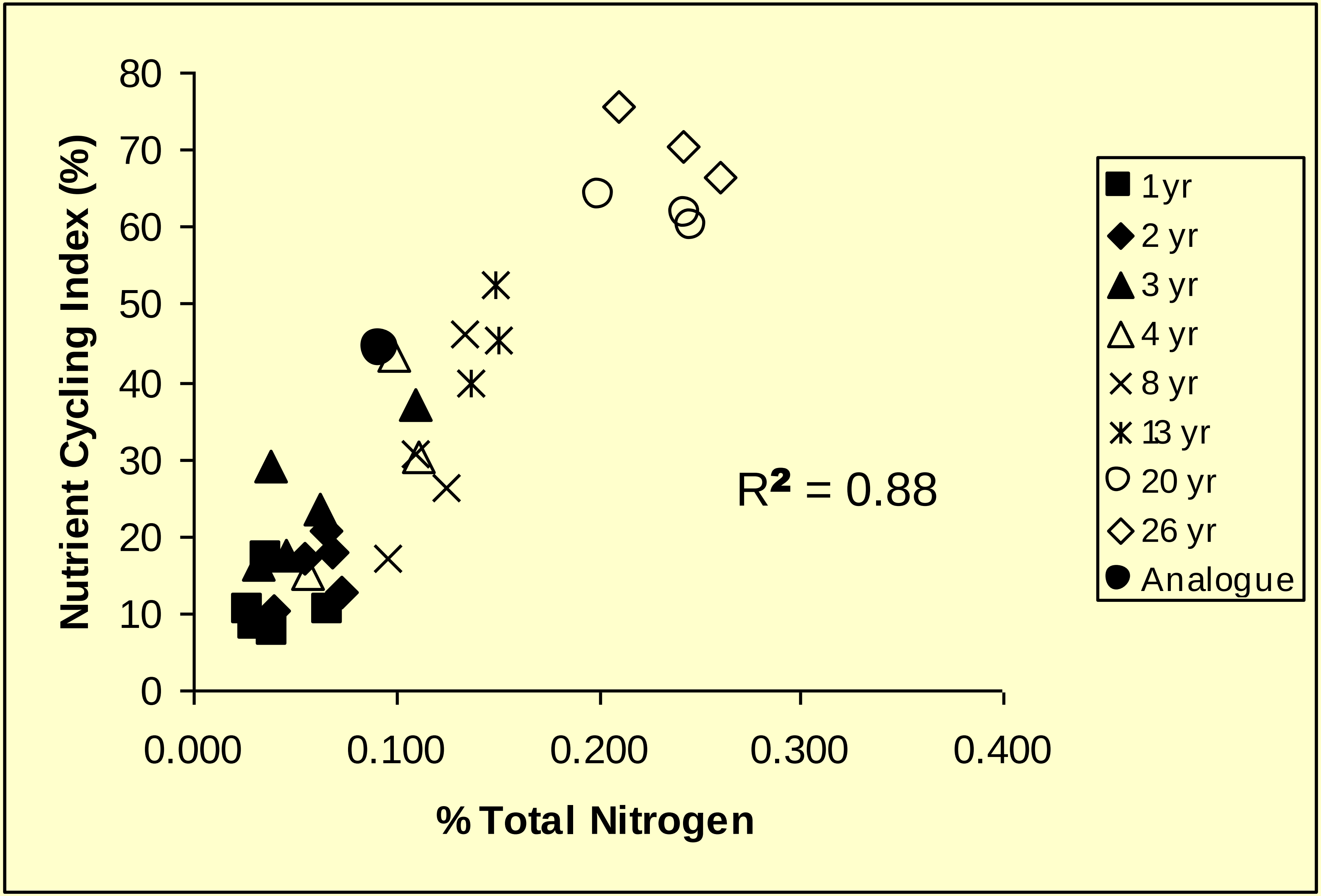
1. Thresholds of potential concern (sensu Du Toit et al)
2. Critical (major dysfunction)

This information is made available immediately, using the spreadsheet template

Time sequence from a bauxite mine: 1-Year old rehab.

