Rangelands NRM
Western Australia

Australian Government
Department of Agriculture, Fisheries and Forestry

Rangeland Rehydration

Re-covering the Red using local knowledge

E.M.U. Ecosystem Management Understanding

1

Field Guide

by

Ken Tinley & Hugh Pringle

a.

b.

Frontispiece: Seasonal Wetlands – the essential habitat.

Aerial views of the 12km long Wanna Swamp, a tributary of the Lyndon branch of the Gascoyne River.

(a) View down the length of the swamp with Mt Augustus on the horizon. The swamp plant cover includes: northern bluebush, and perennial grasses - claypan, neverfail, Roebourne, swamp and possibly some Mitchell grasses. Coolibah trees occur as sparsely scattered to clumped groves (Bibbingunna landsystem).

(b) The swamp's ponding sill is identified by a green rim of grass cover, the overflows are towards the foreground creek. Note the sill is under threat of breaching by headward erosion from the bare soil area adjoining the creek. Foreground, and at left, bare eroded sheetwash plain covered in a gibber surface.

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Ken Tinley - ken.tinley@optusnet.com.au

Hugh Pringle - hpringle1@bigpond.com

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Dedication

To the pastoralists we worked with in the southern rangelands who showed a willingness and openness to try something new and to share their knowledge of their land with us.

Contents

Preface 8

Acknowledgements 9

Introduction 10

Erosion – the insidious process: 10

The Pastoralist's View: 11

A Short Answer: 11

[A] Managing Rangelands: The Ecological Imperatives 20

(1) Arid and Semi-Arid Zone 20

(2) Moist Zone 22

(3) Present Rangeland Conditions 23

(4) Being Mindful of the Signs of the Land 28

(5) Human induced changes 29

(a) Altered fire regimes 29

(b) Impacts of infrastructure 30

(6) Grazing features frequently overlooked 31

[B] The EMU Approach 35

(1) Introduction 35

(2) The Drainage Unit Context 36

(3) The Indispensable Air Perspective 36

(4) Salient Factor Analysis 36

[C] Landscape Diagnosis and Baseline Record 38

Combination of six exercises:

(i) Pastoralist's baseline mapping exercise, (ii) Station air traverse, (iii) Ground traverse of key areas, (iv) Map recording of findings, (v) Fixed-point photo record, (vi) Truthing follow-ups

Contents

[D] Landscape Repair: Rehydration Methods 43

Erosion Control Methods 43

The Erosion Repair Tool Box (Table 2) 43

(1) Sieve Structures 43

(a) Live Plant Filters 43

(b) Scrub/Brushwood Filters (loppings) 48

(c) Mesh/Netting 48

(d) Sheet Materials 49

(e) Rakes 49

(f) Gabions 49

(2) Gully Stabilisation 65

(3) Banks/Bunds (embankments) 65

(4) Solid Structures 75

(a) Drop Structures 75

(b) Stone or Earth Sills 75

(c) Weirs 75

(d) Sand dams 75

(e) Rock Bars 76

(5) Road 'Rivers' and Road Barriers 80

(6) Mechanical/Electronic Aids 80

Summary of Erosion Control Methods 83

(a) In-channel structures 83

(b) Managing water out on the plain 83

(c) Enhancing existing overbank flood outlets 83

REFERENCES & FURTHER READING 84

APPENDICES 88

Appendix 1: Definitions and Explanations 88

Appendix 2: Plant Names 91

Appendix 3: EMU Monitoring Tickbox 92

Preface

The Australian rangelands make up 80% of the continent. Scattered over their vast resource poor areas are run-on habitats and pastures, occurring at all scales and in all terrain components. These include major river floodplains, flood-outs, grassy and wooded pans, and local moist fertile pockets patterned to drainage or as mosaics of local depressions and fertile patches. It is to these strips and islands of fertile habitats that many of the native Australian animals were associated (Davies 1973; Morton 1990; Morton et al. 1995). A survey of the conservation status of the bird fauna of arid Australia, for example, identified that the greatest decline of birds was related to the run-on and chenopod habitats (Reid & Fleming 1992). These are the two habitats that have been the focus of continuous stock grazing since the inception of pastoralism in the mid 1800s (e.g. Mabbutt et al. 1963; Speck et al. 1964; Wilcox & McKinnon 1972; Stafford Smith et al. 2000).

In present times the critical rangeland feature is the ongoing loss, literally the stripping out, of the essential run-on habitats. This has profound implications for biodiversity conservation and for the carrying capacity of livestock. Run-on habitats at all scales, however, are the most susceptible to change and extinction from natural geomorphic processes without humans and stock being involved. What the two in combination have done, and still do, is to greatly accelerate and spread erosion and desiccation.

"The potential productivity of the arid zone was rapidly reduced by the loss of the fertile patches, topsoil and perennial plants'…hence…'restoration of damaged shrublands will not succeed unless fertile patches are recreated" (Friedel et al. 1990; Pickard 1993). These "..favoured areas were 'indicator landscapes' requiring particular attention to maintain their productivity. If they were in good order, less preferred areas would be too" (Friedel et al. 1990). The "achievement of ecologically sustainable land management relies intimately on maintenance of ecological function in resource-rich areas" (Morton et al. 1995).

This field guide is focused on helping restore the 'indicator landscapes' or 'best country' as part of a whole station ecological management approach that can benefit generational continuity of biodiversity conservation and rangeland enterprises "where the degree of success is high and the treatment cost-effective" (Ludwig et al. 1990). Here we provide a guide for ecological management of rangelands, based on drainage, with some tools to repair them. We also strongly support local initiative and creativity in building unique, best-fit solutions.

KT & HP

For scientific names of plants refer Appendix 2 p. 99.

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The unflinching and vital support of both EMU and ESRM from Greg Brennan, Department of Agriculture and Food Western Australia (DAFWA) and his tenacity in not giving up until our work had been collated and made available for more widespread use.

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Introduction

Erosion – the insidious process:

Over the millennia erosion and deposition are the natural geomorphic processes shaping the landscape. Since the advent of nomadic pastoralism to the present day of fenced grazing, human and stock impacts have increasingly accelerated the rate and expansion of erosion. This has caused far reaching and cascading changes in soils, plant cover, fauna, and the demise of wetlands and floodplain grasslands.

From the ground or vehicle the view of heavily grazed land involves a trick of foreshortened perspective, making remnant strips and patches of plant cover appear denser or in better condition than they really are. Even gullied areas don't look as threatening when viewed from ground level as their dimensions and extent are mostly out of sight. Seen from the ground it is thus easy to believe that 'all that the country needs is some rain and she'll be right'! Only the aerial view exposes the dimensions, linkages and extent of erosion - and this is of first importance in order to identify any potential threats to the best stock country (see **Figure 7b**).

Widespread and continuous depletion of soil moisture by erosion is the most underestimated fact across rangelands worldwide **(Figures 4, 5)**. It is the ultimate cause of pasture degradation and the hobbling of grazing enterprises. As the erosion process is initially subtle and insidious in terrain of low relief where the slightest drainage gutter, such as a cattle pad masked by grass, can initiate and entrain the unplugging of soil moisture, it is easily overlooked.

At all scales in landscape ecology the key process initiating change is the development of drainage incisions. These migrate upslope and laterally, led by erosion nickpoints (headcuts) that 'pull the plug' out of a system, and alter the soil moisture balance towards aridity **(Cover photo** and **Figure 8)**.

The presence of incision headcuts therefore are predictors of potential change in perennial pastures towards woody-weed scrub dominance or the development of badlands and scalding. These are expanded by surface flows and soil moisture being drawn increasingly towards the growing incision from ever further away **(Figures 7, 8)**. Although rainfall is the critical factor in drylands, the quantity of rain that falls is only of indirect or partial importance to plants. The amount of available soil moisture is of far greater importance. This is directly related to three coactive natural influences (a) slope/runoff, (b) soil profile (particularly topsoil porosity) and (c) density of perennial ground cover, particularly of grasses and chenopods.

As bottomland pastures are the foundational support for grazing stock, the indispensable management requirement for these pasture lands is their rehydration by rainwater harvesting and spreading through the application of simple interventions at key points **(Figure 18)**. Of all landscape processes this is one where a "stitch in time saves nine"! However, because of the interactive linkages in ecology this alone will not change the health of the rangelands without also managing the total grazing pressure.

In the final count stemming the loss of top soils and haemorrhaging of soil moisture together with herbivore grazing management is the crux to successful, sustainable pastoralism and maintenance of biodiversity.

"dry well
the dropped stone's thud"
(Lee Giesecke)

The Pastoralist's View:

"Why bother? We don't know in what way changes in climate will play out. Maybe rainfall will increase in our area, then the land will be rehydrated anyway and any blocking and diverting of drainage will only make flood damage worse. So I think let things be and the people on the land will just have to adapt."

"We as pastoralists are dealing with very large stations in vast landscapes, and are already overburdened with the management of running a stock enterprise. With few hands we have to deal with the responses to the extremes of flood, drought or fire, and the idiosyncratic swings of markets – while supporting a family and their needs. Truthfully we just don't have the time – we are stuck in our maintenance rounds. We do not own the land, it is leasehold and with disabling government policies such as high rentals, decline of basic rural services, and political injustices such as the sandalwood trade and abruptly blocking the beef trade - it seems a big ask to expect pastoralists to take on more land management. What's more, we have tried controlling erosion and it doesn't work. That's why, at first glance, rehydration sounds idealistic and impractical – in short, for us, a waste of time, effort and money."

A Short Answer:

The rehydration process is to get rainwater to be absorbed into the soil and to remain longer. It can be defined as "improving perennial groundcover, particularly grasses, and sustainable livestock productivity by rehydrating the land through control of total grazing pressure and strategic interventions to slow water flow".

In this field guide the remedial rehydration process is explained. Essentially it involves rainwater harvesting and spreading, using simple earth bunds and sieve structures at the critical control points of drainage. These slow runoff and deflect flow around erosion gullyheads. Hence, whichever way climates may change, towards increased flooding or increased drought, rainfall will be more effectively absorbed into the soil where there is groundcover and the excess free to run off. Many erosion control efforts in the past were either located in the wrong place and/or were inadequate to the task.

It is worthwhile highlighting what the natural and changed features are that epitomize rangelands today, and review what we can do to apply creative 'best fit' ecological and economic solutions that support sustainable productivity and generational continuity in Outback living and management. The term ecology used here is directly related to people on the land learning to understand the relationships and interactions in their environment, and to manage creatively with landscape processes for the sustainable wellbeing of their country. We need to remember that the "future is not some place we are going to but one we are creating" (author unknown).

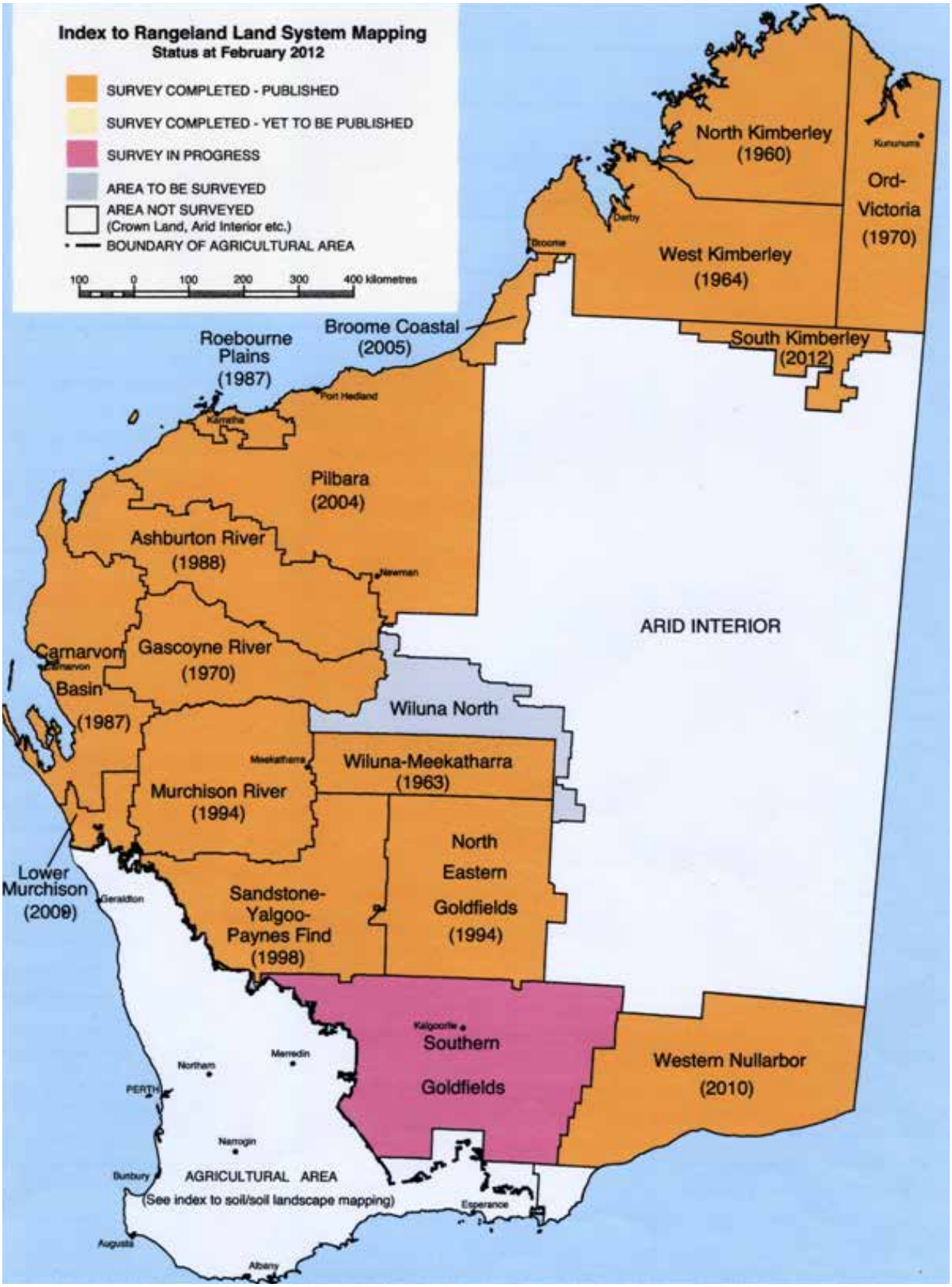


Figure 1: Rangelands of Western Australia.

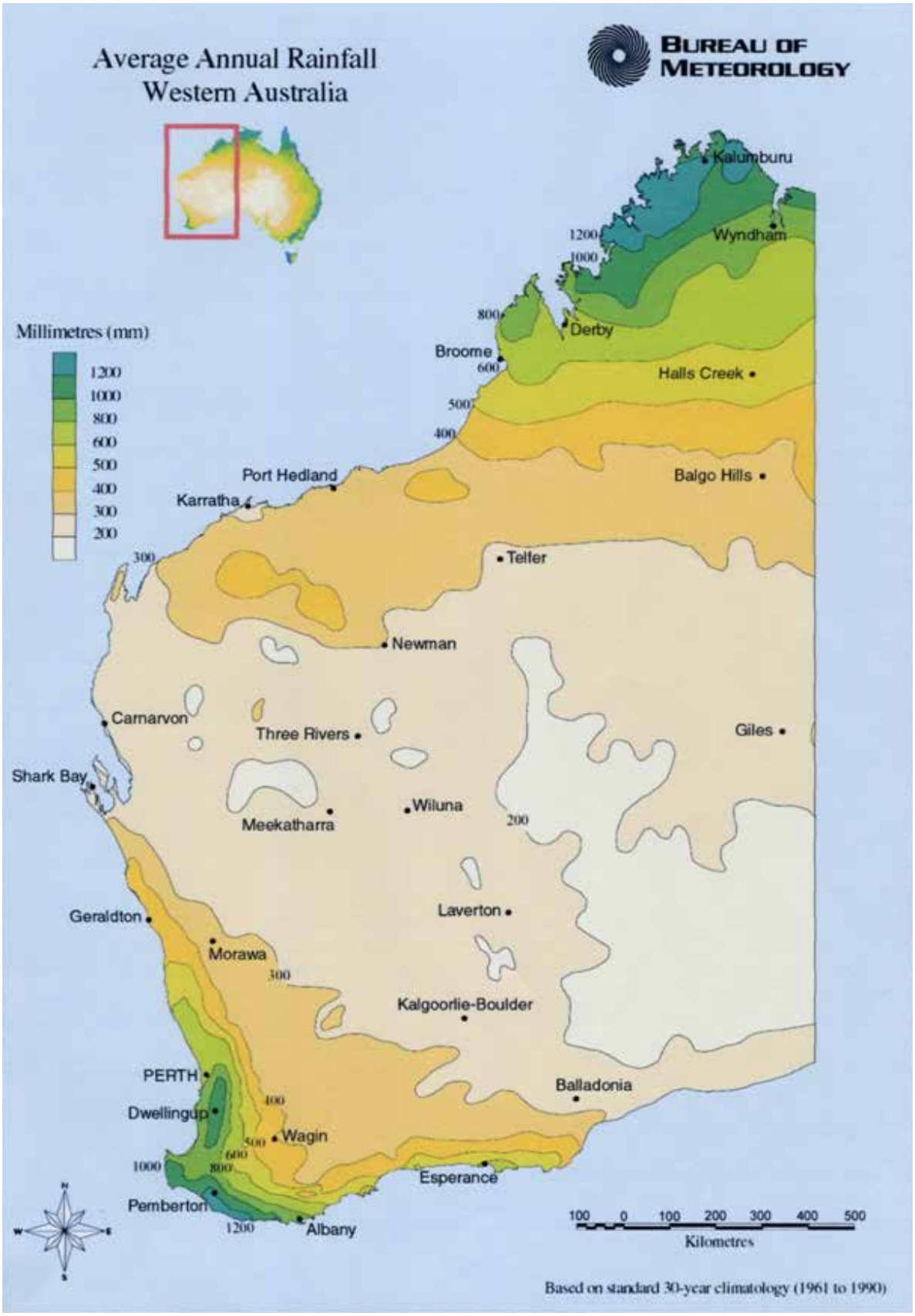


Figure 2: Average Annual Rainfall, Western Australia.

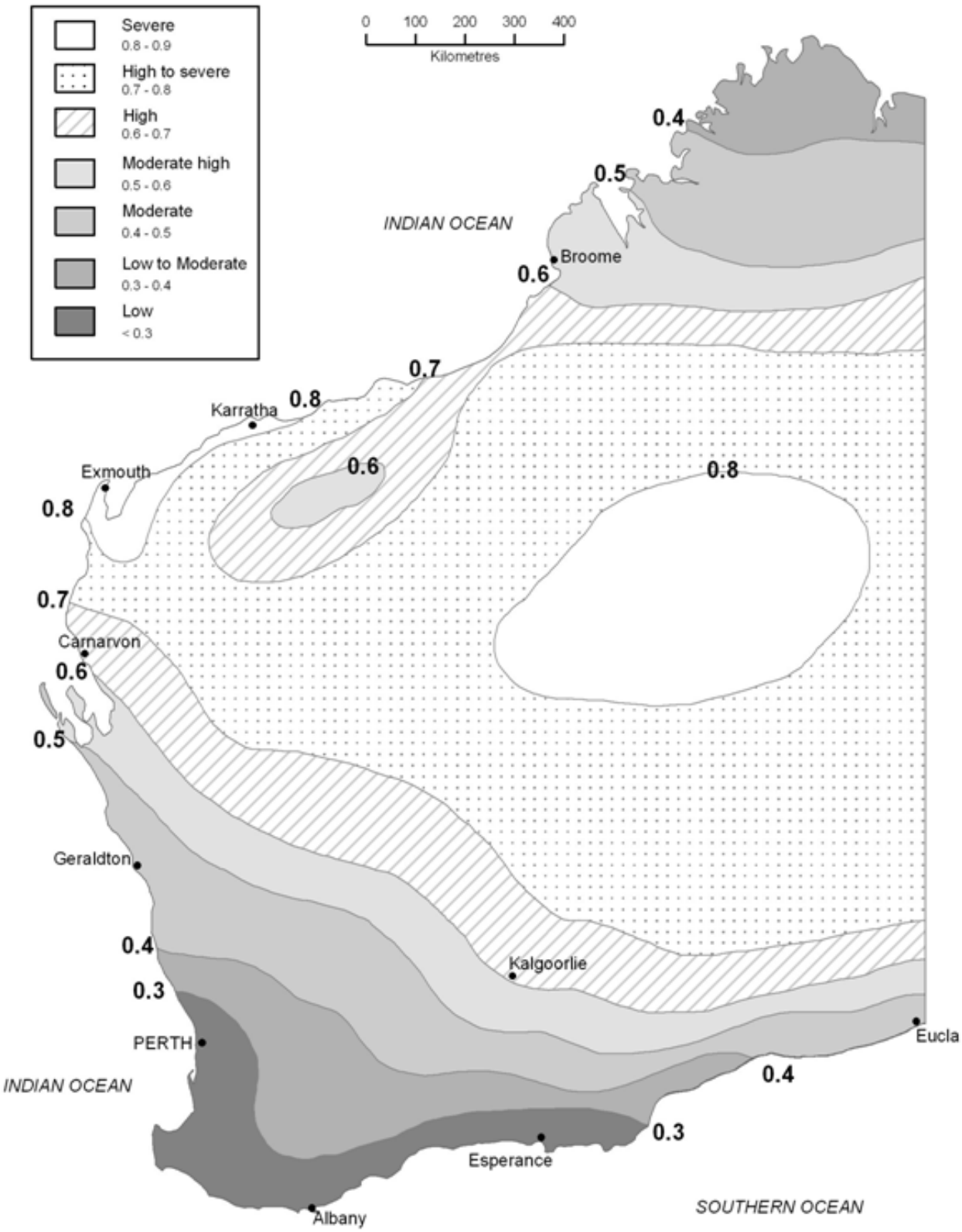


Figure 3: Drought Risk Index in Western Australia. (COLLS K & WHITAKER R, 1995.)

