3. Field based assessments of present condition, erosion processes, and trajectory

The field component of this project aimed to produce the information necessary to identify areas corresponding to the rehabilitation priorities described in Chapter 2. Achieving this requires knowledge of the present condition, conservation value and trajectory of the area, and the cost and probability of success of appropriate rehabilitation techniques in the area. The specific goals of the field work were:

1. Present condition of the area:
    - Describe typical features of eroded and intact landscapes.
    - Identify any obvious controls on the form and distribution of erosion features.
2. Conservation value of the area
    - If possible, identify large areas of intact soils that would be a high priority for protection from erosion. Investigate using the erosion mapping of Cullen (Cullen, 1995) to extend this outside areas visited during field work.
3. Trajectory of the area
    - Assess the potential for using Cullen's mapping as a benchmark against which to measure the trajectory of degraded sites on the Plateau.
    - If possible, assess trajectory for the limited areas covered by field work.
4. Cost and probability of success of rehabilitation
    - Identify, as far as possible, the processes that are preventing vegetation recovery or driving ongoing erosion across a range of sites.
    - For any high priority sites, identify any threatening processes that should be a target for rehabilitation works. Identify the types of intervention needed to rehabilitate such sites.
    - Make qualitative assessments of the level of success of existing rehabilitation works, and estimate how applicable these methods would be to other areas.

3.1. Methods

Fieldwork was conducted by foot and by helicopter to the sites identified in Figure 18. Most fieldwork was of a reconnaissance nature. A comprehensive field proforma was developed but found to be very time consuming and restrictive. The field proforma is presented in the Appendices. However, it was judged more important to use the limited field time to visit a large range of sites rather than to reproducibly measure the characteristics of a few sites. For this reason, sites were identified by GPS point, and documented with photographs and notes. Attempts were made to assess the condition of the soil profile, and the probable long and short term trajectories of the site.

The location of field sites visited on foot was influenced by the location of existing monitoring sites and rehabilitation work, ease of access and a desire to visit areas in both the glacial and the periglacial regions. Sites visited by helicopter were chosen to cover a broad geographic range of sites, taking in areas of different erosion intensity including areas outside the present erosion mapping and the 1961/62 fire boundary. This allowed a search for signs of historic erosion in presently vegetated areas.

With a few exceptions, the presence and intensity of active erosion processes were inferred from features created by those processes, rather than assessments of the actual processes. For example, wind erosion was inferred from deposits of sand and granules on the upwind side of obstacles. In some cases, it was possible to observe erosion processes in action, particularly those related to overland water flow in wet conditions.

Indicators of soil condition used were the micro-topography and rockiness of the soil surface, overall soil depth, the presence or absence of an A horizon, the relative proportions of vegetation and bare ground, and vegetation height and complexity.

Assessments of long term trajectory were based on a comparison of Cullen's 1995 mapping and the 1990 aerial photography on which it was based, with present conditions. These comparisons were made in the field by comparing the current proportion of bare ground with the mapped value, and by comparing the 1990 aerial photographs that Cullen used in his mapping with the most current photographs available. The limitations to using Cullens work for this purpose are discussed in Section 3.2.4.

Short term trajectory was indicated by the presence or absence of evidence of any active erosion processes. Characteristics of the vegetation were also used, including within generally bare areas the presence, density and health of colonising plants estimated to be old enough to have survived at least one winter, and recent signs of either growth or death of existing vegetation over soil scarps and erosion pavements.