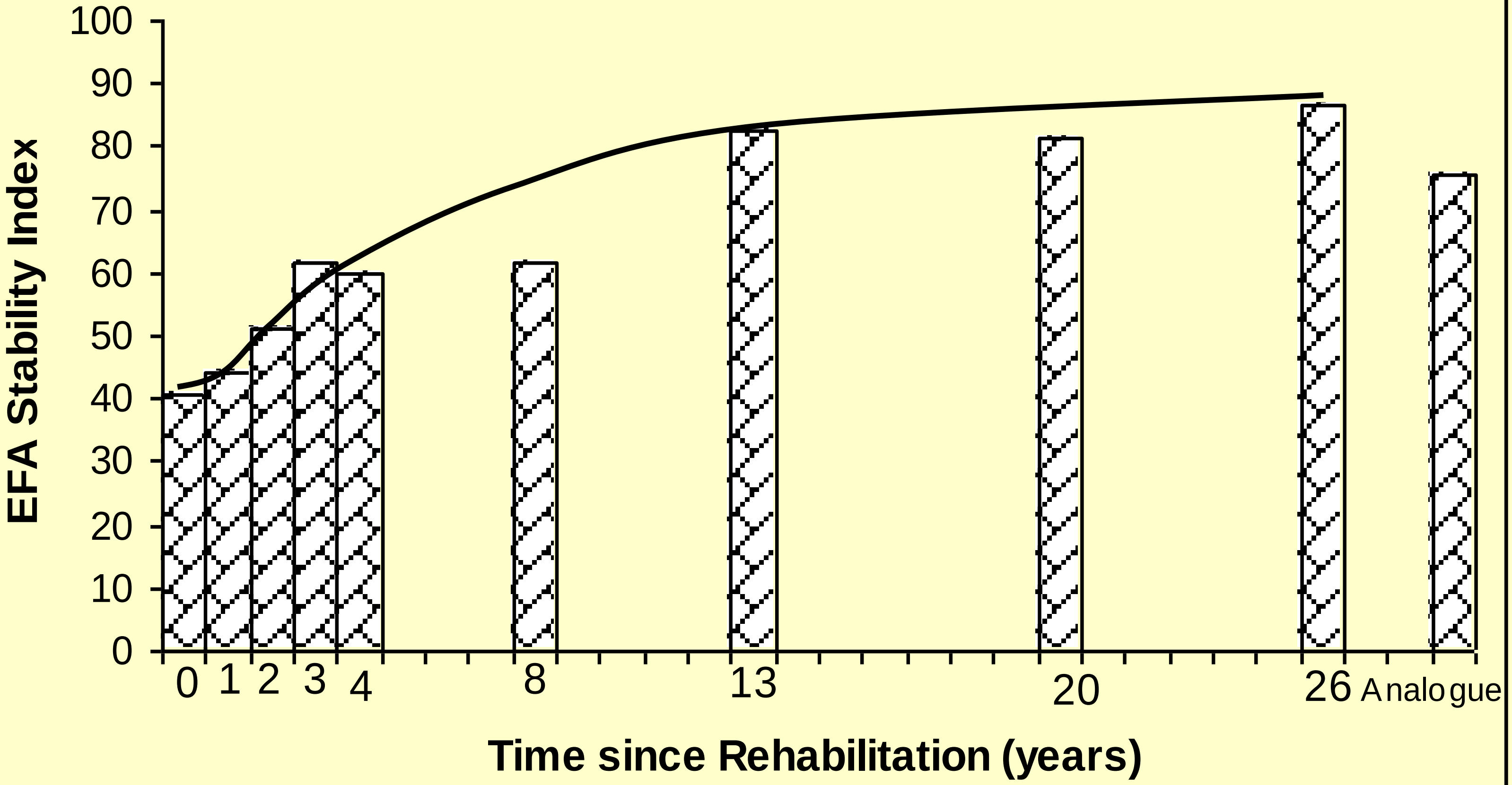
4 years old

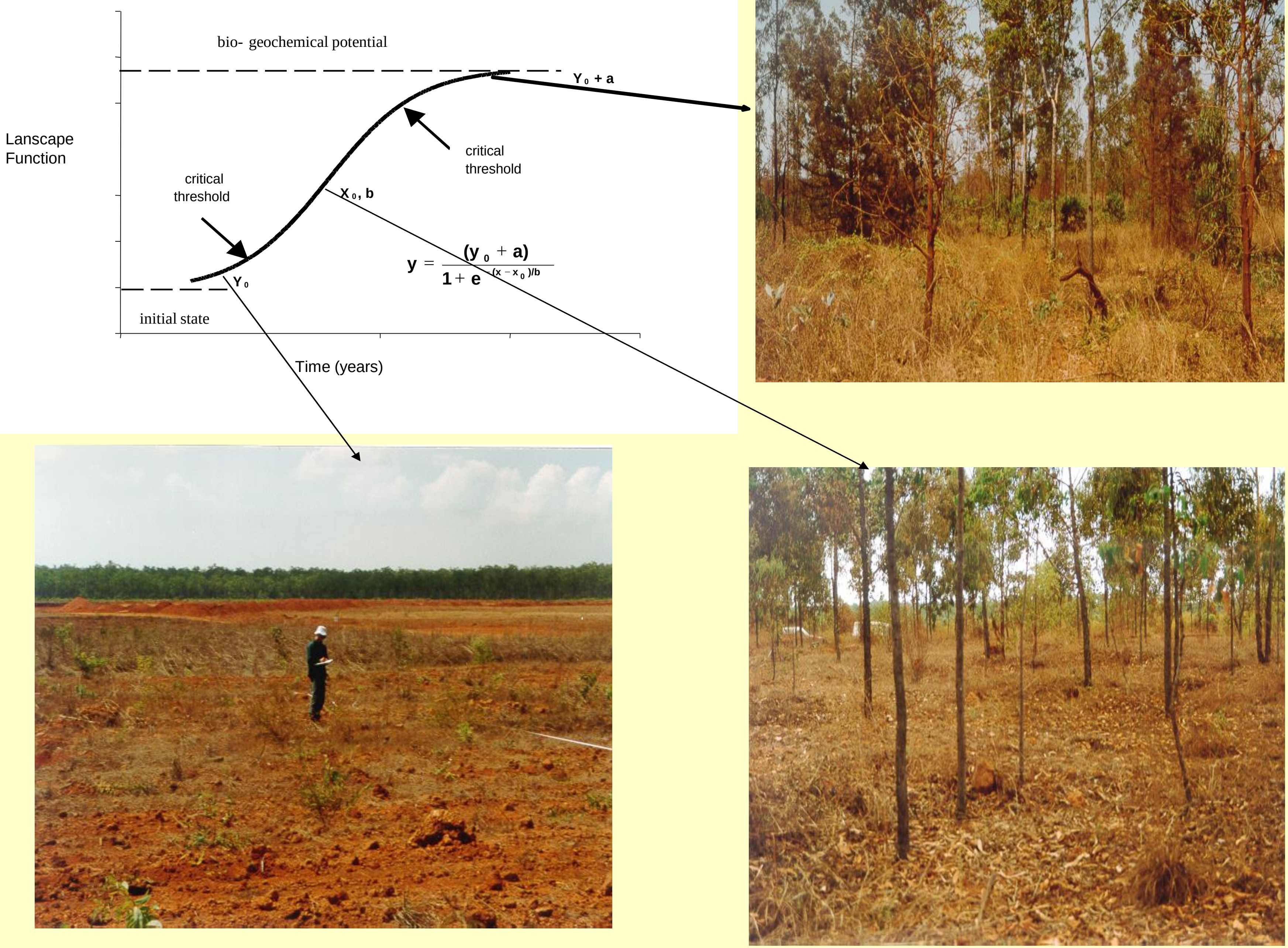