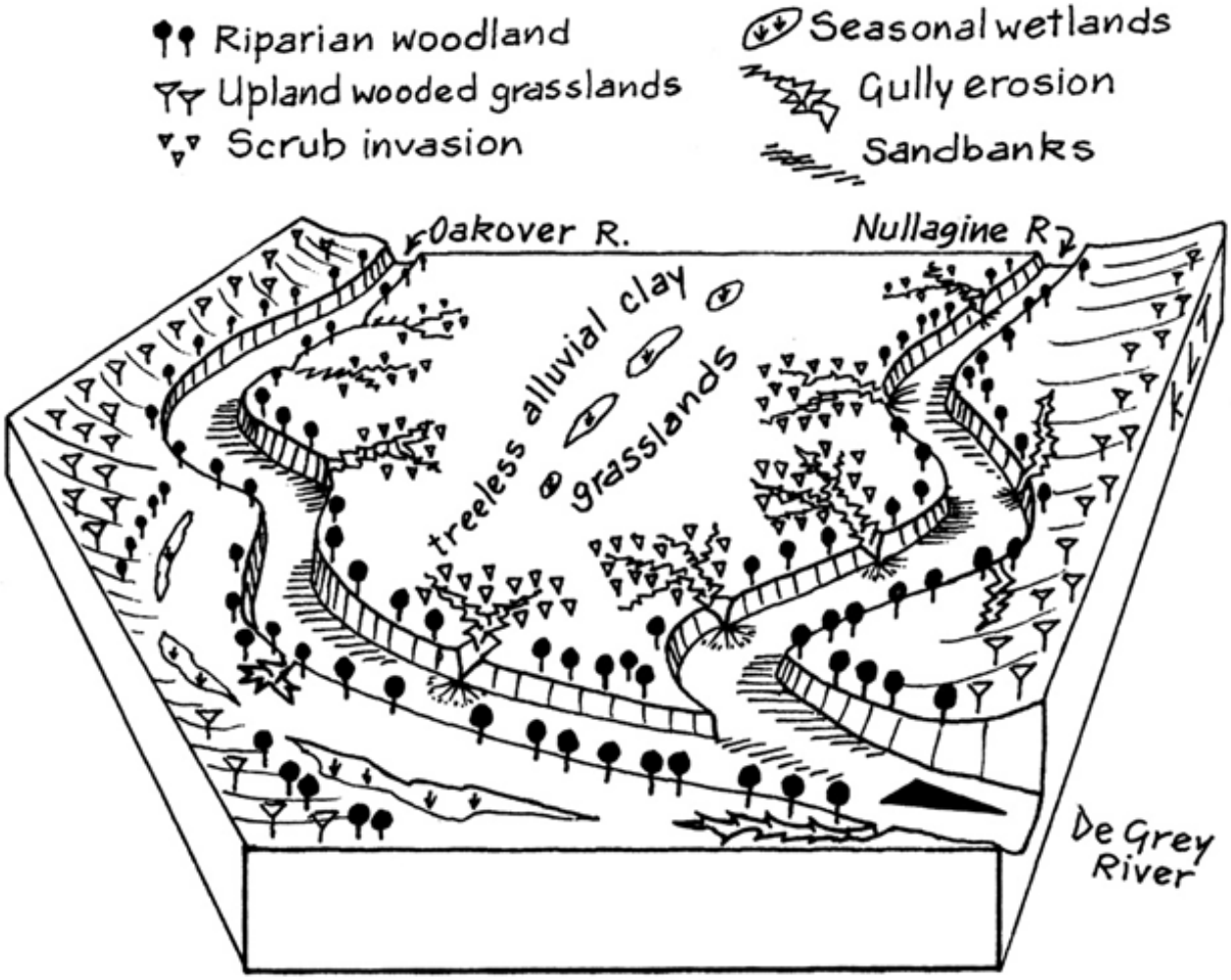


Figure 4: River down-cutting, perched floodplain.
Alluvial grass plain perched above deeply incised river channels. Overbank flooding only in exceptional rain events. Series of deep branching gully erosion cells cutting back from entry or exit points of flood waters or along stock/vehicle tracks. Scrub invasion is associated with the headward spread of each gully.

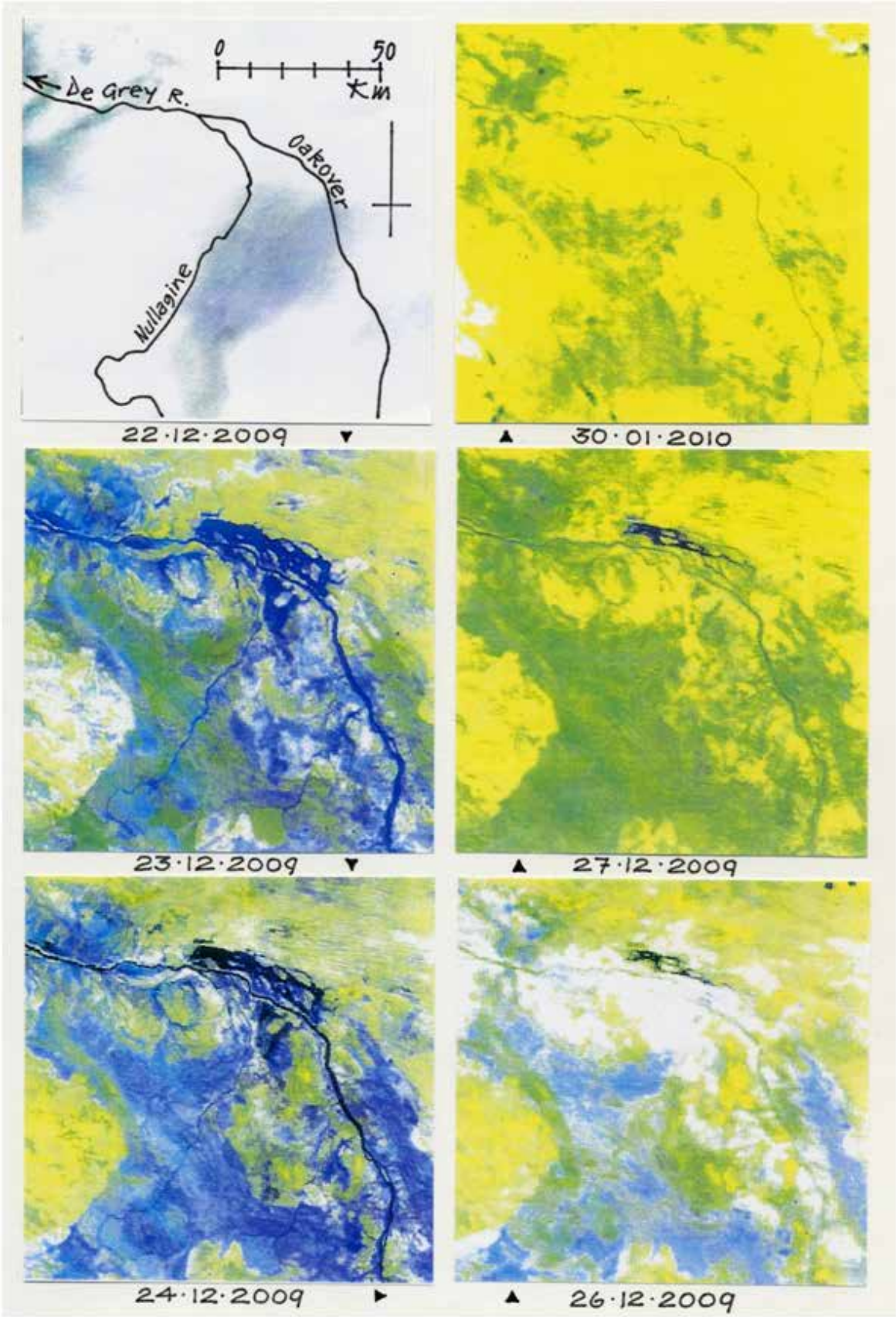


Figure 5: Satellite record of the passing of Cyclone Laurence across the Oakover-Nullagine confluence area (total rainfall dumped here 279mm), showing the extent of the flooding and the surprisingly rapid runoff and evaporation loss within 10 days. Note that floodwaters lay longest on the linear depression along the north side of the Oakover River. (Satellite imagery sequence per kind favour of Professor Mario Ferri, Satellite Remote Sensing Services, Landgate, Floreat, WA).

a.

b.

c.

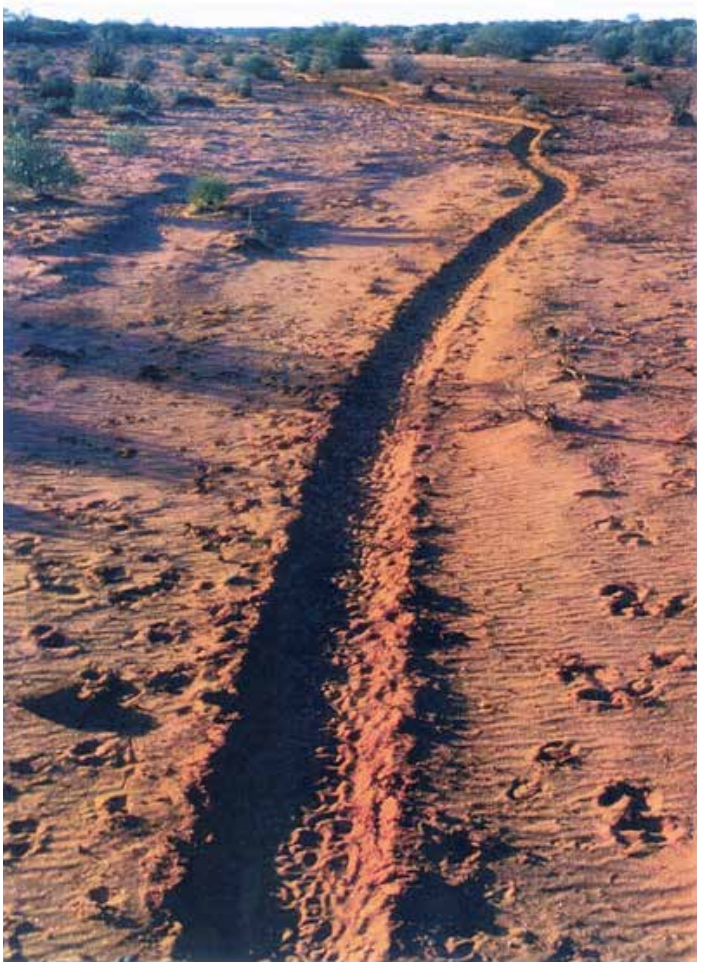
Figure 6: Floodplains, Scrub and Scalding. Examples all in the same area:
(a) Part of a Mitchell grass floodplain of clay soils in good condition, with woody plants confined to the creek levees,
(b) Floodplain with coolibah and dense wattle scrub invasion along an old track,
(c) Sheet eroded and salt scalded outer floodplain that used to support chenopod shrublands overgrazed by sheep in the early years.

a.

b.

Figure 7: Initial scrub invaders, the first signs that breached floodplain grassland soils are in an aridifying trend.
(a) Typical scrub invasion pattern of floodplains along the drier edges of tracks, fencelines and cattle pads (NE Kimberley).
(b) Top End (Keep River catchment) example of scrub invading unplugged floodplain Mitchell grasslands. Scrub first colonizing the drier micro-ridges between the gilgai micro-basins. Typical invaders of black soil plains here include: bauhenia, conkerberry, gutta-percha, rosewood and silver box.

a.



b.

Figure 8: Wetlands - a tenuous existence dependent on the persistence of their ponding sills.

(a) A main cattle watering pool in the lower part of a floodplain, poised to being eliminated by the breaching (unplugging) of its ponding sill by an upstream cutting gully nickpoint. Note cattle pads parallel to the drainage, and an old track cutting across it.

(b) Cattle pad linking watering points with depressions of green grass ('sweet spots'). Thunderstorm rains turn the pad into a gutter that links up, erodes out and eventually destroys the 'sweet spots'.

[A] Managing Rangelands: The Ecological Imperatives

An appreciation of the following ecological characteristics and historic facts of Western Australia (WA) are imperative to successful and sustainable management of our rangelands. Increasing your knowledge about the patterns and processes of the land will make you better able and more prepared to deal with whatever eventuates.

(1) Arid and Semi-Arid Zone

The Australian aridlands range from tropical to subtropical wattle scrub-grasslands through to deserts across mostly broad gently undulating plainsland with scattered or grouped hill ranges. In WA the arid rangelands cover the greater part of the state - from the higher rainfall Kimberley region southwards for over 1500km to the Nullarbor low plateau plains that abut the Great Australia Bight **(Figure 1)**.

The major arid regions comprise of the western end of the Great Sandy Desert linear dune plains, the mountainous Pilbara-Ashburton region of rocky plateaux, fold ranges and inselbergs and flat floored valleys (Mt Meharry at 1251m the highest point), and the Gascoyne and Murchison regions drained seaward by major seasonal river systems such as the DeGrey, Fortescue, Ashburton, Gascoyne and Murchison. A broad outwash coastal plain extending from the De Grey delta down-coast to Shark Bay fronts the uplands of the first three regions.

The Gascoyne and Murchison regions rise from the coast in broad topographic steps to the main regional watershed on the Interior Continental Plateau at 500-650m elevation. This N-S trending divide (followed closely by the Great Northern Highway) separates westward drainage to the Indian Ocean from eastward internal drainage to series of saltlakes. Between these lake systems and the Nullarbor are the Goldfields rangelands.

There is a gradual change of summer-dominated rainfall to winter rainfall across a broad overlap zone in which there is much variation even within the same district. This variation will likely increase with a warming-drying climate change (Bureau of Meteorology 1998, 2000; Beard 1990 Figures 2.7, 2.8 Bioclimatic Zones). Across the region rainfall is from less than 200mm in the central Murchison and inland Nullarbor to nearly 350mm over the 1000m high Hamersley mountain lands in the Pilbara **(Figure 2)**.

In aridlands rainfall is highly variable in space, time, quantity and intensity and is interspersed by dry seasons and droughts of varying duration and severity. A flush of new growth and flowering after effective rains in the growing season is often decimated by lack of follow-up rains before it can set seed. Growing seasons are relatively short in both summer and winter - hardly exceeding a month in many years.

Flash floods produced by intense thunderstorms and tropical cyclones can deliver from 30 to over 200% of the annual average rainfall in a single event. Such storms also produce strong winds that initially cause dust storms from deflation of bare areas, followed by torrential rain and erosion. Heavy hail falls can also occur which leave corridors of smashed woodland in their wake. The main regions affected by tropical cyclones occur in northern Australia.

Climate change predictions affecting WA and Northern Territory includes an increase in the sea surface temperature of the Indian Ocean which suggests increased cyclone activity and hence an increasing rainfall trend in the NW and centre. The opposite trend is indicated for the SW winter rain region of decreasing rainfall (Bureau of Meteorology "Climate Change"). However, by "fitting" your management closely to the existing climatic regime, and keeping track of the weather patterns through Weather Bureau predictions, it is possible to work with the changes to be prepared for whatever eventuates. A strategy combining anticipatory and adaptive management.

Aridity is not solely a matter of little rainfall. It is increased by sparse cloud cover with high temperatures, heat waves in summer, and below the tropic, frosts on winter nights, high evaporation and low relative humidity; and the high reflectivity associated with bared soils or grassland surfaces.

There is a high diversity of soils from sands to clays, and stony and gravely types (Tille 2006). The lighter sandy, loamy and duplex profiles have the best water balance for plants in aridlands, contrasting with the heavy clays typified by Mitchell grasslands. Though having a high field capacity, moisture in clays is tightly bound and unavailable to plants in dry conditions (Tille 2006).

Many aridland soils have thin porous topsoils susceptible to erosion where the groundcover is depleted. The removal of these exposes a water-shedding subsoil at the surface. In mulga country the presence of a hardpan at shallow depth, even extending in many parts to beneath the bottomland alluvia, results in most plants being reliant on extensive lateral root systems. Hence, wherever topsoils are stripped most plants die back from water starvation.

Drought risk from just south of the latitude of Broome all the way to inland Nullarbor is high to severe **(Figure 3)**. At the other extreme tropical cyclones cross the Pilbara coast every two or three years on average, mainly between January and March, and track inland typically on a south-easterly trajectory **(Figure 5**; Bureau of Meteorology 1996 Figure. 30; 1998 Figure. 31).

The most valuable pastures, excluding the Nullarbor which is a low limestone plateau with very localised surface drainage, are (1) bottomlands (and basalt uplands in the Pilbara) of perennial grasslands on clays, alluvial soils and river frontage, (2) the chenopod shrublands, and those mixed with palatable wattles, currant bush and eremophilas **(Figure 9)**. These have been heavily grazed by both sheep and later cattle since the inception of pastoralism. Many areas are now overgrazed and overbrowsed out of reach **(Figure 12)**. Extensive areas are sheet and gully eroded, and are requiring rest for perennial plants, particularly the grasses and chenopods, to recover to the seed set stage **(Figures 6c, 9b, 13, 14)**. Many floodplain areas and wetlands are breached by gullies and invaded by 'woody weed' scrub such as black mulga, curara, bardi bush and needle bush **(Figure 10)**.

From the Carnarvon coastal plain across the southern rangelands there is such a high density of artificial waterpoints (mainly windmills, on average 3 to 5km apart) that in some areas the trampling high-use zones of up to 3km radii touch or overlap. In these situations there is little respite for plant growth recovery. Also these areas are frequently sheet eroded causing water starvation and death of woody plants. Only an aerial view shows the real extent of stock pads and bared ground that have coalesced to such an extent that the increased runoff volume results in their self-generated expansion and further spread **(Figures 6c, 15b)**.

The introduced buffel and birdwood grasses that have become established and spread along river systems are, on one hand, saviours of cattle but on the other, where they have invaded riparian woodlands and chenopod shrubland, they carry damaging fires which kill the chenopods. The invasive buffel is also blamed for habitat simplification, reducing the habitat to only one or two perennial grasses, and the general reduction of biodiversity.

From the Kimberley to the Nullarbor a most important topfeed source for all stock and feral browsers are the bushclumps and thickets that develop beneath trees, or indeed any perch, from the seeds excreted by berry-eating birds **(Figure 11)**. Of the 63 woody plant species preferentially browsed by stock in the Gascoyne-Murchison region nearly half are bird dispersed 'berry' plants e.g. berrigan, currant bush, desert willow, mingah bush, 4 species of the sandalwood genus and 10 palatable chenopods. The numbers and condition of bushclumps can be used as indicators of habitat health and trend as they only become heavily used when the intervening grazing has been depleted. Like other palatable plants the bushclumps are also browsed out closer to water and are more intact at a distance away from water. Berry bushclumps also occur in some spinifex grass areas despite fire as they are resprouters, although this likely depends on the repeat frequency of fire and the protective canopy spread of the perch-tree.

(2) Moist Zone

The Kimberley region, an isolated block of plateaux and ranges (Mt Wells is highest point at 983m), is drained radially seawards by many rivers of which the largest are the Fitzroy, Drysdale and Ord. In the southeast the internal drainage system of Sturt Creek ends in Lake Gregory amongst desert dunes. All the river systems are subject to massive flooding in midsummer from thunderstorms and intense cyclonic disturbances mainly over a short four-month period (December-March). The region also bears the brunt of tropical cyclone extremes that dump torrential rains carried by strong winds (Bureau of Meteorology 1996).

Most of the higher rainfall part of the Kimberley region is composed of rugged terrain of "low to very low pastoral potential, and extensive areas unsuitable for pastoralism" (Rangeland Management Branch 1985: Notes for Map Sheet 1). The most important high potential grazing areas are chiefly the bottomlands and river frontage country of the major rivers that support a variety of tufted perennials including: curly bluegrass, buffel, Mitchell, and ribbon grasses. The largest areas of which occur in the southwest along the Fitzroy and Meda River systems (Payne & Schoknecht 2011: Djada, Duffer, Gogo landsystems). Much of this had already been degraded from past overgrazing by sheep, cattle and the increase of feral stock and the native wallaby populations by the time of the first rangeland survey in 1959 (Speck et al. 1964). During this time wallabies have increased to large numbers since heavy stock grazing kept feed short.

Other important grazing areas in the southwest are the salt couch grasslands on coastal flats south of Broome. Smaller areas of bottomland pastures occur in the eastern part along the Ord and Dunham rivers and the upper Sturt Creek system in the southeast. Elsewhere scattered patches of moderate to good pasture potential of bluegrass and kangaroo grass occur on the basalt clay soils for example (e.g. Barton and Isdell landsystems: Speck et al. 1960; Stewart et al. 1970).

Adjoining the main drainage lines are tributary valley-side and outwash pediments often with a mixed cover of soft spinifex and bunch grasses. The savanna woodlands on various kinds of loam (earths) soils, lateritic and tropical podsols are typically leached acid profiles supporting very tall cane grass to 4m height beneath a varying density of eucalypt woodland such as stringybark and woollybutt 15-25m in height. "The nutritive value of the high rainfall cane grass pastures is low to very low. As well as low protein and carbohydrate levels, the phosphate level is low" (Perry 1960: page 45). Characteristically cattle physical condition drops off rapidly at the end of the rains leaving them thin for up to six months, requiring feedlot fattening-up for export. Also, repeated burning destroys the critical protein rich topfeed plants.

The understorey below the robust cane grasses is often a floristically rich short grass-forb layer that is important for cattle feed. However, the habitual annual burning of cane grass to produce a 'green pick' has depleted the grass-forb layer as well as the topfeed scrub and shrub components, resulting in monocrop regrowths of cane grass and expansion of the 'missing middle' topfeed layer **(Figure 12)**. The practise of late wet season burning also depletes perennial grass nutrients and hence their vigour. At the end of the rains burning the rank grass is also required to open up country for mustering and to reduce tick populations (Perry 1960).

Amongst the most important pastures are those on alluvia and the clay-plains of Mitchell grasslands, which are kept free of fire wherever possible. However, "in poor wet seasons there is little to no growth of either ephemerals or perennials… because of the poor moisture character of heavy clay soils, little to no growth occurs with falls less than 50mm" (Perry 1960: page 27).

In healthy ecological condition these soils are seasonally or irregularly flooded or waterlogged and are hence characteristically treeless – without woody plants of any kind. This is due to their high moisture holding capacity under a dense grass cover that inhibits the establishment of woody seedlings, and their desiccation with cracking soils in the dry.

In the dry season cattle lose weight on Mitchell grasslands unless northern-bluebush and other shrubs such as legumes are present in large enough amounts to provide the bulk of protein. Another supportive drought reserve grazing combination for the Mitchell grass is where it abuts soft spinifex. With continuous heavy grazing the more palatable perennial grasses and legumes are replaced by the spinifex grasses whose dominance is reinforced by fire (Russell Smith 1995).

Where floodplains and clay grasslands are in a aridifying trend, due to inadequate flooding from excessive run-off loss down erosion gutters, they are invaded by scrub that are initially confined to the drier convexities of the gilgai ridges **(Figure 7b)**. Many of which are valuable topfeed plants such as: mimosa bush, bauhenia, conkerberry, lantern thorn bush, rosewood and supplejack.

(3) Present Rangeland Conditions

The historic to present published records of overgrazing impacts in all rangelands emphasize the depletion of the palatable plant cover especially perennial grasses and shrubs, baring of soils from erosion, increase of woody weeds, annuals and unpalatable plants. Vegetation simplification through overgrazing renders arid rangelands vulnerable to climatic change as they are close to tipping points towards desertification, or woody weed dominance. Bare areas stripped of their topsoils are coalescing and expanding, increasing rain runoff and fragmenting habitats into patches **(Figures 13, 14)**. One of the most valuable of these habitats is river floodplain pastures. They are frequently severely degraded, denuded and salt scalded **(Figure 6c)**. The combination of overgrazing effects has resulted in a fundamental shift in catchment function from water absorbing to water shedding, resulting in increased flooding and soil loss as exemplified by the Ashburton River (Mitchell & Leighton 1997) and Gascoyne River (Wilcox & McKinnon 1972; Waddell et al. 2012).

Chains of wetlands and floodplains at all scales have become 'unplugged' by guttering and gully erosion. Instead of moisture recharging the landscape, buffering flood intensity and providing the best perennial grass grazing in the dry season, these once treeless alluvial grasslands are being invaded by wattle scrub and coolibah woodlands **(Figures 10, 40b)**. Worse, many riverbeds have undergone down-cutting, incised deeply enough that their floodplains have been left high and dry (perched) out of reach of flooding except for the exceptional events **(Figure 4)**.

In the present day, climate change and over-abstraction are seen to be the greatest threat to Australian wetlands (Rochier et al. 2001). However, the overlooked primary threat is the breaching of their ponding sills which occurs with every heavy rain. Unless they are re-plugged, wetlands become extinct and are replaced by dryland systems.

Erosion is commonly initiated and/or exacerbated by badly positioned roads, tracks, fencelines and waterpoints. Overgrazing in wooded country, such as the Murchison, results in scrub encroachment by mulga and unpalatable wattles and poverty bushes. In the spinifex grasslands, however, the opposite effect of woody plant elimination is happening, from recurring out-of-control fires that cause the demise of mulga woodland and bushclumps (Latz 2007).

Sheep grazing tends to focus on the highly favoured chenopod shrub and grass pastures on duplex base-rich soils, for example those associated with the snakewood wattle in the Pilbara (Van Vreeswyk et al. 2004a, Land Type 15, pp 164-167). Topsoil stripping caused by erosion followed on the overgrazing and trampling out by the excessive sheep numbers that peaked between 1910 and 1940s (e.g. Payne et al. 1987, Figure. 3; Curry et al. 1994, Figure 5; Payne et al.1998, Figures 2, 3; Van Vreeswyk et al. 2004a, Figure 3) **(Figures 9 and 10)**. Where favoured sheep pastures have stony subsoils, topsoil loss results in the development of stony gibber surfaces that can remain largely bare for a century or longer. Though many gibber surfaces may be of great antiquity, pre-pastoralism anyway, due to soil truncation by extreme flood events many areas are actually a legacy of sheep overgrazing on their preferred pasture types. Walking up the faint slopes from these stone mantled surfaces one can often find the retreating edge of the topsoil remnants (though many reckon "it's always been like this").

Enormous cattle numbers are equally destructive of favoured grasslands, floodplains and seasonal wetlands. As evinced by the classic Ord dustbowl denudation that occurred over only about a 30 – 40 year period after the first 1880 pastoral settlements in the southeast Kimberley (Payne et al. 2004). The critical erosion problem caused by cattle are their pads, or paths, formed by habitual single file plodding between favourite grazing areas and water. These pads initiate interlinking drainage gutters that result in the unplugging and drying out of wetland grass pastures and their replacement by scrubland **(Figure 8)**.

Today the rangelands you manage are usually only a poor reflection of what they once were and it is critical that you acknowledge that but do not take the blame. The challenge is to look forward towards a new relationship working with the landscape processes. In WA there are still areas of healthy rangelands of pastoral value in the major catchments. However they are too few and far between and often only remain due to features such as lack of surface water, poisonous plants or being furthest from homesteads, yards or shearing sheds. The amount of topsoil that remains determines how much the land can bounce back to full health if given rest from mouths and hooves. Secondary (replacement) vegetation that is suited to livestock can still establish as long as its not directly on hardpan or saline surfaces. In summary "The worst areas of degradation and erosion are on the most valuable pasture lands" (Payne et al. 1988: page 5).

a.

b.

Figure 9: Chenopod shrubland.

(a) A rare occurrence of a healthy diverse chenopod shrub and wait-a-while wattle community on calcareous duplex soils (pH 8 – 8.5). The plants recorded in the photo area include: currant bush, frankenia, fuchsia bush, golden bluebush, lax bluebush, pink-seeded bluebush, ruby saltbush, sago bush, silver saltbush, tall saltbush, warty eremophila, wait-a-while wattle.

(b) Sheep overgrazed chenopod shrubland - reduced to a monocrop of sago bush on similar soils to (a) but with the topsoils stripped off, exposing the calcareous gravel clay subsoil. Each shrub is perched on a pedestal of remaining topsoil with blown and sheetwash debris.

a.

b.

Figure 10: Fenceline effect: Wattle scrub replacement of chenopod shrublands and floodplain grassland.

(a) Sheetwash plain draining from left to right. Up to the edge of the dense woodland in the background, this used to be chenopod shrubland similar to that right of the fence. Overgrazing and topsoil stripping resulted in the replacement of chenopods by wattle scrub.

(b) Floodplain soils supporting overgrazed claypan, Roebourne and swamp grasses guttered by erosion channels, resulting in dense invasion of scrub, mainly black mulga and curara.

a.

b.

c.

d.

Topfeed role of berry birds in bushclump formation.

As recorded from air and ground surveys across the western and central part of the Australian aridlands and the northern monsoon savannas, thicket clumps around the bases of trees and other perch sites form a vital archipelago habitat. From the air these are seen as a varying dot pattern across most landscapes. The bushclumps, or thickets, result from berry-eating birds voiding the seeds at a perch. Many of the perch trees are typically dispersed by other means such as wind, water, ants or ungulates. Other perch sites are on or around rock outcrops, pool margins, termite hills, fence-poles and windmills.

Bushclumps vary from a few small shrubs to 7m tall dense thickets and as wide as the perch-tree canopy (over 10m wide) **(Figure 11b)**. They are composed predominantly of woody plants with brightly coloured, small berry fruits, or berry-like arillate seeds that range in size from 3mm (rhagodias) to 30mm (quandong). A partial list of berry plants from the mulga country comprises 26 families, 33 genera and 64 species, of which 45 species (70%) are browsed by stock and feral ungulates. Of these, 26 species or 40% are highly preferred. In the arid rangelands the most conspicuous berry seed dispersers are the Singing and Spiny-cheeked Honeyeaters (KT: personal field records).

Berry birds and perch-base thickets are keystone components of scrub country otherwise containing relatively few topfeed plants. As prime movers in ecosystem dynamics, their involvement enhances diversity through changes in habitat structure and form, and species composition, increases resilience, as well as productivity and hence carrying capacity for browsers and berry feeders (a feedback loop). Their presence and condition are used as indicators by the EMU assessment process for landscape health, functional integrity, carrying capacity status and trend.

Figure 11: Bird mediated berry-thickets.

(a) A berry-thicket beneath a boab in the northeast Kimberley.

(b) Berry-thicket (the same width as the crown) beneath a river gum in the northeast Goldfields. This composed of 8 berry bearing small trees and shrubs: berrigan (6m), curara, currant bush, desert willow, naked lady, native boxthorn, ruby saltbush and tall saltbush.

(c) Ruby saltbush growing around fence-posts.

(d) Berrigan in flower with stem (cauliflorous) flowers and fruits.

(4) Being Mindful of the Signs of the Land

"It is difficult for man to see the seeds of his own undoing in a quiet pastoral scene of cattle or goats grazing contentedly on a hillside. For the early stages of overgrazing are not reflected in any loss of condition in the animals. An arid grassland or shrubland can continue producing fat cattle, sheep or goats long after the vegetation has reached a critical stage, and it is only when the nutritive forage suddenly vanishes and merely weeds remain that the magnitude of the disaster is revealed. Then it is too late for easy remedial action" (A. Starker Leopold 1963: page 168. American ecologist).

Over time erosion and the changes in the native vegetation's structure and composition brought about by selective grazing of the palatable plants within reach, results in the successional replacement of the kinds of stock and wildlife better adapted to the change. This is neatly summed up by the Bedouin saying from Arabia: "cattle open up, sheep nibble out, goats clean up, camels come to stay but are driven out by marching dunes".

The pasture land problems that originated during pioneer time have been worsened by the subsequent human infrastructure. Roads, tracks and fencelines have multiplied the gutter drainage **(Figures 7a, 47, 48)**. Continuous grazing confined to paddocks has compounded the desiccation of landscapes due to the loss of topsoil and lessening rain infiltration i.e. chronic 'declining rain use efficiency'. Together these have entrained ongoing changes in the composition of the plant cover towards scrub, the least palatable plants, and annuals. These changes have already caused a shift to pastoral reliance on goats (in the absence of dingoes). Goats are arid adapted and successfully breed even in drought periods, but they compete with both sheep and cattle in using all browse layers.

In most naturally productive landscapes today the major causes of degradation are erosion gullies. Improved grazing management alone will not change which plants will grow on dehydrated soils. Without stopping the gully nickpoints and helping to spread flows out of the erosion channels, to enable moisture to be retained in the soil for longer, the rangelands will continue to dehydrate and become less productive in carrying capacity – except for browsing stock **(Figures 10b, 14)**.

The most obvious negative legacy other than bared land are the "woody weeds". They are a symptom of degradation and why many of them are called "poverty bushes". However, these do not cause the poverty of the landscape, they are merely the messengers. Woody weeds do best when the land is drying out. To malign them without listening to their message about the real underlying cause is to miss the point – the nickpoint!

Today's pastoralists are caught in a 'Catch 22' situation – needing to be able to cope with legacy management but also having to adjust to change without spending a huge amount in time, money and manpower. Two critical skills for living successfully in changeable arid landscapes are: (a) mobility, and (b) versatility. Where (a) is to move stock on a rotational or itinerant strategy allowing for pasture spelling or rests, and (b) being able to do more than one thing (having more than one enterprise) depending on changing circumstances.

The process of rangeland rehydration involves reading the changing signs of the land and identifying what these signify for the pastoral enterprise. The goal is to restore the functional wholeness and resilience of station systems, particularly the "Best Country". Together with grazing imperatives such as rotation and spelling – the rehydration process entrains the natural processes to do most of the recovery and maintenance work in the face of climatic swings, so that the landscape is again prepared for any eventuality. Basically this means the maintenance, or enhancement, of ecological diversity - for which pastoralists are the front line conservators.

(5) Human induced changes

These include altered fire regimes and the impacts of infrastructure which have wrought massive changes in the rangelands. The stock impacts have come about from continuous grazing pressure that gutted the rangelands, particularly since the advent of fencing.

a) Altered fire regimes

It is difficult to judge what fire regimes existed prior to pastoral development and the gradual urbanisation of Aboriginal people and decline in traditional cultural land management. As recorded by anthropologists, patch burning or "fire-stick farming" was a major tool of grassland management throughout the rangelands in early times (Rhys Jones 1969, 1973) and the huge, intense wildfires that we have today would likely have been less prevalent through the Aboriginal mosaic burning approach (Burrows 2000; Burrows et al. 2006; Latz 2007; Gammage 2011). Some key considerations for future fire management include:

I. Repeated, hot, dry season fires in the Top End may remove critical protein browse upon which livestock depend for many months of the year and lead to progressively better fire-adapted sorghum and kerosene grasses of lesser nutritive value. This widespread approach appears counterproductive when viewed in the longer term.

II. In grassy habitats with important drought-buffering browse species (both top feed scrub and trees and the understorey shrubs such as tree base clumps) hot, landscape-scale fires should be avoided and quarantined if they occur. To do this may require an integrated approach of fuel load management and adequate access and preparedness to stop a fire as soon after ignition as possible if desired.

III. Some vegetation types are fire-sensitive and struggle to recover from hot fire. The most widespread of these are chenopod shrublands and two key and interrelated factors may be at play to create fuel loads able to carry a destructive fire in these landscapes. Firstly, overgrazing can open the vegetation up and allow massive grass growth following good summer seasons as occurred in the southern Goldfields and Nullarbor in the mid 1970s. In the northwest lower Gascoyne catchment a culprit is buffel grass which once established and not grazed sufficiently may lead to massive wildfires. The resulting buffel grass "monocrop" is poor for most wildlife and severely decreases the durability of key drought buffering habitats.

IV. Hot fires are also destructive of wetlands, riparian habitats and in moist sites surrounding major hills and mountains.

V. In the moist rangelands, frequent dry season fires are responsible for severe damage to the unique monsoon forest patches and to cypress pine and heath communities. These intense fires also result in the elimination of the mid-storey in eucalypt forest and woodland **(Figure 12)**. In the absence of rain late dry season fires on a floodplain will burn the soil surface humus, despite the grasses still being green (Russell Smith 1995).

VI. In the aridlands groundcover eliminated by fire leaves the landscape bare of plant cover for up to six months, or longer in drought conditions, exposed to erosion by wind and accelerated erosion from the first thunderstorm deluges.

VII. Fire may be used to control "woody weeds", particularly the wattles, most of which are killed by fire and re-establish from seed. This is most effective when plants are still small and can be counterproductive when scrub has matured. This is particularly so if follow up fires or other treatments, such as soil flooding, are not employed to ensure high scrub mortality. One fire, no matter how hot, will probably not suffice as many other scrub species are re-sprouters (e.g. mimosa bush, lantern thorn bush).

(b) Impacts of infrastructure

Altered natural surface drainage and concentration of grazing are the two most prevalent impacts of infrastructure. Clearly they are often connected, such as where the location of watering points and fences funnel animal impact (particularly pads) and initiate landscape incision processes and landscape leakage.

The early years of pastoral development in all regions other than the Nullarbor Plain occurred before drilling rigs or "polypipe" were available. Thus grazing was intensely focused around rivers, creek pools and a scattering of wells which were also usually along drainage tracts, where shallow and good sources of fresh groundwater were best accessed. This focused the impacts of grazing, by what would now be regarded as ridiculously high numbers of livestock, in those parts of the drainage ecosystem most vulnerable to degradation and the initiation of gullying. Clearly, this pattern of early pastoral development made inevitable the legacy of acute degradation of the most valuable landscapes – an unfortunate reality that contemporary pastoralists now face.

Now days, with reticulation technology, there is no need to have watering points for livestock in fragile landscapes, even if that is where the well, bore or dam is located. Unfortunately there are still far too many watering points within the ecologically critical, fragile drainage alleys of bottomlands. Other fragile landscapes, where watering points inevitably lead to widespread soil erosion problems, such as breakaway footslopes are very difficult to repair.

(c) Dams

Dams can also be a major cause of alteration to surface flows - obviously by damming. However less obvious, and rarely planned to fit the natural drainage pattern, is the spillway where excess water is released from the side of the dam. Constricted, spurting flow off the spillway erodes the channel downstream. This typically forms a nickpoint that proceeds to cut back up past the overflow to intercept the inlet, leaving the dam dry except when flows are exceptional. If the inlet slope of the dam is not battered down, this will be a source for headward erosion and future major gully heads.

A common misconception is that a major creek is needed to ensure dams never run dry. A relatively small creek or drainage line that flows more regularly will be far easier to dam, require far less ongoing maintenance and be full just as often as a dam on a big creek. Dams have to be in the drainage alley to harvest water, but the provision of the water to stock does not need to be in such a vulnerable part of the catchment ecosystem, particularly with modern reticulation technology. The fencing of dams is a prerequisite to managing total grazing pressure, including feral stock and kangaroos.

In contrast to open dams with their erosion-causing spillways, evaporation loss and salinisation, sand dams are the classic conservation method for storing rain runoff in aridlands. Sand dams protect the stored water from evaporation loss due to the protective surface layer of dry sand, thus providing longer lasting water for stock and wildlife (see section D4d).

(d) Fencelines

Fencelines were generally installed north-south and east-west with scant regard to landscape pattern and vulnerability. Where small areas of highly preferred pasture types were included with larger areas of country less attractive to stock, the degradation of the preferred areas was inevitable **(Figure 10a)**. Fencelines running up and down slope or parallel to drainage lines in floodplains also focused pads in the direction of flow and initiated gully erosion and landscape dehydration **(Figures 7, 10b)**.

(e) Main roads & access tracks: "Track Creeks" and blocking flow

Access tracks intercept natural sheet flows and concentrate them, releasing them at the next valley floor. This has two local impacts. Most obviously it dehydrates the area downslope of the track. The coursing of water along the track itself physically draws water to it from upslope and this means there is less infiltration of surface water. The faster the sheet flow, the less the soil is able to absorb it. The concentrated flow then causes accelerating erosion in the valley floor.

Roads of all kinds are major causes of directing water away from the natural drainage lines or blocking flow in plainsland **(Figures 47, 48)**. Where a track is cut down into the soil, it can also cause erosion upslope in the form of migrating gully heads or wide terraces that may be only a few centimeters deep or a major gully.

Access tracks are also a major cause of gullies that unplug wetlands either directly, by breaching their ponding sills, or indirectly by being the nickpoint source of a gully head that eventually does the same thing. "Track creeks" upslope can also divert water away from inlets to wetlands leaving them parched **(Figures 47, 48)**. All of this can be avoided by correct planning and installation of access tracks. As a rule tracks or roads should avoid bottomlands of all types. Where they have to cross concentrated drainage, it should be at right angles to flow and at exactly landscape level, even if reinforced with calcrete rubble for all weather use such as the major trucking tracks from cattle yards or woolsheds (see section D5).