20 years old

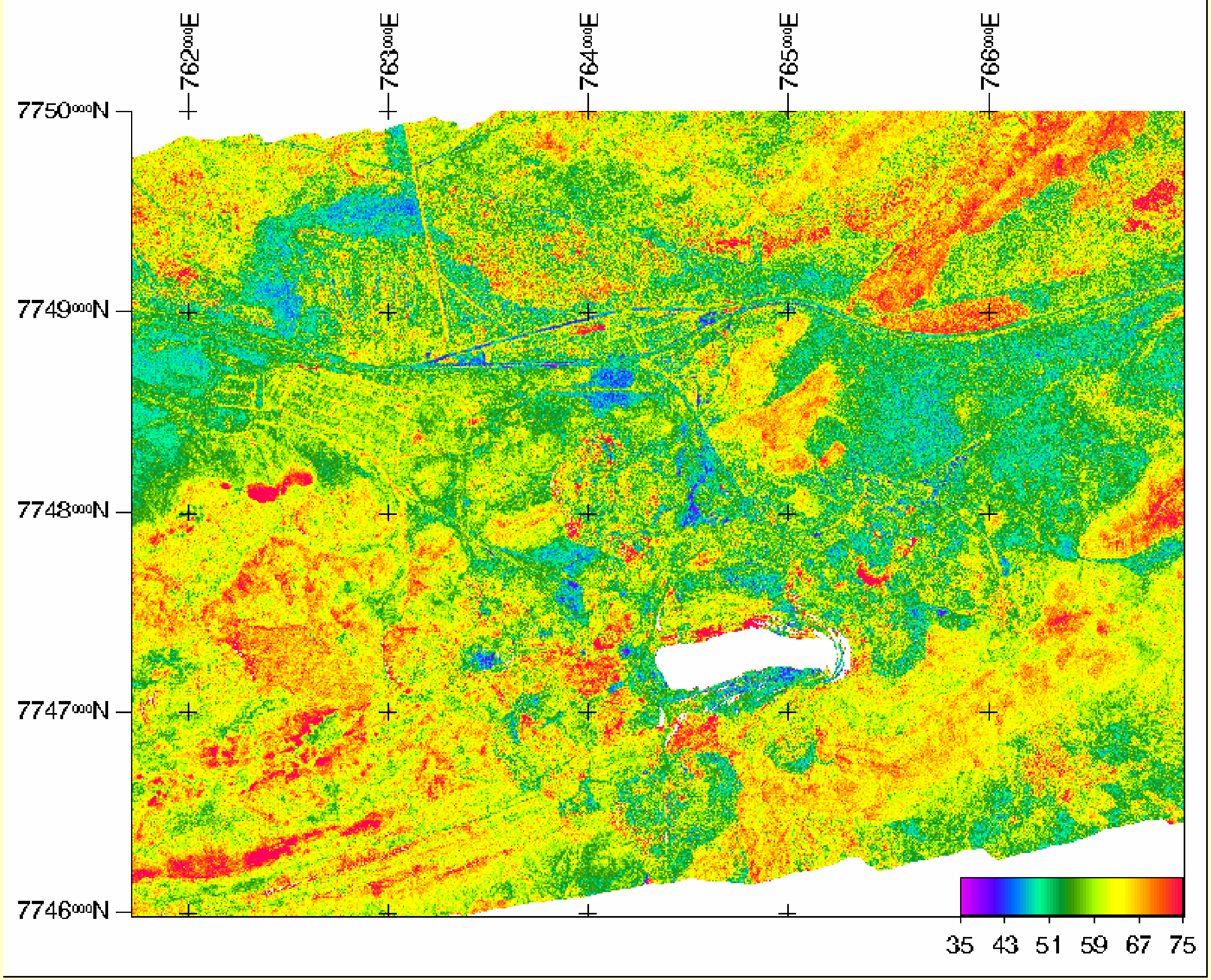


The nutrient cycling index verified by soil Nitrogen conc. increase over time.