(6) Grazing features frequently overlooked

I. The diversity of landsystems provides a variety of plant resources at different times in relation to wetting and drying.

II. Seasonal or opportunistic grazing follows the wetting-drying sequence of different landsystems as expressed by their soil moisture condition.

III. Seasonal up and down slope (catena) grazing is where stock (or wild ungulates) naturally graze the upslope areas during the rains and the flooded bottomlands get a rest. As the slopes dry out stock move downslope, and then occupy the bottomlands in the dry season. Where there are large areas of bottomland pastures these and the immediately adjacent slopes can be used on a rotation basis.

IV. Opportunistic grazing is the movement of stock to where isolated thunderstorms have produced a green flush.

V. The capacity of the landsystems to harvest rainfall through infiltration is dependent on the porosity of its surfaces and on adequate ground cover.

VI. Long flooding inundation can kill perennial grasses. When this is followed by a dry period, causing cracking of the alluvial soil, the next flood can rip the soil out (Graham Forsyth, Three Rivers Station: personal communication).

VII. Too long rest (spelling) without harvesting results in perennial grasses becoming rank and moribund with dead centres; i.e. perennial grasses require the stimulation of harvesting at appropriate intervals and degrees of intensity, by grazing, fire or mowing.

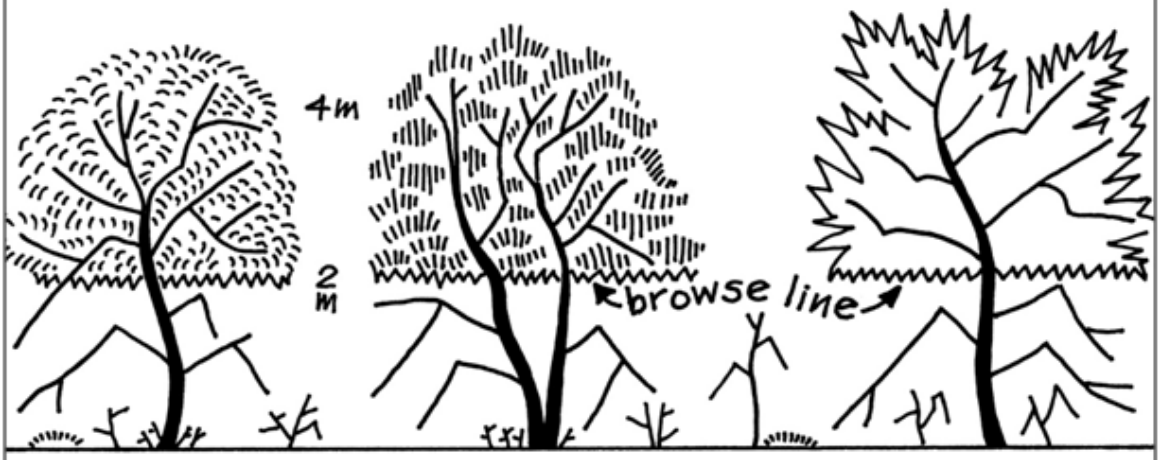
VIII. Overgrazing occurs when the duration and intensity of grazing exceeds either what the key plants can tolerate or affects their potential for recovery (Savory & Butterfield 1999).

IX. Shade is an important requirement for all stock.

a.

Rangeland in good condition before overgrazing or too frequent fire.
Several layers with recruitment of diverse plants for all layers.
Perennial grasses present.

b.



The same example after overgrazing &/or excessive fire.
Trees and scrub browsed or burnt out of reach.
No recruitment or replacement stages – hence 'Missing Middle',
so canopy trees are said to be 'Standing Dead'.

Overgrazing: preferred shrub & groundlayer species reduced & replaced by weeds.
Frequent burning: palatable grasses reduced & replaced by fire tolerant species.

Figure 12: The 'Missing Middle' and 'Standing Dead'.

(a) Rangeland in good condition before overgrazing or too frequent fire. Several layers with recruitment of diverse plants for all layers. Perennial grasses present.

(b) The same example after overgrazing &/or excessive fire. Trees and scrub browsed or burnt out of reach. No recruitment or replacement stages – hence 'Missing Middle', so canopy trees are said to be 'Standing Dead'.

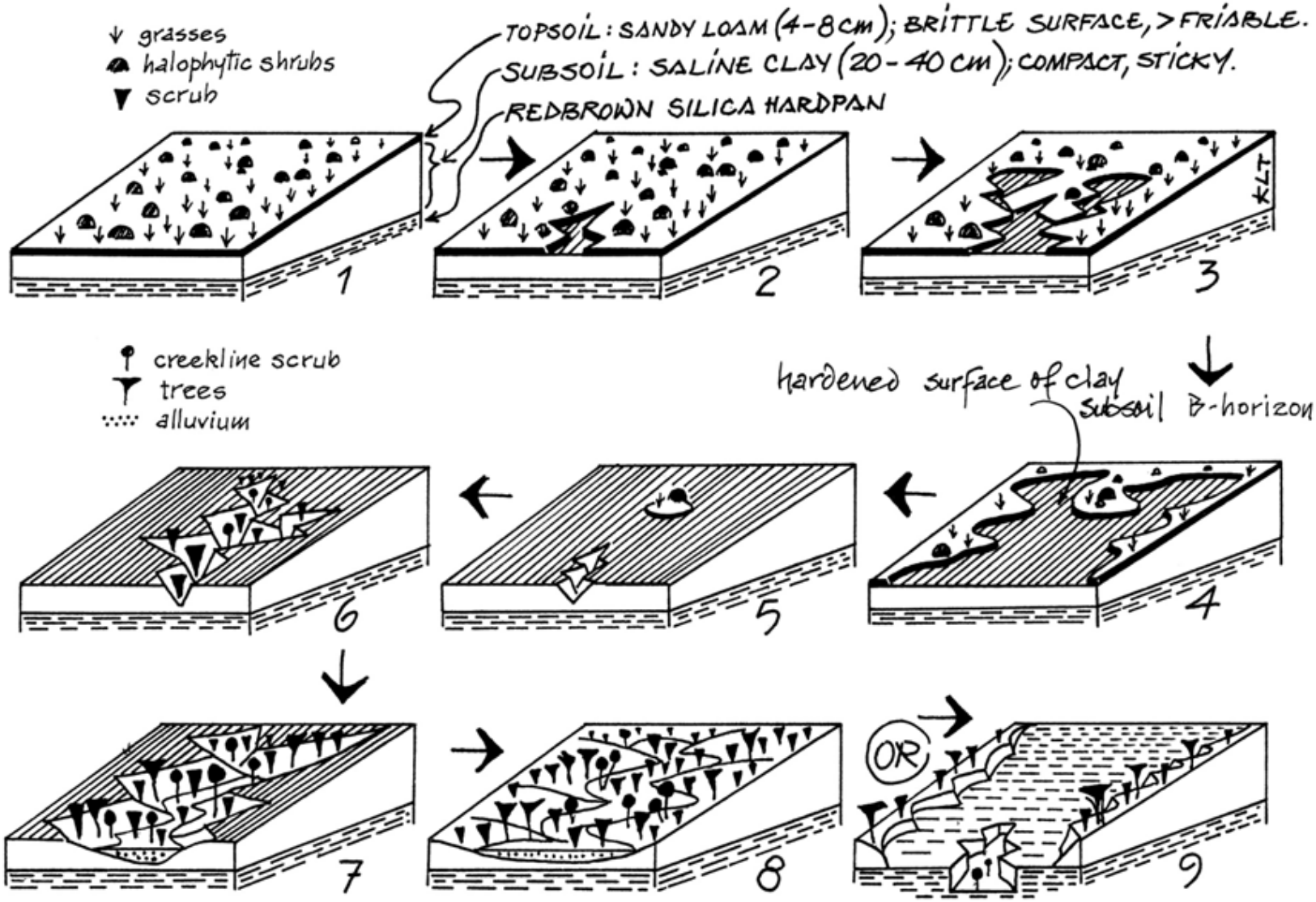


Figure 13: Fragmentation and Coalescence Succession.
Example of a soil-vegetation replacement sequence. Overgrazing with topsoils stripped by erosion resulting in the demise of a chenopod shrubland. Coalescence of the bared clay subsoil areas becomes the new land surface colonized by scrub. If unchecked, erosion will continue, with variations, down to the hardpan.

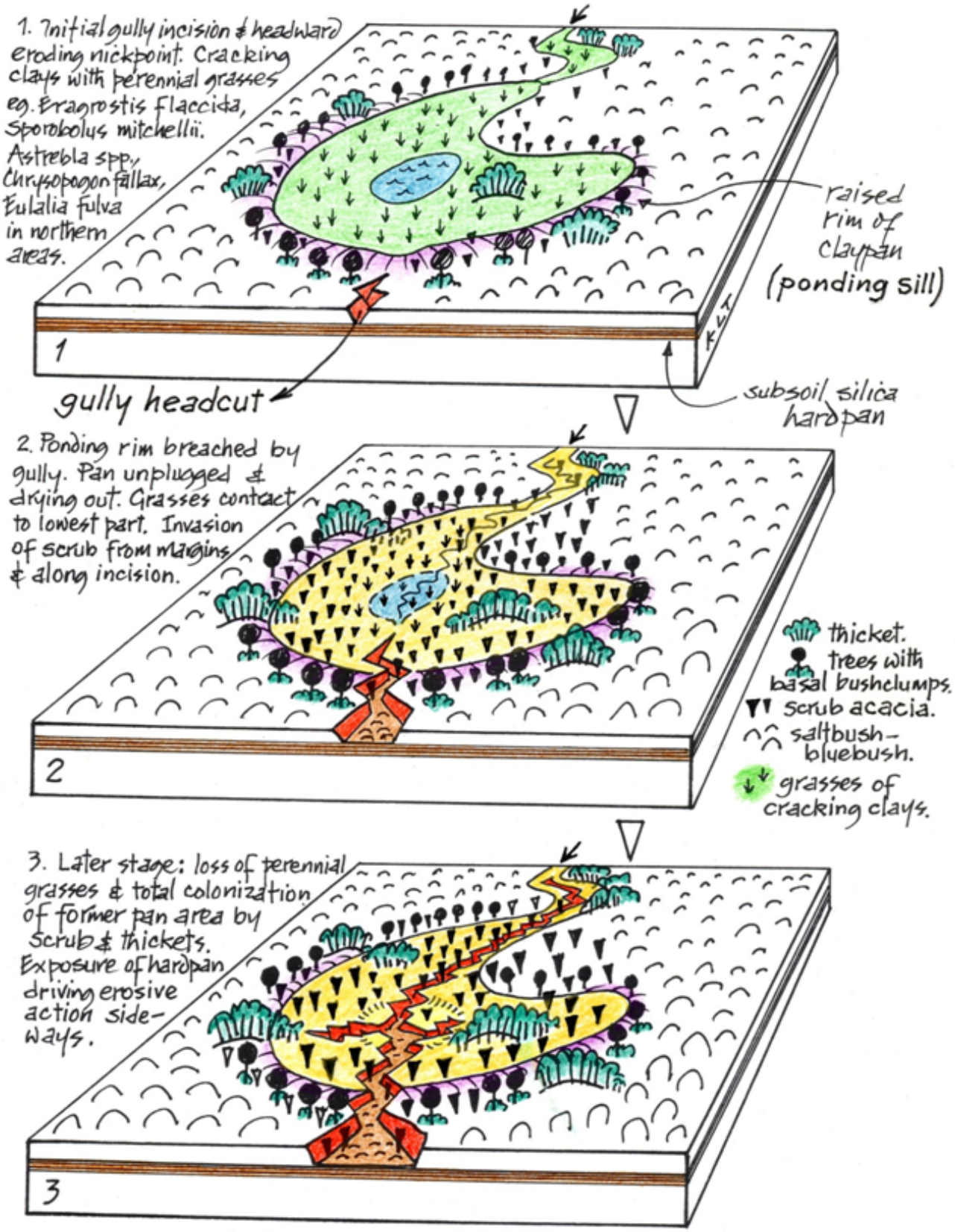


Figure 14: Gully nickpoint breaching of a ponding sill; transforming a seasonal wetland perennial grass habitat to dryland scrub.

[B] The EMU Approach

(1) Introduction

EMU stands for Ecosystem Management Understanding. Each station is a community or association of plants and animals interacting with each other and their physical environment. Each station is viewed as an ecological management unit, albeit with artificial boundaries, that is part of a particular drainage system.

The EMU Approach helps managers to 'fit' not 'fight' natural processes through improved ecological understanding. The approach is an interpretive process to visually recognise landscape patterns and processes, and to identify indicators of change. This is accomplished through aerial and ground traverses together with the pastoralists' mapping their local knowledge on overlays in response to some 15 questions.

With their enhanced understanding of the functioning of their station landscapes, pastoralists can achieve an ecological appreciation and a greater ability to manage sustainably. As a system without feedback is dumb, monitoring change is essential. Under the EMU approach this is done by means of date recorded map overlay notes, a 'tick-box' record and fixed-point photos. In this way it is graphically possible to track condition and change in a whole station context, providing feedback to identify whether conditions are the same, worsening or getting better.

Rangeland ecological management means close observation and understanding of the interactive influences between stock and the physical (drainage and soils) and the living (plants and other animals) components of a station. This knowledge enables the development of station specific ecological 'best-fit' management responses to entrain the natural processes to do most of the recovery and maintenance work. A core objective of EMU is biodiversity conservation because the variety and condition of the native flora and fauna is the ultimate basis to the viability of pastoral enterprises.

The fundamental objectives of EMU are to build:

(a) Within-property self reliance, and

(b) District/catchment level interdependence and collaboration.

The ultimate success of EMU occurs when pastoralists rarely require extension help and instead help guide other pastoralists in mapping their station knowledge and learning how to recognize and interpret the signs of their land for management purposes.

In sum, the EMU exercise identifies and analyses the constraints and opportunities that will make a real difference in managing rangelands effectively in an ecologically sustainable manner.

(2) The Drainage Unit Context

Watershed divides separate catchment drainage units into compartments. Landscape change imposed by human and stock activities, however widespread, is likely to be expressed differently within the bounds of each drainage compartment depending on its physical makeup and plant cover. Thus each drainage unit forms the unifying context for land survey, planning, management and monitoring. It is the integrative basis for devising effective management strategies and for predicting change from present land uses. It is important to emphasize for management purposes that tributary units down to the smallest scale are all partially enclosed by divides except where they exit to link with larger branches.

This means you do not have to study an entire water catchment, just the tributary unit where you are standing. With the proviso that (1) you identify what is happening upslope/upstream of the problem area, and (2) check downslope if there is any influence from where your tributary joins the next branch or branches – these may be drivers of erosion if they have much deeper channels. Where a major river traverses a station, the valley-side tributary catchments assume greater importance as moisture recharge support for the bottomlands, and you don't want this water lost to the main river.

(3) The Indispensable Air Perspective

Only from the air can you get the comprehensive view over the entire panorama – the totality of the landscape context. Only from the air can landscape patterns, relationships, dimensions and linkages be perceived, and the degree of change and trend in vegetation and drainage processes. Trying to judge land and pasture condition only from the ground is 'one-eyed'; a partial view **(Figure 15)**.

(4) Salient Factor Analysis

This analysis is a synoptic graphic approach to identify the most important of the multitude of features that make up the station landscape. Maps of geology, topography, drainage, soils and vegetation at the same scale are used as the base maps for the map overlay analysis method of McHarg (1969). As a composite of these landscape features rangeland landsystem maps are used as the base map. These are enlarged for each station to a scale of 1:100.000 (1cm=1km) and depict in colour-code the composite terrain patterns of landform, geology, soils and vegetation. Together with a satellite/Google image of the station at the same scale these are used interchangeably. The satellite image helps familiarise observation skills for the aerial view exercise that follows.

a.

b.

Figure 15: The Indispensable Aerial Perspective.

(a) A Pastoralist Monitoring Site (PMS) is being installed by local extension staff and pastoralists. The small PMS quadrat is located on one of the few topsoil remnants. What will the count of the quadrat grasses and shrubs tell the manager about the health of the broader landscape and how to manage it?

(b) The aerial view of this exact area shows its devastation by erosion channels and sheet erosion with only patches of yellow grass and some scrub left on the ever-diminishing topsoils. The PMS tells you virtually nothing about landscape functioning, condition and trend.

[C] Landscape Diagnosis and Baseline Record

As the first step the baseline overlay mapping exercise involves the pastoralist and partner and/or manager to record by hand their local knowledge drawn on overlays in answer to some fifteen questions. The diagnostic sequence is comprised of six interactive exercises: (i) Pastoralist's baseline mapping exercise, (ii) Station air traverse, (iii) Ground traverses of key areas, (iv) Map recording of findings, (v) Fixed-point photo record, and (vi) Truthing follow-ups.

The station's first baseline sequence of exercises generally takes up to two or two and a half days – often done over a weekend when the pastoralist is more likely to be available. The activities in each exercise, listed below, will be run through by the facilitator before they commence **(Table 1)**.

The first stage of the process can be done on your station individually or with a group of stations. In both cases the initial focus is on baseline mapping interspersed with some field traverses to visit mapped issues **(Figure 16)**. A flight, at about 120-130m (400ft) above ground level, is made over key features identified during the mapping process. If a workshop approach is used, the participating stations are flown in follow -up visits. In one-on-one exercises the station is usually flown in the initial visit too.

This sequence of exercises is for the pastoralists' to first record their local knowledge drawn onto map overlays in answer to some 15 questions that identify and assess the salient station features as an ecosystem within wider systems i.e. the ecosystem understanding. The flight and overland trips to key areas help to identify where there is most value in intervening to protect and/or restore productivity **(Figure 17)**. A follow-up visit from the facilitator generally occurs about four to six weeks later in which major opportunities for change are reviewed and implementation is planned.

The map overlay process guides the selection of a set of landscape monitoring sites. These are assessed the first time, then every second or third year, as a "tick-box" record **(Appendix 3)**. A fixed-point photo record is also made of the sites both from the ground and the air. This is the pre-eminent means of recording monitoring information for tracking change and for planning, refining, managing and revising.

Developing greater proficiency in landscape management is markedly enhanced by maintaining an ongoing dialogue with the base map and overlays by drawing in new field data with the date of the observation. Hence it is recommended the map and overlays are laid flat on a small table or bench amenable to ease of access at all times (i.e. not rolled up or hung on a wall).

Management needs to be by means of careful observation and thoughtful intervention. The landscape is the textbook to be read and understood. The diagnostic process is more about 'share and do' than 'show and tell'- and attempts to elicit responses and capabilities instead of cramming facts.

Recovery ecology is both a means and an end, for as we learn how to restore land health, we in turn are changed in our relationship with the land. This change in attitude and objectives enables pastoralists to ask not 'what can I get out of this land' but 'what does this land have to give if I co-operate with it' (Mollison 1988: page 3). In other words, "What is the ecologic best-fit usage of my land?" This then provokes the further question – "What is there about my land that is valuable in ways other than grazing?"

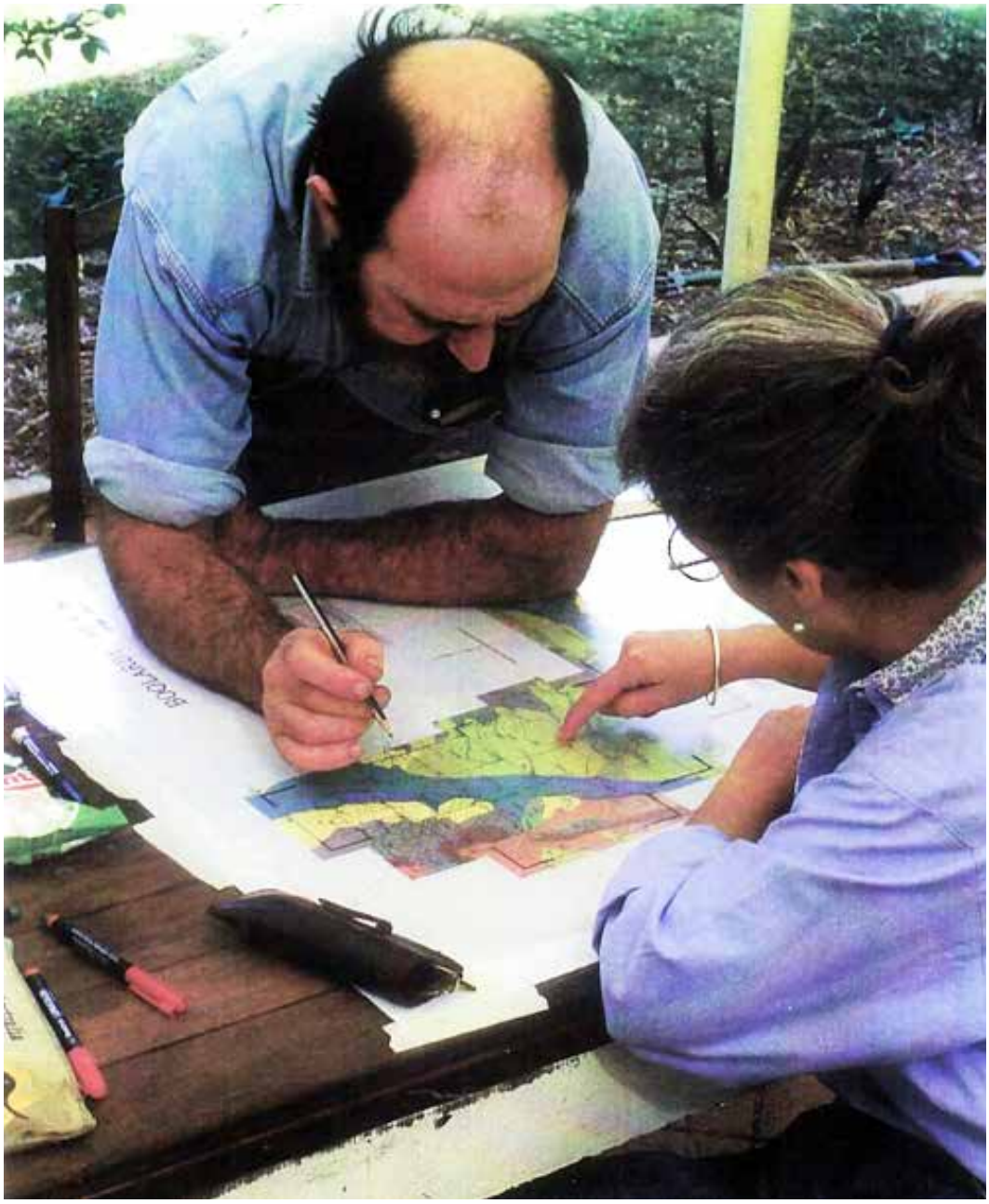


Figure 16: Pastoralists drawing their local knowledge onto transparent film overlain on an enlarged landsystems map of their station. (Mark and Caroline Halleen, Boolardy Station, Murchison River catchment). (Photo: Janine Tinley)

a.

b.

Figure 17: Explaining the Field Evidence.

(a) Mark and Caroline demonstrate to the EMU facilitator (HP) their understanding of the findings of their mapping in relation to the last flood event.

(b) A ground traverse: pastoralists with the authors, one standing and explaining (KT), the other photographing a last patch of topsoil (HP), Murchison River Catchment (Photos: Janine Tinley).

Table 1:

Key stages in Ecosystem Management Understanding (EMU)™

© Ecosystem Management Understanding (EMU)™

1: Initial meeting
Explore landholders key issues and objectives, management history etc.
Reaffirm *complete confidentiality.*

2: Overlay mapping exercise
Build the ecological baseline of the property using the landholders knowledge.
Identify the key issue areas and most important interactions and drivers of change.

3: Aerial survey of key issues and areas mapped
An aerial traverse route is planned together based on assessment of the landholders mapped knowledge.
Digital photos are taken of key issues during the flight.

4: Flight debrief and plan ground inspections
What did we see, map the key issues we saw and consider them in context of the initial mapping... what do we think is going on? Use photos from flight on a TV.
Visit key areas on the ground to check interpretations and assessments.

5: Major review: Reassess and identify (map) management priority areas.
i) Where is the most important country in need of some strategic intervention? Identify them on an overlay with simple dot points to capture just what really matters and what we think needs to be done.
ii) Consider if additional expertise is needed to build a few key projects based on mapped priority areas.
iii) Is existing monitoring telling you what you really want to know where you want to know it? Make a plan to fill the gaps of what you really want to do.

A: Build priority project proposals
Seek external funding if required.

B: Implement project(s)
Establish baseline monitoring BEFORE starting works that will record if it "worked".

6: Install property monitoring system
Your "intelligence" system of what matters and where based on mapped management priorities. YOUR "finger on the pulse" system of feedback information.

REVIEW, REVISE and REFINE
Ongoing learning by doing.
Map all major observations and revelations on a new overlay left out on a small table for this purpose.
Revisit the visual "plan" at least annually.

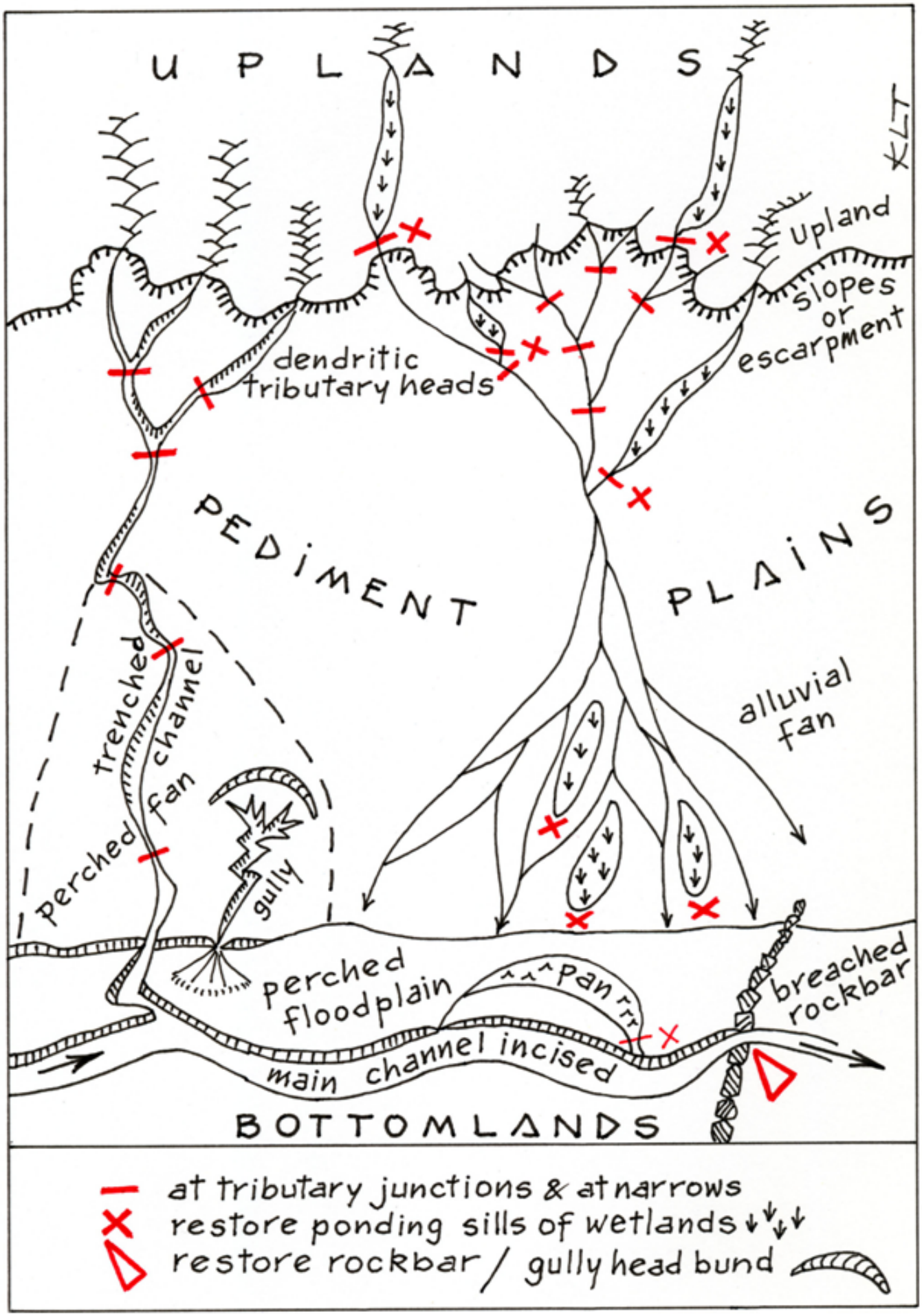


Figure 18: Examples of Critical Drainage Control Points in a landscape.

[D] Landscape Repair: Rehydration Methods

Erosion Control Methods

The information below gives an idea of some options. This is not a soil conservation manual and landholders are encouraged to refer to established soil conservation manuals and seek expert advice when planning major works.

There are many ways to slow and spread water and pastoralists can be creative, using what they have at hand in terms of materials and machinery. **However, it's very easy to make things worse by not fitting the rehabilitation work into the critical control points in the affected landscape (Figure 18)**. As a rule, "plonking" anything solid on flats or in channels makes things worse **(Figure 22b)**. Any structure or object needs to be keyed in carefully and the question asked; "How will the flow try to beat me here?" Always first assess whether subtler or simpler interventions that minimise damage to the land are considered before embarking on any major earthworks. Also be aware of, and meet, any regulations that apply to your patch, for example clearing vegetation of cultural or biodiversity value.

The Erosion Repair Tool Box (Table 2)

(1) Sieve Structures

(a) Live Plant Filters

These can be established in relatively calm areas without any supporting physical sieves (see options below). However, they can – even should – be part of any filter strategy. This is particularly so where sieves are anchored to the ground and will inevitably rust through. In the rangelands it is illegal to introduce foreign plants, particularly in the drainage and run-on areas that are highly susceptible to invasion by potential problem plants that become major threats to biodiversity conservation and management control (e.g. rubber vine in Queensland rivers and sensitive mimosa in the Top End). The excellent drainage recovery programs by Peter Andrews (2006) in his 'Natural Sequence Farming' approach would be recommended as long as native plants from the local region were used and not willows and other foreign plants.

There are suitable native plants that can be used in every rangeland region of Australia, thus we recommend not using exotic plants. Some of the best are the large sedges and perennial grasses with tough, fibrous root systems that transplant easily and spread rapidly to form effective filters. Sturdy perennial grasses also do this job naturally: for instance, lemon-scented grasses in sandy-stony areas, river reed, bulrush and creek cane-grass. Also woody riparian plants such as lignum, pandanus and the smaller, multiple-stemmed paperbark and tea-trees. Whole plants should be carefully dug up and put into prepared holes and watered, preferably just before or early in the growing season. Spreading the seeds of these plants in key places, such as where flood debris has been trapped and at sieves, would help reinforce any planting (refer to **Figures 19, 20, 21**)

Table 2 : Erosion Control Methods

(A progression from simplest with least disturbance to more complex with greatest initial disturbance)

(1) Sieve Structures:

- (a) Live Plant Filters
- (b) Scrub/Brushwood Filters (loppings)
  - (i) Sheet erosion
  - (ii) Gutters & Shallow Gullies
- (c) Mesh/Netting
  - (i) Laid flat
  - (ii) Rolls
  - (iii) Suspended
  - (iv) Fences
- (d) Sheet Materials
- (e) Rakes
- (f) Gabions

(2) Gully Stabilisation

(3) Banks/bunds (Embankments)

(4) Solid Structures

- (a) Drop Structures
- (b) Stone or Earth Sills
- (c) Weirs
- (d) Sand Dams
- (e) Rock bars

(5) Road "Rivers" & Road Barriers

(6) Mechanical/Electronic Aids

- (a) Ripper
- (b) Ploughs (chisel, pitters, opposed discs, niche seeders)
- (c) Spiked Roller
- (d) Grader, bulldozer, bobcat, front-end loader
- (e) Field laser level (200m range) with staff

a.

b.

Figure 19: Self-stabilising processes (both views upstream).

(a) An old eroded station track, abandoned and gradually healing from the growth of sedge clumps and a pond below the fall.

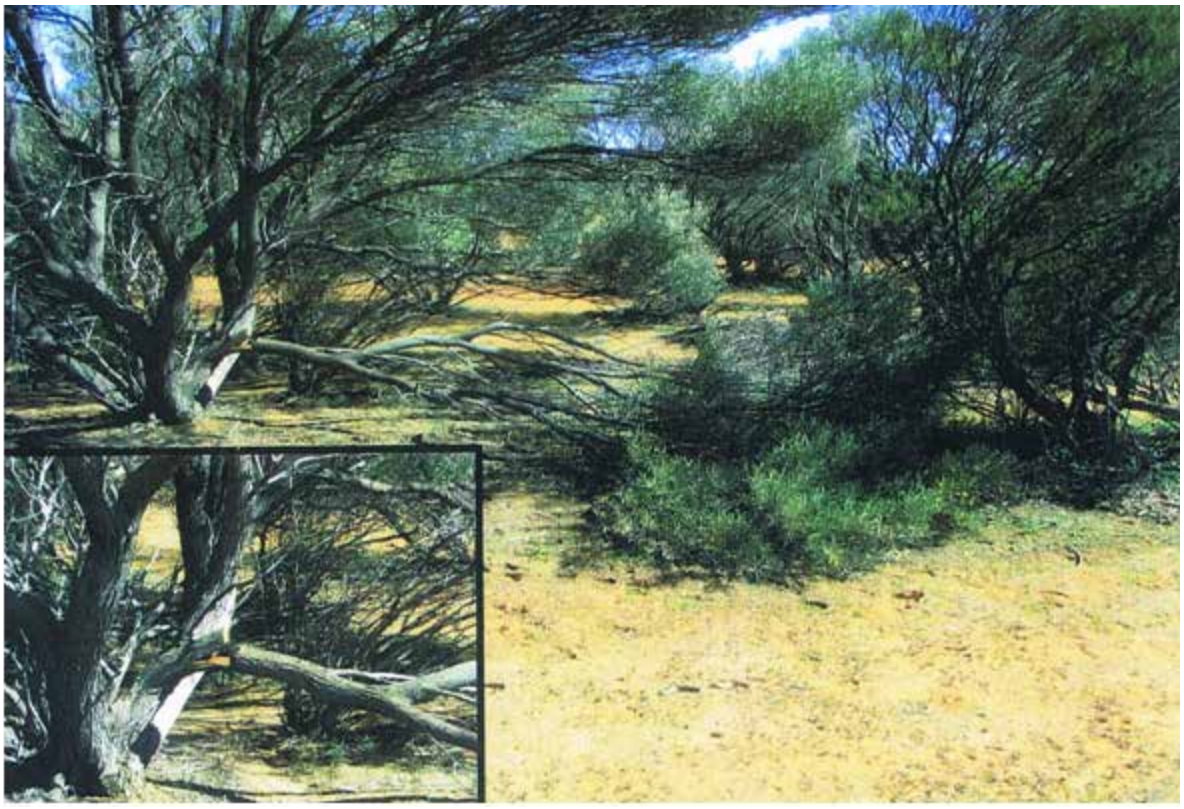
(b) View upstream showing fallen branches blocked against two trees causing the deposition of a sandbank in an upstream direction and colonized by dense growth of sedges (Photo: (b) PJ Waddell).

a.

b.

Figure 20: Living plant filters.
(a) Initial stabilising effect of lemongrass on old tracks in sandy to stony granite soils.
(b) The robust creek cane-grass. Widespread across the arid rangelands, this is an ideal plant to establish on the upstream side of mesh rolls.

a.



b.

Figure 21: Flood debris and live plant foliage sediment traps.
(a) Flood debris obstruction build-up of a creek bed sandbank.
(b) Half-cut live branch with foliage lying on the ground traps sediment and debris as it continues growing (Photos: PJ Waddell).

(b) Scrub/Brushwood Filters (loppings)

I. Sheet erosion: In areas that are sheet eroded, reconnecting remnant topsoil islands is easily and effectively accomplished by laying cut scrub or dead branches along the contour across these gaps. The scrub will slow and filter flows of water and wind and trap sediment, litter and seeds **(Figure 23)**.

It is important to extend scrub sieves up onto each island to avoid water cutting round the sides. Ripping, at right angles to the flow, and adjacent to filters on the upslope might accelerate re-vegetation but must be balanced against the cost **(Figures 38, 39)**.

For large sheet eroded and scalded areas it is worth trialing running a spiked roller (of the kind used in road construction) across the bared areas. The pitting of the soil traps seeds and water and increases infiltration, thus reducing run-off. Gibber surfaces can be lightly graded, sweeping only the surface stones into bands 3 to 4m broad at right angles to the flow. The bands of stone will slow down run-off and trap seeds and silt.

II. Gutters and shallow gullies: Scrub filters can also be used successfully to stabilise rills and shallow gully heads, whether the heads are knocked down first or not. If possible, knock the heads down to stop the turbulent flow tumbling and undercutting back upslope. However, the heads can be left if scrub is packed in tightly for at least a metre above and two metres below the head **(Figure 27)**. Scrub filters should be pinned in place using pickets and wire – tied with a single strand **(Figures 24, 25, 26)**. When lopping side branches off living scrub always leave a central stem so that the plant can continue to grow.

Laid scrub is a very useful tool for small heads; it does not require machinery and can "nip any nickpoint (headcut) initials in the bud". Scrub filters slow run-off and trap plant debris, seeds and dung. They also decompose and release nutrients into the soil and usually act as a filter for water and wind transported fines and litter, rapidly forming functional fertile patches. Packed scrub often provides shade and protection from stock for the establishment of plant growth that over time reinforces or takes over the filtering role **(Figures 24, 25, 26)**.

Although laying cut scrub is labour intensive and most effectively done as team work, it is simple and effective for low gully heads and in particular for re-linking fragmented habitats **(Figure 23)**. Curara, which is one of the main scrub invaders of aridifying wetlands, is the most valuable scrub for brush packing ('The problem is the solution!') due to its stiff needle-like foliage which retains its form when dry.

(c) Mesh/Netting

Mesh can be used in a variety of ways and situations. For example: (i) laid flat **(Figure 28)**, (ii) rolls **(Figures 29, 30, 31)**, (iii) suspended **(Figure 32)**, or (iv) fences **(Figure 33)**.

These physical filters of flow help to slow the water, which means it is more likely to spread laterally and change channel function from being erosional (cutting down and sideways) to depositional (filling up with precious topsoil). Mesh can be laid flat across shallow gully headcuts **(Figure 28)**, but are best placed where the drainage forms narrower necks and just below channel junctions where there is less turbulence **(Figures 18, 36, 37)**.

Sieves can be particularly useful where flows are very strong, because the water is slowed, not checked. They are far cheaper and quicker to install than solid weirs. The size and robustness of these sieves should fit the energy of the local environment, ranging from ringlock rolls to sturdier septic-mesh rolls (e.g. Wooleen envirorolls). The mesh size should be around 10 x 10 cm; anything smaller becomes jammed with plant litter forming a barrier instead of a sieve. The sieve rolls are likely to rust over time and so a challenge is to replace their filtering function by planting a live sieve of strongly rooted perennial plants **(Figure 31)**. This will save having to replace the sieve and puts the process back in the hands of Nature.

(d) Sheet Materials

Impediments to flow can be suspended from heavy-duty cable across major channels to make the passing water have to work harder to proceed downstream. This slows and spreads water in a similar manner to sieves. A range of suspended materials can be used: corrugated iron sheets, heavy steel mesh (e.g. reinforcing mesh for concreting), heavy chain, car tyres or steel reinforced conveyor belt matting. The critical feature is to ensure that the lower edges of these suspensions are free to rise and fall with the passing of a flood. Try to keep the cable above flood height to allow big branches or dead stock to pass through. The cable can be fastened to a purpose built structure or to major trees (with polypipe sleeving to protect the tree). Props will be needed about every 10 metres for wide channels. This approach has been applied extremely successfully as floodgates on Todmorden Station near Oodnadatta in South Australia, using heavy steel mesh tied together and shaped to the channel. Make sure each panel is only fastened to the one below at one hinge line so that the structure is free swinging. One of these across the Alberga River in the same area went at least a metre underwater in 2011 with no problems **(Figure 34)**.

An interesting variation is to hinge the sieve to the channel floor using springs that allows flood flows to flatten the structure and then spring back into place as the flow recedes.