Standard LFA interpretation process



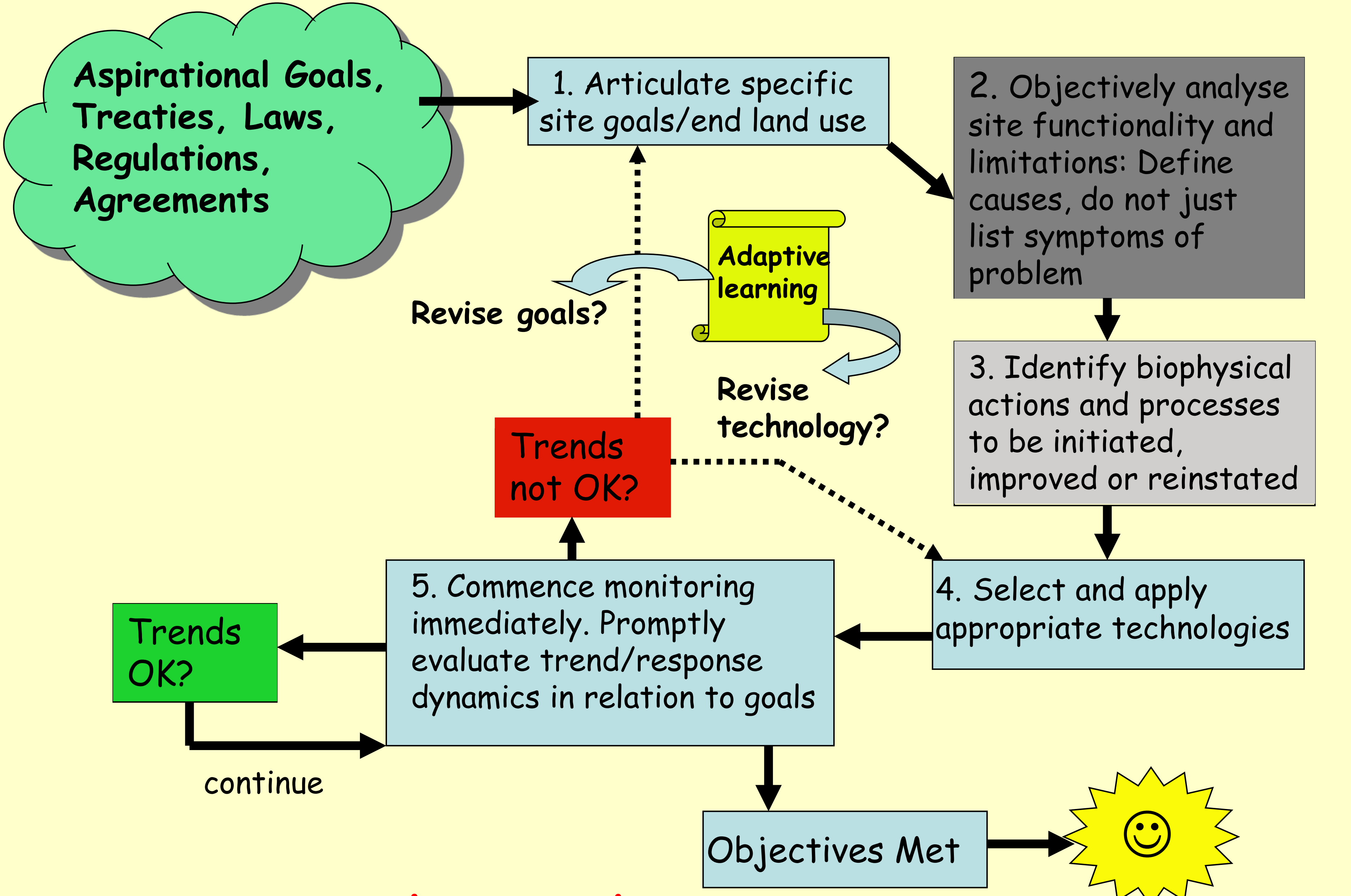

bio- geochemical potential
$Y_0 + a$
Lanscape
Function
critical
threshold
critical
threshold
X_0, b
$y = \frac{(y_0 + a)}{1 + e^{(x - x_0)/b}}$
Y_0
initial state
Time (years)



Spatial distribution of the LFA stability index by calibrated hyperspectral remote sensing

- In 2008, Lacy, Biggs and File reported that about $M5.5 had been returned to Mining Cos for reaching a significant milestone – a stable, non-eroding, non-polluting landform.

- These sites were judged to have conformed to the following sequence of assessments, planning, execution and monitoring



A stepwise rational approach to monitoring restoration. LFA used in steps 2 and 5.

Orderly Process Summary

- It is crucial to define long term objectives, in **measureable terms** at an early stage.

- Adopt a "round-table" involvement of all stakeholders, including Regulators and the community, rather than an adversarial or "stand-off" approach, because successful closure is in everyone's long-term interests. Design the mine monitoring process documentation: transparent, coherent, integrated.

- Plan a logical sequence of steps in **acquiring and evaluating** information about threats and opportunities.

-

- Engage with the emergent science of **landscape ecology** from the earliest stage, thus actively providing a coherent stream of information to assist in the long term goal of mine closure ("cradle to grave"). No one discipline can provide all the necessary information.

- Use appropriate monitoring tools that have **prompt**, **feedback to management**, expressed in appropriate terms, to provide "the right information at the right time" and to begin to synthesize the case for eventual closure from an emerging body of information.

- Expect and embrace **adaptive learning** as an active process as monitoring inputs provide justification for remedial action

Summary of LFA Principles for Mine Closure

- The assessment of landscape function is an appropriate tool by which to assess whether closure criteria are trending in the right direction or have been met on minesites and surrounding landscapes.
- The LFA procedure is derived from established principles in landscape ecology
- LFA indicators can be used from Day 1 to identify favourable and unfavourable soil materials and identify the effect of threatening processes on constructed landforms
- LFA output can assist in correcting poorly performing rehabilitation by the timely identification of deficient ecological processes.

•LFA uses indicators, as suggested by ANZMEC, rather than complex, expensive and specialised measurements, which are mostly never integrated.

•Prompt information feedback to management or regulators.

•LFA has been implemented in climatic ranges from 50 mm to 10,000 mm rainfall and in a number of other land-use scenarios.