(e) Rakes

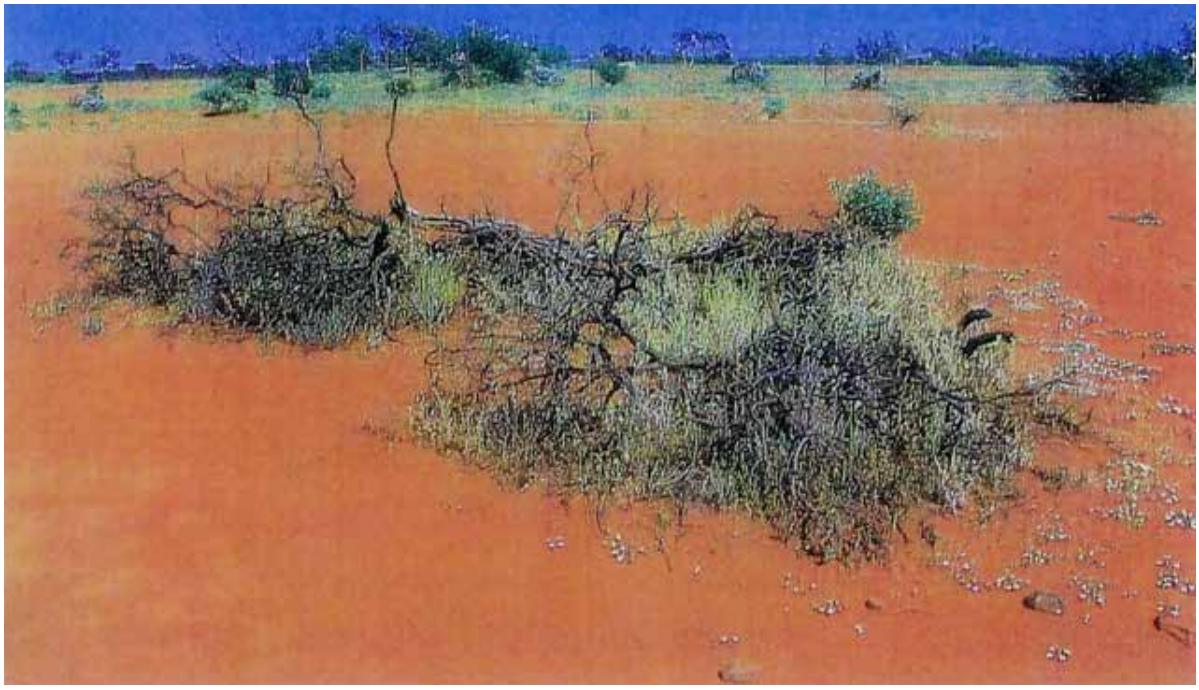
Drill rods can be placed at metre intervals across rock bars in channels to slow the flow and flip the system from erosional to depositional. Ferro-cement can be used, but may not be necessary if the rods can be snugly installed to a metre depth. The rods should be as high as the channel banks (or the estimated previous channel height before erosion cut it down). The "rakes" can be done in series for maximum effect. Rakes are best done where the bar is solid rock (i.e. not friable rock like shale or hardpan) and makes up both the sides and the base of the channel. Soft edges are prone to side cutting as the water will always look for an easy way round. It may be possible to protect soft sides. But this always carries risks of eventual side cutting.

Fixing drill rods in place requires special rock drilling equipment so is most feasible if there is a mine nearby **(Figure 35a)**.

(f) Gabions

A favourite erosion control method used in Africa, where there are many hands, are gabions of stone-filled mesh rolls. Typically these have been a total failure when placed in earth sided gullies and have instead exacerbated erosion **(Figure 35b)**. The simple rule is: a hard impeding structure, like a gabion or old vehicle tyres, only works where the sides and floor of the gully is rocky i.e. hard on hard works. Soft (sieves, mesh, scrub filters) on soft, or soft on hard works. But hard on soft does not.

a.



b.

Figure 22: Demonstrating the contrast of 'soft on soft' and 'hard on soft'.
(a) Dead branches collect wind and water borne debris that supports new growth.
(b) Tangle of old fencing wire has trapped sediments and seeds which aids growth of grasses and weeds. In contrast, old vehicle tyres worsen erosion (Photos: PJ Waddell).

a.

b.

Figure 23: Reconnecting fragmented habitats with brushwood.

(a) Aerial view of sheet eroded and scalded once 'best pastures' of chenopods, overgrazed in early times by sheep. If deemed worthy of repair, black markings indicate where brushwood (cut scrub) can be laid and pinned in place to form linkages between remnant patches. Stock and kangaroos would have to be kept out.

(b) Stripes of mulga contour groves in advanced stages of fragmentation on bare sheetwash plains.

a.

b.

Figure 24: Brush packing of shallow gully heads in a scrub invaded floodplain grassland.

(a) View upstream: Example of a shallow gully head packed with brush and pinned in place with star pickets and a single low strand of baling wire looped around the stems. Scrub tips face upsteam and overlap the headcut by 1m. Dry season aspect. Note the bare throat area with pinnacles of soil held by the stubs of perennial grasses.

(b) View downstream of the same site after rain and shallow flood. Note throat area smoothed off by erosion, and the growth cover of annual grasses.

a.

b.

Figure 25: A gully head adjacent to Figure 24.
(a) View downstream showing large amount of trapped debris – litter, seeds and dung.
(b) View upstream showing establishment of perennial grasses in the protection of the brush packing.

a.

b.

Figure 26: Failed example of brush packing.
Brush packed into gully head but not to 1m across the vertical edge of the nickpoint lip, hence erosion continued to cut back and to scour out the throat area.
(a) View downstream,
(b) Vertical view. Flow from right to left.

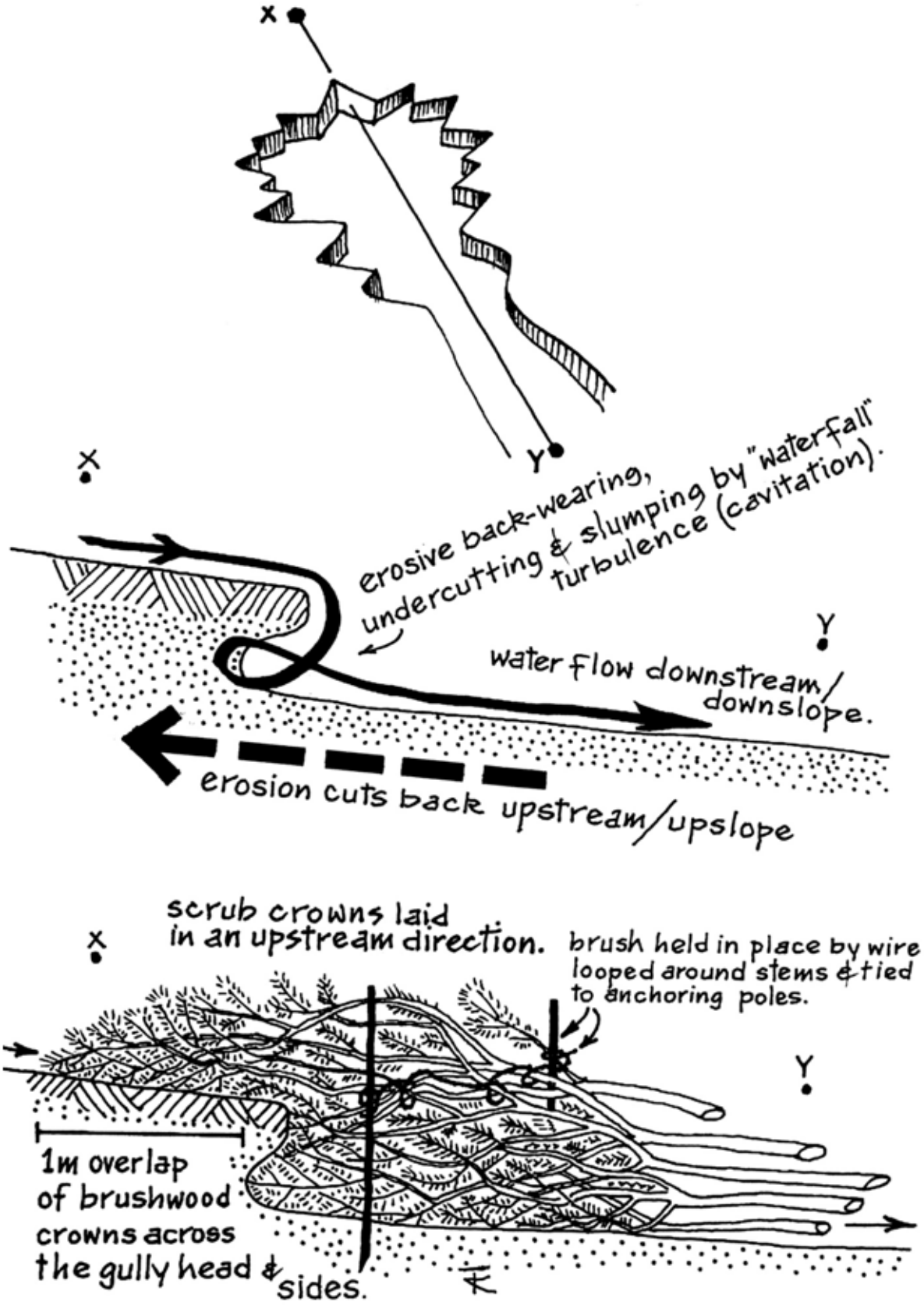


Figure 27: Shallow gully head erosion and correct method of scrub packing.

a.

b.

Figure 28: Shallow gully stabilisation using flat laid mesh.
(a) The gully nickpoint/headcut (Photo: PJ Waddell).
(b) Mesh in place (Photo: PJ Waddell).

c.

d

(c) Dry season aspect.
(d) After rain and shallow flooding with grass flush and accumulation of debris along the leading edge.

a.

b.

c.

Figure 29: Mesh roll sieve structures.
(a) Constructing the mesh roll.
(b) Emplacement of rolls in series across a flood channel, to slow runoff, trap sediment and debris.
(c) Successful functioning of a mesh roll after rains (Photos: PJ Waddell).

Figure 30: Station communities with school children constructing a mesh roll.
Materials of plastic coated mesh, lightly stuffed with needlebush (Photos: Lucy Brownlie, Yakkabindi Station).

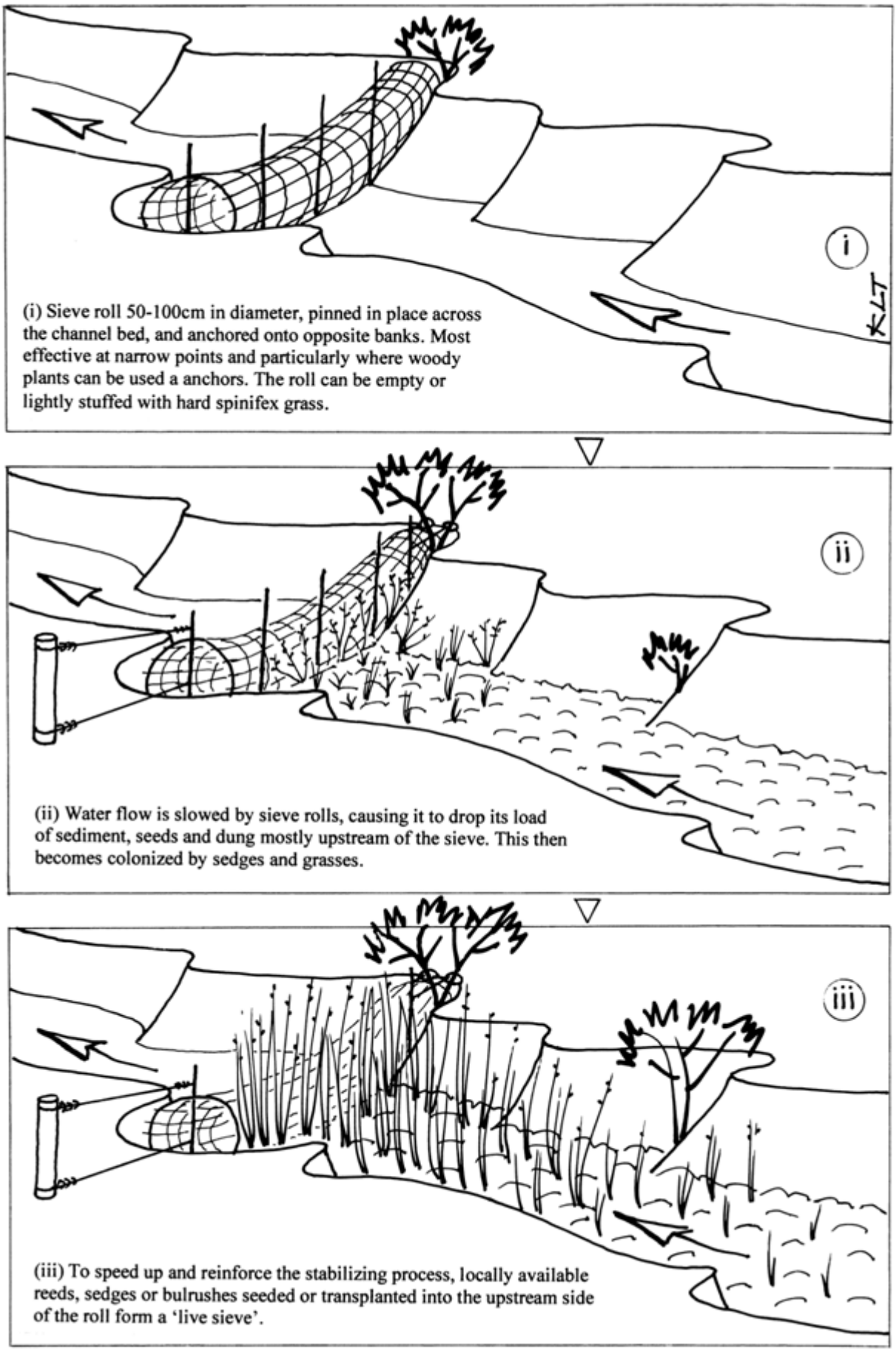


Figure 31: Netting/Ringlock Sieve Rolls.

a.

b.

Figure 32: Mesh fence suspended at key points across a creek.
(a) Fence secured on the trees using polypipe as a protection for the bark.
(b) Flow right to left. The mesh fence traps debris but in large floods lifts up allowing free flow of large branches (Photos: Hugh Pringle).

a.

b.

Figure33: Lateral mesh wings extending out from a suspended mesh fence on opposite banks of a creek.
(a) Far enough from the creek edge to catch the main flood-out.
(b) Close-up of fence work (Photos: Hugh Pringle).

a.

b.

Figure 34: Suspended conveyor belt.
(a) Emplacement of the conveyor belt at a narrows.
(b) After the first rains a massive build up of sand and flood debris (Photos: Hugh Pringle).

a.

b.

Figure 35: Rakes and Gabions.
(a) A rake filter formed by a single line of drilling rods with the view upstream of a long pool now filled with sand, protecting the store of water from evaporation. Rakes can also be set in a series of lines across the flow.
(b) 'Hard on soft'. A failed gabion (Photo: PJ Waddell).

(2) Gully Stabilisation

Gully heads are the active face of erosion and tend to split and spread as they cut back upstream or upslope **(Figures 36, 37, 40)**. While they are generally regarded as a soil erosion issue, the most ecologically and commercially damaging aspect of gully heads is that they literally draw water to them from the surrounding land. In the rangelands this is fatal for the functioning of ecosystems and businesses based on renewable natural resources.

Gully heads typically require a combination of stabilising methods depending on the size and severity of the gully system and what materials and machinery are available. A key action is to knock the walls of the gully head down. Small shallow heads can be broken with a shovel, pounded flat or trampled-in (most effectively by concentrating a herd of cattle on the site for a short time using an attractant like molasses or salt). If the heads are slightly deeper (up to about 50 cm), deep ripping may be enough to stop the head cutting back **(Figures 38, 39)**. Heads can also be flattened with a grader or front-end loader bucket very quickly if shallower than about a metre and a half and stabilised with calcrete rubble bunds **(Figure 41a-f)**.

Deeper gully heads may be knocked down more effectively with a dozer. Gully heads metres deep might best be flattened using carefully placed explosives, or where available, filled with large calcrete blocks and the headcut shielded from flow by a large bund with down-curved ends **(Figure 37)**. As a rule, the gully sides should also be sloped back, especially where they are actively cutting laterally.

If a bank or scrub filtering is not used, it may be necessary to flatten and harden the ground at and above a flattened gully head to form a stable surface 'platform'. In small areas, geotextile can be used with a stone armouring. Crushed calcrete rubble is very effective, particularly if it can be a few centimetres thick and rolled. Extremely effective is to deep rip at right angles to flow above the treated gully head **(Figure 38)**.

(3) Banks/Bunds (embankments)

Successfully knocked down gully heads should become a gently sloping or level platform with battered sides. A down-curved bank can then be built around the head to either spill the water away from the gully, or to slow it down and direct it back into the gutter lower down **(Figure 37)**. The former is easier, but the choice may be determined for you by the shape of surrounding land. Some key points to remember when building banks:

- Keep all slopes gentle, this will minimise ongoing maintenance.
- Build every bank on a 'platform' deep ripped at right angle to the flow so that it forms a solid core below landscape level.
- "Spill" the water away slowly and widely, no "spurting" water away.
- Do your level measurements to make sure your spillways will work as planned before and after construction.
- Keep all disturbances (especially vehicles and motor bikes) away from spill zones at the end of banks.
- Whether you make the bank higher or lower, just make sure you do not create new problems.

As with all bunds, it may be useful to either flatten out any angry channels, or insert a series of mesh sieves far enough distance upslope to allow turbulent (erosive) flow to calm, slow and spread before it hits a check or diversion bank. This is particularly important if you don't have machinery yourself and want to minimise the risk of costly repairs.

Embankments can be used in two main ways. To check channel flow and spill it away to one or both sides - a check bank, or diversion bank if planned to send water to a particular place or in a particular direction. Diversion banks are important in a stream capture situation to (a) block the pirate tributary that has cut back from a lower level and taken over an adjacent drainage system, and (b) for reconnecting the affected drainage, directing flow back along its length and its associated flood-outs **(Figures 42, 43)**.

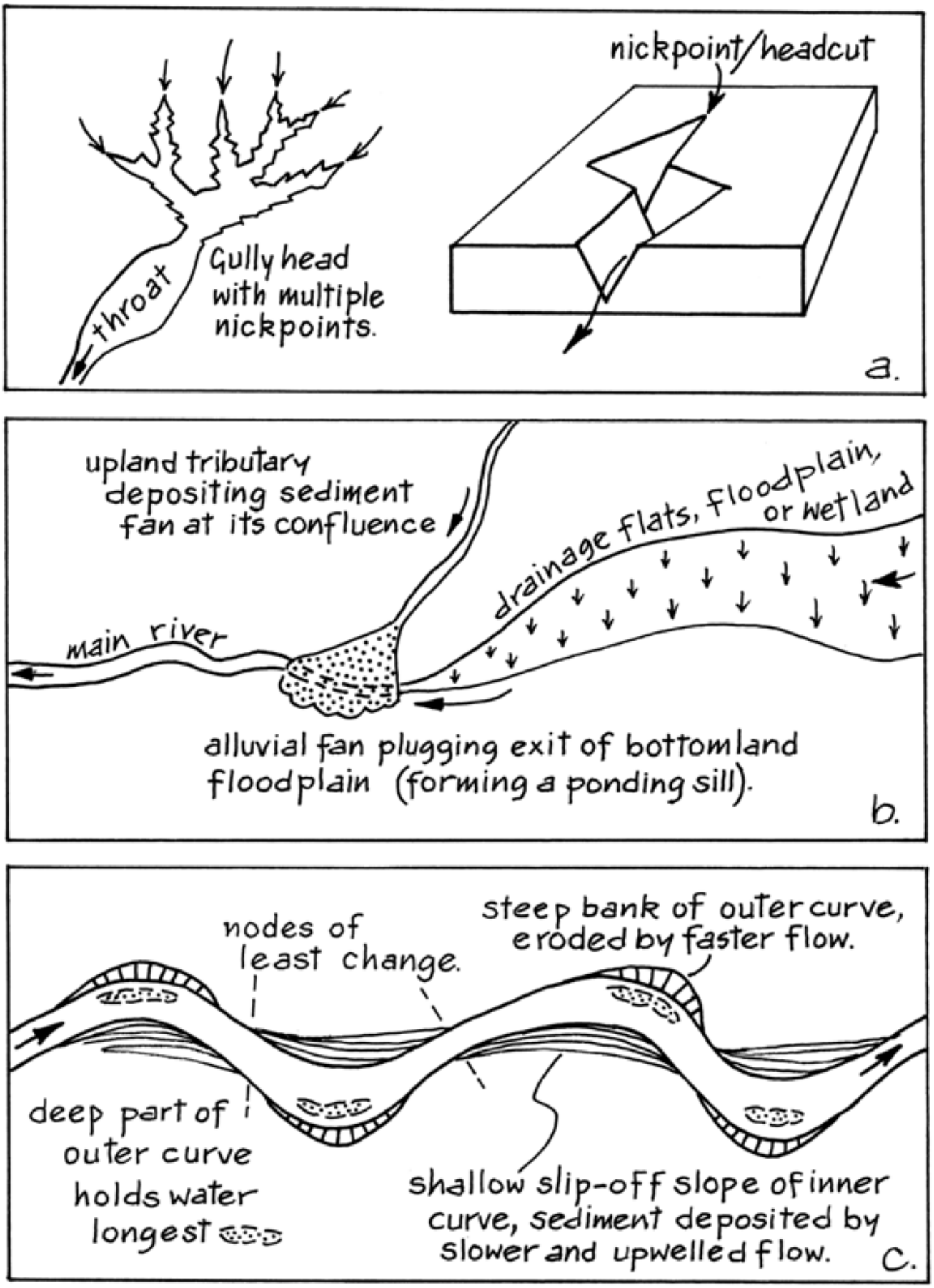


Figure 36: Nickpoints, Alluvial Plug and Meanders.
(a) Nickpoints, (b) Alluvial plug, (c) Meandering channel

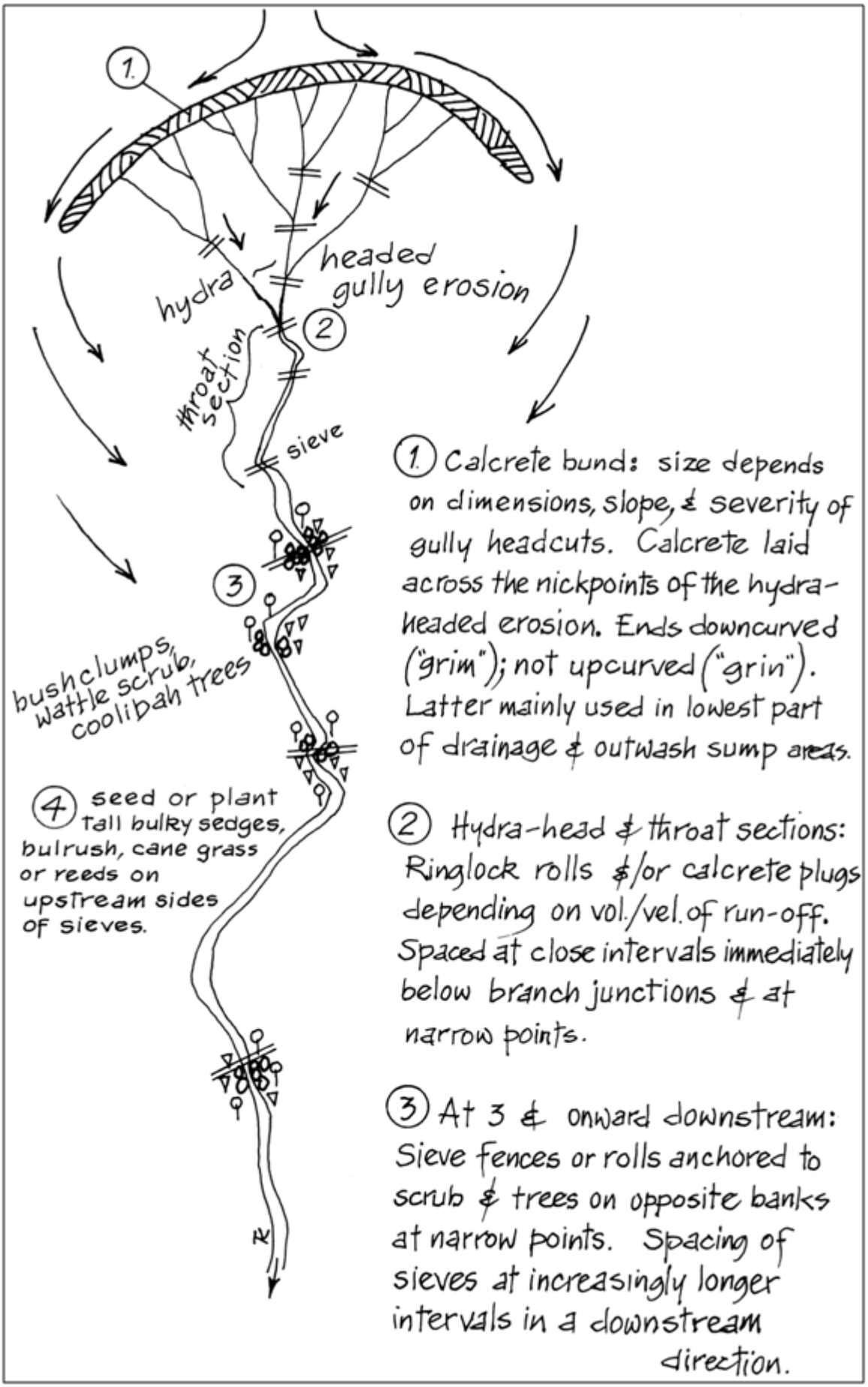
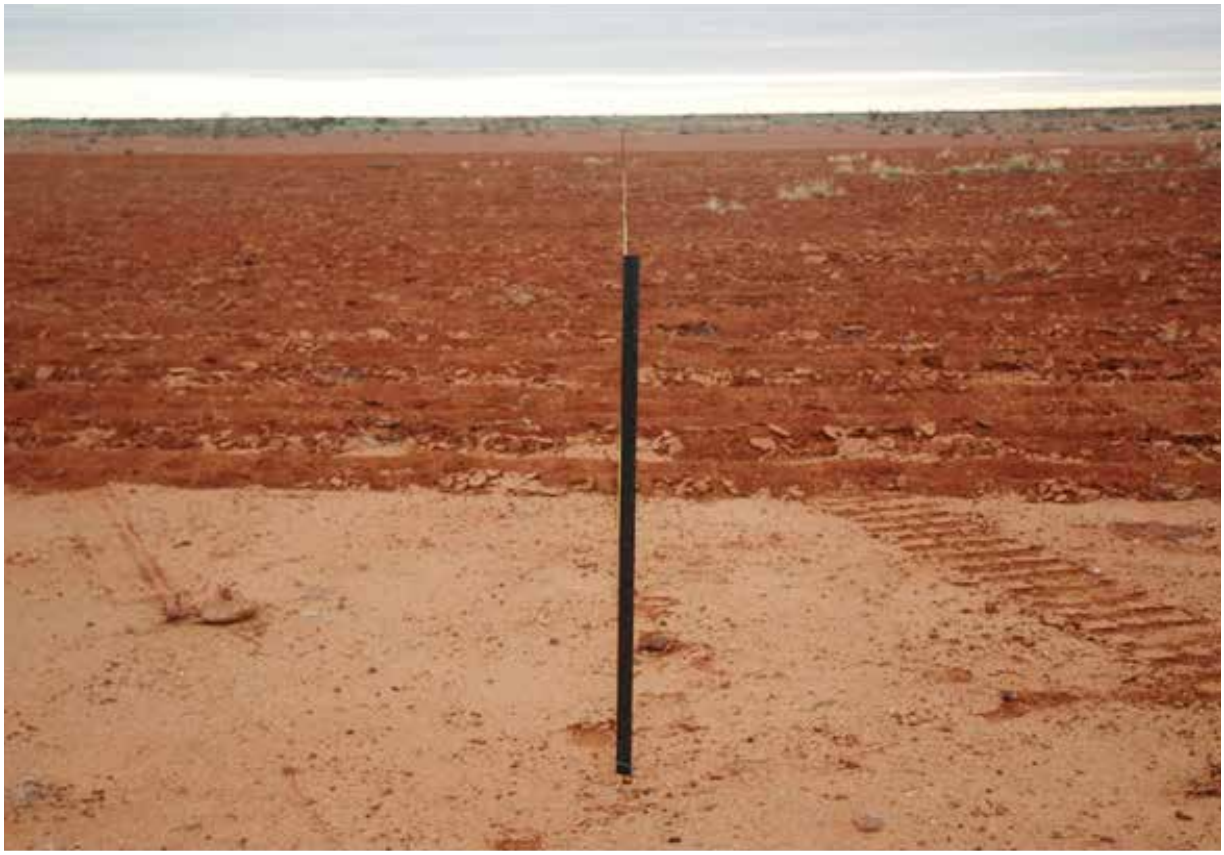


Figure 37: Bund and sieve layout for stabilising gully heads and their erosion channels.

a.

b.

Figure 38: Deep ripping across small and non-aggressive gully heads.
(a) Before, (b) After (Photos: Hugh Pringle).



a.

b.

Figure 39: Contour ripping has proven successful in central Australia.
(a) After ripping (b) The vegetation recovery at the same site (Photos: Hugh Pringle)

a.

b.

c.

Figure 40: A gully breached upper Gascoyne floodplain

(a) Healthy, mostly treeless, floodplain grassland of mainly swamp and claypan grasses. Some neverfail and Roebourne grass in depressions. Dry season aspect.

(b) The same grassland type in the wet on an adjacent part of the floodplain. Gully nickpoint eroded down to 1m depth, historically caused by a fence and track crossing lower down. Note even size/age invasion of coolibah trees.

(c) Same area as (b) in the dry, showing heavily grazed grassland and even age invasion of needlebush adjacent to another gully head.

a.

b.

c.

Figure 41: A six photo sequence of stabilising shallow gully heads using calcrete rubble bunds.

(a) One of multiple shallow gully heads in untreated state.

(b) Nickpoint lip trimmed down using front-end loader bucket edge.

(c) Calcrete bund positioned on top of the flattened headcut lip (bund 1m -1.3m wide x 0.6m high). Compacted using the under surface of the loader bucket, with lower angle slope on upstream face. Note location of the same lone needlebush in the next two photos.

d.

e.

f.

Figure 41 continued:

(d) Completed calcrete bund (Sept.2005). Drainage from right to left, main eroded channel lined by taller coolibah and wattle in the background.

(e) Same locality after local summer rains (no flooding). Perennial and annual grasses flourish, stabilising the disturbed surfaces (March 2006).

(f) Close-up of calcrete bund covered by dense, tall growth of both annual and perennial grasses along the base of both sides of the bund. The flat crest of the bund is the last to be colonized by grasses.

a.

b.

Figure 42: River piracy.
(a) View upstream from the causeway showing an old eroded station track that met with the main road. (b) Calcrete bund or causeway positioned to block a stream capture point and reconnect feeder drainage to a linear series of wetlands. Together initiating causes and promotion of the stream capture **(Figure 43).**

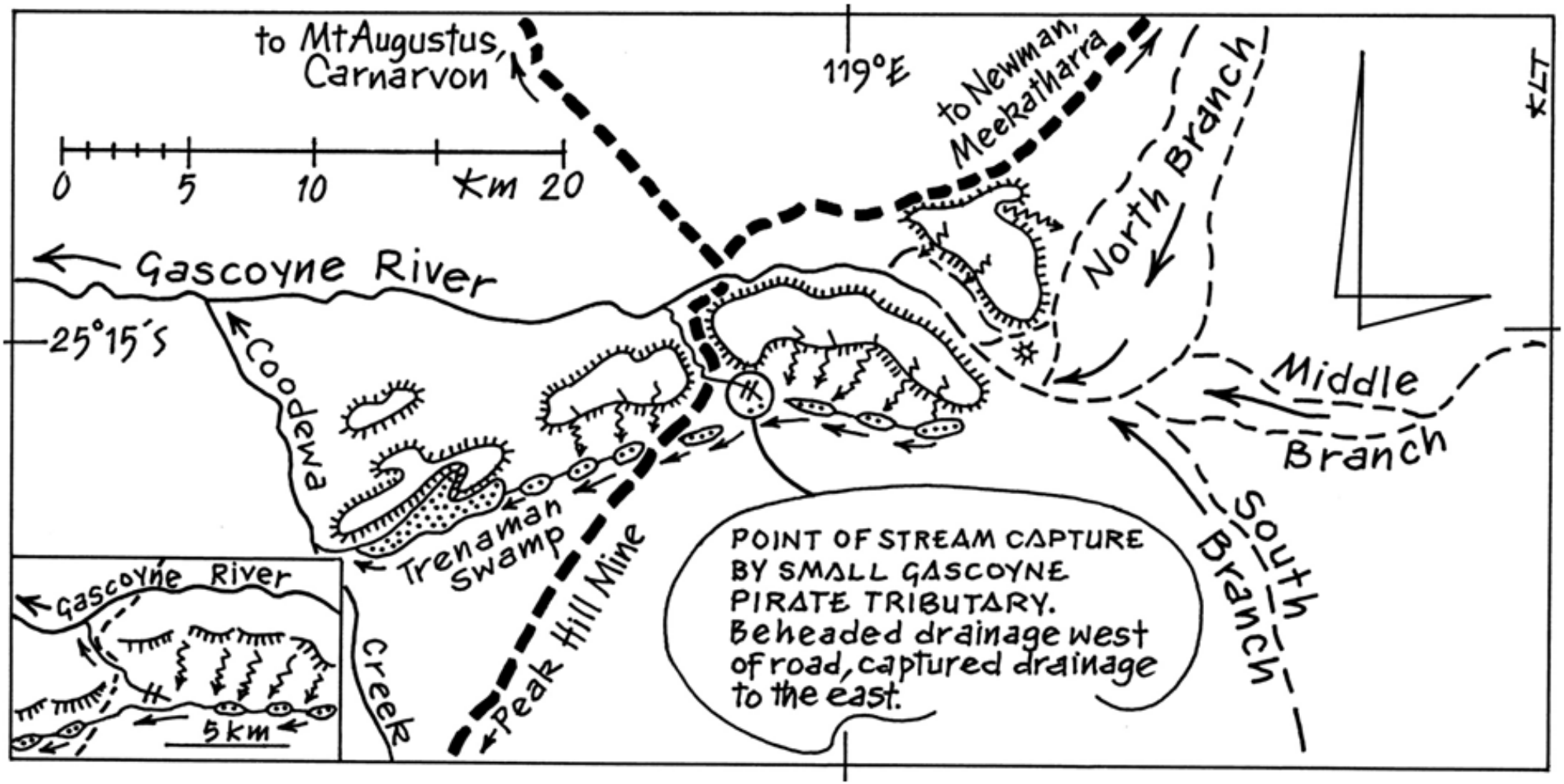


Figure 43: River Piracy.
Stream capture of a linear series of seasonal wetlands along the south side of several hill ranges by a small Gascoyne tributary cutting back upslope through a saddle in the hills. This was initiated and aided by the convergence at the saddle of an old station track with an unsealed main road used since ox-wagon days.

(4) Solid Structures

(a) Drop Structures

Where banks are to function as weirs they require a dipped centre to allow flow to spill over away from the vulnerable sides, but this requires special construction to avoid undercutting of the bank on the fall side. One method is to use a "drop structure" (where the flow is checked and dropped) but is tricky to construct unless some really flow resistant material is at hand (e.g. calcrete rubble). Otherwise, geotextile armouring with rocks heavy enough to withstand flows will be needed. This protects the prepared surface ("platform"), the structure and the apron immediately below where the water drops. Refer to end of Gully Stabilization (D2) regarding formation of the 'platform' **(Figure 44)**.

A range of materials can be used including cement, large rocks and carefully tied up car tyres filled with sand. One pastoralist has used carefully measured and cut tree trunks with a dip in the centre to allow easy flow through the centre and away from the edges of the channel.

The apron onto which water will tumble may need to be reinforced. The width of the reinforced section needs to be at least double the height of the structure to prevent undercutting. This can be done with a range of materials from cemented rock to geotextile with a rock covering, depending on what is available and the likely energy of the flows. Corrugated iron sheets can also be used as long as they can be attached to the structure strongly enough to withstand the tumbling waterfall.

(b) Stone or Earth Sills

Wetlands or floodplains are typically ponded by a low convexity at their exit or overflow ends. These may be solid such as a rock dyke, or a "soft" sill formed of plant-stabilised sediment. Erosion incisions from flood waters, tracks or pads lower the sill level releasing the ponded water like an unplugged bath, resulting in the demise of the wetland habitat. Even a lowering on only 30cm can affect a vast area of wetland in relatively flat terrain (e.g. **Frontispiece photos**).

To re-plug wetland sills, a low bank or deeply embedded wall-like structure exposed above ground level about 15cm has the double function of (a) reinforcing or restoring the wetland ponding sill (convexity), and critically (b) blocking the threat of sill breaching by an upstream cutting nickpoint. Depending on the size of the wetland and its overflow at the sill, soil stabilised by plant growth, a calcrete bund or cement blocks can be used to help repair the sill **(Figure 45a)**.

(c) Weirs

Weirs are low dams of substantial solid structure used to restore cut down channels to their previous undisturbed level, and in the process slowing and spreading the water flow. Weirs require a dipped or notched centre to keep flow away from the banks, plus a rock or concrete spillway. As they may be quite costly and time consuming to build, weirs need to be carefully planned and the site well chosen to ensure maximum effect and the best chance of long lasting success. As with all works, regular surveillance and occasional maintenance may be required **(Figure 45b)**.

(d) Sand dams

The ultimate aridland adaptation for rainwater storage and conservation is the sand dam that has been used from antiquity to the present day (refer Google "Sand Dams"). This is a dam built across a rocky watercourse that becomes filled with sand from rain runoff, or manually filled where local sand is in short supply. The sand acts as a sponge, filters the water and blocks evaporation loss, as the water is stored below the dry surface sand layer, out of reach of evaporation.

Very important for stock and wildlife is to either have a slightly porous wall, down to a certain depth, that slowly leaks water out; or more efficiently, a tap outlet to control flow. The tap should be positioned about a quarter of the way up the wall so that sufficient moisture is retained in the dam to facilitate wetting and recharge even by light rains. This also means that sufficient water remains to be accessed in times of dire need by digging holes in the sand, as kangaroos do in dry times. The preceding degree of saturation is very important so that rain runoff caught by the dam is not used up in recharging the sand aquifer from the floor up.

The advantages of sand dams include:

- Simple, low cost, low maintenance.
- Protects water against evaporation, as the water is stored below the dry surface sand layer out of reach of evaporation.
- Provides natural filtration (disinfection) of water.
- A source of water protected from the breeding of mosquitoes and other insects.
- Reduces contamination of the sand aquifer by stock or wildlife.
- Recharges adjacent surrounding soils.

(e) Rock Bars

Outcrops of rock across a riverbed are important for pooling flow in an upstream direction, inhibit river down-cutting and spread flood waters laterally onto floodplains. Where these are breached **(Figure 46)** the drop in flow level may leave the adjacent floodplains in a perched drying out condition. To restore effective flooding the breach can be repaired using ferro-cement up to the same level as the remaining part of the rock bar.

Footnote: Being hygroscopic calcrete rubble is the supreme material for stabilising low gully heads and establishing banks as it compacts when wet.

a.

b.

Figure 44: A 'Drop Structure' for water flow to tumble down onto a lower level.
Constructed of old fence posts. (a) Sideview, flow left to right. (b) Front view upstream (Photos: Hugh Pringle).

a.

b.

Figure 45: Sills and Weirs.

(a) Low ponding sill (30-40cm high) to block upstream cutting gully head (at left), and to protect wetlands from elimination by gully breaching. Drainage from right to left.

(b) A failed weir that was poorly positioned in the landscape. The solid structure 2.5m high was built into a drainage line between soft-sided slopes that offered limited resistance to the eventual build up in volume and velocity of water during a large rainfall event. Eventually resulting in a 'blow-out' in the area of least resistance. (Photos: PJ Waddell)

a.

b

Figure 46: The Milly Milly Rockbar.
(a) The aerial photo shows the rockbar position in the centre across the flow (from right to left).
(b) The breached gap in the rockbar, amenable to repair would help to spread floodwaters laterally onto the floodplains.

(5) Road 'Rivers' and Road Barriers

Sheet flows are often intercepted by tracks and fencelines and directed along them instead of across them to rehydrate the landscapes downslope. This is a major problem in rangelands and is easily avoided by proper planning and maintenance of infrastructure **(Figures 47, 48)**.

The need for remedial works can be avoided by:

I. Planning tracks along contours and as close to the watershed as possible.

II. Crossing drainage tracks and valley floors at right angles to flow.

III. Leave the land level perfectly flat when sweeping a new track (perhaps using a "stick rake"; pushing scrub along in front of a machine).

IV. NEVER make windrows (soil/gravel ridges left behind by the shedding end of the grader blade) - they exacerbate dehydration, block overland flow causing water starvation downslope and can initiate erosion where they are breached (usually in a more active drainage zone susceptible to gullying).

V. Keep off all tracks when wet, and commit to repair works if it is imperative to go out in the wet.

Speed bumps or whoaboys are low, trafficable banks across tracks that return harvested water back to their natural drainage systems and overcome water droughting on downslope sides of channeled tracks. The chance of whoaboy failure is minimised if they are built on deep rip lines perpendicular to the channeled flow. They may be necessary when there has been too much soil loss by down and lateral cutting of the "track creek". However, it is quite common for the amount of material available in unwanted windrows to be sufficient to flatten out the track at the terrain level.

Drains should not be needed in well planned or repaired tracks, but where used, they should be flat and wide floodways that release water gently - no rushing water.

Major roads built on raised beds block the flow of rain runoff, flooding the upslope side and causing water starvation on the downslope side that kills all vegetation including trees for one to two kilometers distance **(Figure 47)**. The culverts used for roads on raised beds are totally inadequate to the task as they dam water on the upside and spurt water out on the downside causing gully erosion **(Figure 48b)**.

(6) Mechanical/Electronic Aids

(a) Ripper.
(b) Ploughs (chisel, pitter, opposed discs, niche seeder).
(c) Spiked Roller.
(d) Grader, bulldozer, bobcat, front-end loader (with ripper attachment).
(e) Field Laser-level (200m range) with staff.

a.

b.

Figure 47:
(a) An example of hardtop main road built up higher than the surrounding sheetwash plain country causing a temporary green paradise on the upslope side and (b) Near total death of vegetation on the water starved downslope side.

a.

b.

c.

Figure 48: Main hardtop road between Mt Magnet and Leinster.

(a) Early section built by the Mt Magnet Shire roads team between Mt Magnet and the Challa turn-off. Constructed level with the surrounding sheetwash terrain – result, no erosion, no water starvation and no death of vegetation.

(b) The 'modern' method built eastward of the Challa turn-off, by a contracted road construction company obviously ignorant of aridland processes. New hardtop road built in parts to 2m above the washplains with small culverts that dam the flow on one side and cause erosion from the spurted water on the outlet side. Vegetation water starved dead and dying.

(c) A traveller tried to get off the new road but the steep sides were a trap. 'Road rivers' have formed along the troughs on either side of the road.

Summary of Erosion Control Methods

(a) In-channel structures

Channels are naturally the highest energy feature of a drainage system and care should always be taken when planning erosion control work to avoid making the situation worse should the works fail. However, successful works within channels if correctly positioned can back up and spread water out for long distances. They can be linked to other works such as putting an obstruction to flow below an overbank channel, which may need to be widened slightly to increase its flood spreading effectiveness.

It is also important to do a series of in-channel works wherever possible as water that has just dropped substantial amounts of sediment at a calming structure will be freer to accelerate and recommence erosion immediately downstream. Where structures may cause flows to overbank, it is important that this is done calmly (wide and very little slope). This means that structures may need to be extended beyond the channel itself – or keyed into a filter or spreader bank.

It is quite possible that with climate change high energy storm events will increase in frequency and intensity. Thus care should be taken to plan for this likelihood and over-engineering may be warranted as a response to this increased risk. This likelihood also reinforces the need to act to calm and spread flows so that in-channel flow does not continue to "steal" increasingly more surface water, dehydrating the hinterland. Refer to the combinations of mesh/netting (D1c), sheet materials (D1d) and banks (D3).

(b) Managing water out on the plain

Always start with your most productive country and work outwards, especially where badly degraded land impinges on best country. Keeping the water out on the plain is possibly more important than putting in ponding banks and so forth. There are often gully heads cutting laterally back from main channels to intercept and steal water flowing across, or ponded, on the plains. These lateral "thieves" need to be knocked down and either re-plugged with bunds (see D3 above) or blocked by a diversion bank that takes the plains water back downslope in its natural course as sheet flow. Series of sieve structures (D1) are the most effective means of slowing runoff on plainsland. However, any strong runoff from upslope needs to be calmed first, particularly where gully heads are involved (D 2 & 3).

Ponding banks are particularly useful where soils have sealed over and have high salt content. Gradually the salt is washed out of the soil profile and plant cover can return. There are many different ways (found in most soil conservation manuals) to plan these banks to spill onto each other, which helps slow flows. Deep ripping the ponded area can greatly accelerate the recovery process, or running a spiked roller across the bared and scalded area can greatly accelerate the recovery process.

(c) Enhancing existing overbank flood outlets

Overbank outlets may fall into disuse due to the main channel deepening and widening, confining most flows within the channel and leaving the floodplain behind in a perched condition. In this case, only by raising the level of the channel bed will overbank flooding be restored. The easiest way is to use one or more of the suspended structures (D1 c, d) that will cause deposition and build up of sediment raising the level of the channel floor. Widening the overbank outlet will help spread the overbank flow and reduce the likelihood of initiating scour or guttering of the immediate floodplain.

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APPENDICES

Appendix 1: Definitions and Explanations

Base-levels: Two kinds of base-levels regulate fluvial processes: (a) Erosion base-level is the lowest level to which a stream channel can incise its bed. Erosion base-levels are primary (e.g. sea level, saltlake or dunefield), secondary (e.g. a rock bar), and tertiary or local base-levels. (b) Deposition base-level is the highest level to which a sediment deposit can be built (e.g. crest of a rock-bar or dam).

Benchmark Paddock: A fenced or unfenced, mostly stock-free or least grazed area, where the highest number of landsystems abut (ecojunction) within a 5 km radius or 10 x 10 paddock size area. A reference area where responses of the different landsystems to extreme events and grazing can be compared and understood in terms of landscape function, biodiversity conservation, phenology and grazing strategies.

'Berry-birds': Birds attracted to feed on typically brightly coloured berries or berry-like drupes and arillate seeds. Seeds are voided at perch sites and can grow into bushclumps or thickets.

Biodiversity: The geographic diversity of terrestrial, freshwater and marine ecosystems. The diversity of their composition, structure and functioning. The number and variety of their plants and animals - their habitats and their genes (expanded IUCN definition).

Catena: A repeat sequence of soils and their biotic components which vary with relief and drainage. (a) A topo-catena sequence is represented by a terrain profile from a hill-top to a valley bottom. (b) An alluvio-catena is a horizontal or faint slope sequence of depositionally differentiated soils. (c) Drainage or valley-side catena is a repeat pattern expressed typically by the valley-side tributaries of rivers. From upland to valley the pattern comprises of (i) a source area of dendritic streams that (ii) converge near or below the footslope, and (iii) spread out into a depositional fan.

Conservation: The wise use of the Earth's resources by humanity by protecting their capacity for self-renewal through ecologically sustainable practices (author unknown).

Critical Control Points in Drainage: Those sites, areas or situations where minimal intervention can have far reaching positive responses that entrain the natural processes to do most of the repair work.

Drainage/Fluvial Ecosystem: Surface drainage catchments or basins are geomorphic units bound by their watershed divides. These contain a size hierarchy of tributary sub-unit compartments each in turn partially enclosed by divides. Each unit contains all the landscape processes and responses between the physical, biotic and human actions that occur within it.

Drainage and Ponding Sills: A sill in a drainage process context is any low convexity, either natural or artificial, that is formative and temporarily protective of floodplain and wetland of all kinds from extinction by incision from upstream migrating gullies. Unless of rock, many sills forming local base levels are composed of unconsolidated detritus held in place by plant growth and are hence mutable. An artificial stone or concrete wall deeply embedded to obviate undercutting, at right angles across flow, with less than about 15cm sticking out above ground level. The fundamental being to form a permanent local base level to block the upstream migration of gully incision (similar to a rock bar). It does not block free flow like a weir does.

Ecology: The relationships and interactions between the physical and living components of the environment, and between the organisms themselves.

Ecosystem: A natural geo-ecological system occurring in definable geographic process unit areas, and characterised by particular physical and biotic features.

Ecotone/Edge Effect/Tension Zone: The shifting transition or overlap zone of influence or interaction between two different ecological communities (e.g. between forest and grassland). Ecotones vary in width and have their own characteristic features in addition to sharing components from the abutting communities.

Hence, ecotones can be zones of greater species diversity than the adjacent communities. Sharp edged ecotones are typically caused by an abrupt change in edaphic conditions, and/or due to high frequency of fire, overgrazing or susceptibility to erosion. An expanding ecotone of 'today' can become the major ecosystem of 'tomorrow'. The ecotone attributes noted here emphasise the importance of ecojunction areas for understanding in what ways the station's landsystems function and interact, as each are likely to have different responses to extreme events.

Ecojunctions: Areas where different ecosystems or landsystems abut, containing representative areas of each type plus their ecotones. The highest number of systems within a chosen radius, say 5km or a 10x10km paddock area at a map scale of 1km=1cm, indicates potentially high or highest ecological diversity. At broad survey scales a 25 or 50km radius is a valuable first indicator of potential highest biodiversity areas.

Environment: Everything external to an organism or group of organisms.

Exclosure: An area, of varying size, fenced off to exclude herbivores. Used as a visual reference site against which a relative assessment is made in comparison to the surrounding grazed areas. Or to protect rare flora, fauna, habitat or as a seed source area (cf. Benchmark Paddock).

Geomorphology: Study of the origin and development of landforms and their formative processes.

Geomorphic Reciprocal: Process shapes form, and changing form shapes process.

Habitat: The place in which a plant, animal or a community lives; characterised by its particular physical and biotic make up.

Keystones: A keystone ecosystem or habitat is one that is indispensable for a particular reason, such as high carrying capacity run-on grasslands and seasonal wetlands and/or permanent springs and seeps in aridlands. Or one that contains and supports a complex vegetation structure and/or a unique array of species e.g. forest patches in savannas. Keystone plants and animals are those that have a disproportionately important role in affecting ecosystem structure, composition and function e.g. fig trees in native forests, frugivores, goats and large herds of stock or game. For further examples: see "Secrets of our Living Planet" BBC Documentary Film presented by Chris Packham.

Landscape Diversity=Terrestrial Ecodiversity: Embracing the total geo-biotic diversity of all kinds of ecosystems at all scales – their geography, landforms, geology, soils, water-types, biotic composition, patterns and processes.

Land Systems: A catena approach to identifying, mapping and managing landscape units. "An area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation" (Christian & Stewart 1953).

Pediment: a low gradient sheetwash plain of weathered material that slopes gently (1 – 7°) down towards the bottomland from the foot of an upland. The lower pediment often a sand-mantled fan.

Resilience: "Capacity of the land to withstand and recover from drought, floods, fire or human mismanagement" (FAO, United Nations). "The amount of change a system can undergo and remain within the same regime – essentially retaining the same function, structure and feedbacks (response diversity)" Walker & Salt 2006.

Savanna: Wooded grasslands or grassy woodlands occurring between the equator and the subtropics/warm temperate overlap.

(a) Arid scrub (trees 5-10m) savanna, thickets, grasslands, and deserts between the 500 and 125mm isohyets, e.g. greater central Australia, Kalahari-Namibia, Sahel Zone of Sahara, Indian Thar Desert. Extreme Desert (per-arid) below the 125mm isohyet.

(b) Moist savanna woodlands/open forest. Tall trees (10-20m) over a grass groundlayer, with dry-forest patches > 1000mm isohyet. e.g. Eucalypt grassy woodlands of monsoon belt across Top End Australia, equivalent in Africa to the Caesalpiniaceous (Miombo) woodlands. A mesic transitional zone between arid and moist savannas (approx. between 500-600mm and 1000mm isohyet).

Soil Moisture Balance (SMB): The amount of moisture required to support and maintain a particular kind of plant community in a state of dynamic equilibrium or balance. Anything that shifts this balance over time towards drier or wetter conditions entrains inexorable changes in the plant cover's physiognomy and species make-up as adjustments to the altered edaphic condition develop.

Six Intrinsic Unifying Ecological Properties:

(1) Everything is connected to everything else.
(2) Everything must go somewhere (a place, habitat).
(3) Nature knows best.
(4) Everything and every being has a role to play (in the healthy function of Planet Earth).
(5) Ever changing/Dynamic
(6) Symbiotic/Synergistic

(For examples see "Secrets of our Living Planet" BBC Documentary Film presented by Chris Packham).

Succession: Sequential replacement changes of land surfaces, vegetation and fauna in response to changes in the environment, such as those induced by geo-ecological processes and/or in-situ developments.
Examples (1) Land surfaces: topsoil truncation exposing the subsoil as the new land surface or gullied plainsland. (2) Alluvial grasslands on base-rich gley soils transformed to solonetzic aridosol scrubland due to cessation of annual flooding. (3) Vegetation Structure/Floral and Faunal composition: (a) changes brought on by undisturbed maturation development of plant community, taller and denser, favourable to shade tolerant plants and animals of closed habitats such as thicket and forest. (b) High diversity of plants forming a variety of habitats – converted by overgrazing and browsing to a simplified structure of out of reach canopy trees only (the topfeed middle and recruitment layers now missing), replacement of palatable plants by unpalatable species and annuals, i.e. to the disadvantage of the original flora and fauna components/make-up.

Sustainability: "Sustainability is based on a simple principle: Everything that we need for our survival and wellbeing depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations" (EPA of the USA). "The key to sustainability lies in enhancing the resilience of social-ecological systems, not in optimising isolated components of the system – by maintaining a system's capacity to absorb disturbances without a regime shift" (Walker & Salt 2006).

Vegetation Stripe Pattern: Pediment sheetwash deposited litter and sand trains in stripes parallel to the contour and colonised by plants (stripe groves). Each stripe alternates with broader bands of bare ground (intergrove) that forms each grove's local catchment. Hence the tiger or zebra-like pattern.

Woody Plants (Macquarie Dictionary, Oxford English Dictionary):

Tree: a perennial woody plant, typically single-stemmed (some trees have forms with several trunks).

Scrub: Small or low trees or stunted trees (e.g. mulga country 3-7m canopy height, emergents 8-10m).

Shrub: multi-stemmed perennial woody plant branching from below or near ground level, so has no clear trunk (e.g. <1.5-3m in the arid, <5m in Top End).

Shrublet: small shrubs, e.g. chenopods, frankenia.

Appendix 2: Plant Names

Large trees:

boab	*Adansonia gregorii*
coolibah	*Eucalyptus victrix*
river gum	*Eucalyptus camaldulensis*
stringybark	*Eucalyptus tetrodonta*
woollybutt	*Eucalyptus miniata*

Small trees (scrub):

bardi bush	*Acacia victoriae*
bauhenia	*Bauhenia cunninghamii*
berrigan	*Eremophila longifolia*
black mulga	*Acacia citrinoviridis*
blue bardi bush	*Acacia synchronicia*
curara	*Acacia tetragonophylla*
desert kurrajong	*Brachychiton gregorii*
desert willow	*Pittosporum phylliraeoides*
fine-leaf jam	*Acacia burkittii*
gutta percha	*Excoecaria parvifolia*
lantern bush	*Dichrostachys spicata*
mingah	*Alectryon oleifolius*
mulga	*Acacia aneura*
quandong	*Santalum acuminatum*
naked lady	*Exocarpos aphyllus*
needle bush	*Hakea preissii*
rosewood	*Terminalia volucris*
silverbox	*Eucalyptus pruinosa*
snakewood	*Acacia xiphophylla*
supplejack	*Ventilago viminalis*
wait-a-while	*Acacia cuspidifolia*

Shrubs:

bluebush	*Chenopodium,Maireana spp.*
chenopods	*Atriplex,Chenopodium, Rhagodia, Enchylaena, Maireana spp.*
currant bush	*Scaevola spinescens*
frankenia	*Frankenia spp.*
fuchsia bush	*Eremophila maculata*
golden bluebush	*Maireana georgii*
lax bluebush	*Maireana thesioides*
lignum	*Muehlenbeckia florulenta*
pink-seed bluebush	*Maireana trichoptera*
ruby saltbush	*Enchylaena tomentosa*
sago bush	*Maireana pyramidata*
silver saltbush	*Atriplex bunburyana*
swamp bluebush	*Chenopodium auricomum*
tall saltbush	*Rhagodia eremaea*
turpentine bush	*Eremophila fraseri*
warty leaf eremophila	*Eremophila latrobei*

Grasses:

birdwood grass	*Cenchrus setiger*
black-soil sorghum	*Sarga australiense*
broad-leaved wanderrie grass	*Monachather paradoxa*
buffel grass	*Cenchrus ciliaris*
curly bluegrass	*Dicanthium fecundum*
creek canegrass	*Leptochloa digitata*
kangaroo grass	*Themeda triandra*
kerosene grass	*Aristida hygrometrica*
lemon grass	*Cymbopogon ambiguus*
Mitchell grasses	*Astrebla spp.*
Murchison Redgrass	*Eragrostis dielsii*
ribbongrass	*Chrysopogon fallax*
sand-soil sorghum	*Sarga stipoideum*
silky browntop	*Eulalia aurea*
silver speargrass	*Austrostipa elegantissima*
soft spinifex	*Triodia pungens*
windgrass	*Aristida contorta*

Appendix 3: EMU Monitoring Tickbox

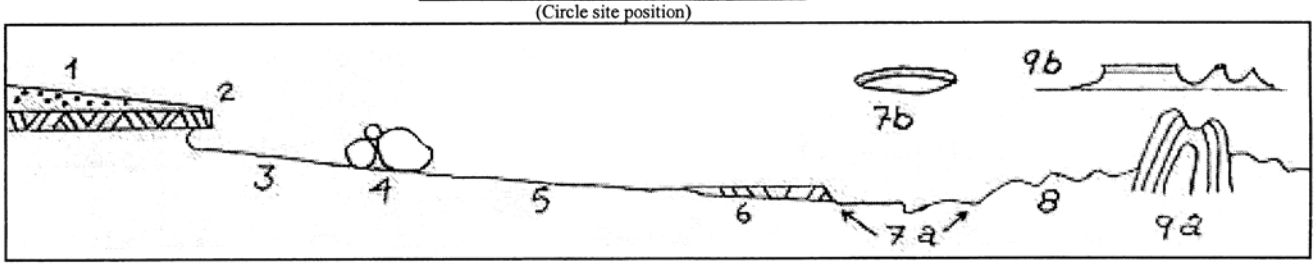
STATION_____ DATE_____

SITE NO:/NAME		PADDOCK		LAND SYSTEM	
NEAREST WATERING POINT	KM	WATERING POINT NAME	PHOTO	DATE	NO
			GROUND		
			AIR		

SPECIFIC MANAGEMENT ISSUES (Reasons for monitoring this area)

MANAGEMENT HISTORY

PROFILE OF PREVALENT LANDSCAPE CATENA SEQUENCE IN THE GASCOYNE-MURCHISON REGION
(Circle site position)



1. OLD PLATEAU SURFACE Red sand over laterite duricrust. (Run-in)	**2. LATERITE BREAKAWAY** Scarp retreat & exposure of saline kaolin (Run-in, -off)	**3. UPPER STRIPPED WASHSLOPE** Saline duplex soil over hardpan. Shallow brittle topsoil (Run-off, -through)	**4. GRANITE OUTCROP** Domes, tors, ridges, hills (Run-in, -off)	**5. MIDSLOPE WASHPLAINS** "hardpan plains" "hard mulga country" (Run-on, -off, -through)
6.LOWER SLOPE SAND DEPOSITION Wanderrie banks, (Run-on,-in,-off, -through)	**7. BOTTOMLANDS** (a) **CREEK, FLOODPLAIN & BILLABONGS** (Run-on, -in,-off, -through)	(b) **CLAYPAN OR SALTLAKE** (Run-on)	**8. UNDULATING TERRAIN** eg. Calcrete country, rolling plains, low rises (Run –in,-off, -through)	**9. RIDGES & RANGES** **(a) FOLD RANGES** Rocky outcrops of tilted strata **(b) TABLELAND RESIDUALS of** Horizontal strata (all Run –in,-off)

LAND SURFACE/SOIL TYPE & COLOUR (Tick)

ROCK TYPE	**Laterite Duricrust**	**Banded Ironstone**	**Granite Gneiss**	**Basalt Dolerite Gabbro**	**Sandstone Quartzite**	**Shale Siltstone Mudstone**	**Silica Hardpan**	**Calcrete Limestone Dolomite**	
SOIL SURFACE	**Stony**	**Gravelly**	**Earthy Loam**	**Sandy**	**Silty**	**Clayey**	**Litter cover**	**Bare**	**Algal Mat**
SOIL PROFILE	**Uniform (same throughout)**	**Gradational (increasing texture with depth)**	**Duplex (texture contrast between top & subsoil)**	**Crabhole Cracking Clays**					

SITE NO	PADDOCK				UPDATED PHOTO GROUND	DATE	NO
SEASONAL CONDITION	EXCELLENT	VERY GOOD	GOOD		AIR		
	AVERAGE	BELOW AVERAGE	DROUGHT				
RAINFALL Quarterly amounts: Total mm	J.F.M	A.M.J.	J.A.S	O.N.D	STOCK HISTORY THIS YEAR		
COMMENTS							

LANDSCAPE PROCESSES

Water in the Landscape (recharge & erosion or deposition)

Is the landscape trapping water effectively				YES	NO
Is there active soil erosion or siltation (sanding -up)?				YES	NO
What kind of erosion?	Sheet/wash	Gullying	Pedestalling/mounding		
What proportion of the sample area is unstable				%	
Is the unstable area	Contracting?	Stabilized?	Expanding?	Incising?	
In the bare areas is the soil covered by an algal crust and / or stone pavement (gibber)?				YES	NO
Other Impacts/Influences	Wind erosion	Fire	Hail	Frosted vegetation	

VEGETATION:

Layering of Vegetation (tick one or more)

❑ Top Layer	❑ Middle Layer	❑ Lower Layer	❑ Ground Layer

Bush Clumps Beneath Trees and Large Shrubs

❑ None	❑ Few	❑ Many

Is There Effective Recruitment Of The Key Plants (insert plant's name)

Flowering	Fruiting/Seed Set	Recent recruits	Recently dead or dying

Plant Kind &/Or Cover Change Plus Browsing & Grazing Influences

Is the overall perennial plant cover	Increasing	Stable	Decreasing			
If increasing, does this involve mainly undesirable plants? E.g. needle-bush, camel thorn	YES	NO				
Name undesirable plants						
Why undesirable?	Taking over good pasture	Unpalatable	Toxic	Burrs	Other	
If increasing, do the invading scrub or weed plants have useful fodder plants growing beneath them?	YES	NO				
Name plants growing beneath:						
Do the trees & large shrubs have an upper feeding reach browse line?	YES	NO	PART OF	THROUGHOUT		
What is forming this browse line?	Sheep	Goats	Cattle	Camels		
To what degree are the lower & ground layer plants eaten?	V. heavy	Heavy	Medium	Light		
To what degree are the bush clump plants browsed	V. heavy	Heavy	Medium	Light		

CONCLUSION:

Comparison With Previous Years Monitoring Record

Is the area?	❑ Improved	❑ The same	❑ Deteriorated