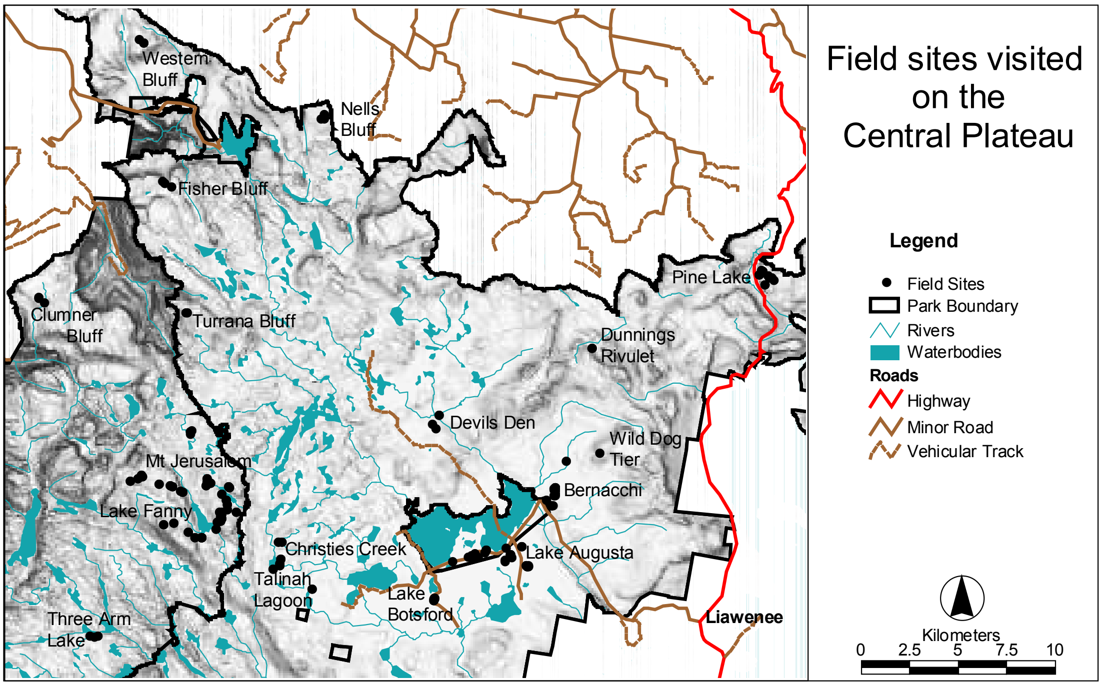


Figure 18 Areas visited in the field during the course of the present study.

3.2. Results and discussion

3.2.1. Ongoing soil erosion and impediments to vegetation recovery

In almost every degraded site visited during the field component of this project, there was some evidence of both ongoing soil erosion and impediments to the recovery of vegetation cover. These include frost heave, sheet flow, channelised flow, wind erosion, animal trampling, digging and localised overgrazing, drought and recreational impacts. Typically, many of these processes will combine at a single site, so that in degrading areas there is a multi-pronged attack on vegetation cover and soil stability. In combination these processes have been described as 'turf exfoliation' and are capable of eroding 'a continuous ground vegetation cover by removing the soil exposed along small terrace fronts' (Perez, 1992). They are also very effective at preventing vegetation recovery on existing disturbed ground. A very similar suite of processes has been described from the High Drakensberg in Southern Africa (Grab, 2002), and the Venezuelan Andes (Perez, 1992). An example of turf exfoliation on the Central Plateau is shown in Figure 19.

The field evidence for each of these erosion processes, the environments within which they operate and the types of feature that they create are described below. We make a distinction between primary and secondary erosion processes. Soils on the Central Plateau are often relatively cohesive, because of their organic or clay content. Where vegetation is intact, a dense root mat increases this cohesiveness. This means the intact soil is difficult to erode. However, once broken up, individual particles can be easily transported. Primary erosion processes therefore mean processes that can erode intact soils. These processes may not be able to transport sediment any great distance, and so be limited in their effects if operating individually. Secondary erosion refers to processes that can transport loose sediment significant distance, but may not have the power required to break up intact soils. Again, this limits the effect of secondary erosion processes that are acting individually.

Figure 19. An example of turf exfoliation similar to that discussed by Perez (1992) and Grab (2002) from just west of Lake Fanny.

Needle ice and frost heave

Needle ice develops in moist soils when the soil surface freezes. Long thin ice crystals develop beneath the thin, frozen crust, lifting it and any material frozen into it off the soil surface (hence the term frost heave). Although individually extremely delicate, needle ice is capable of exerting considerable force. Frost heave has been observed on the Central Plateau lifting stones up to 20 cm diameter, lifting erosion pins out of the ground, and uprooting planted tubestock in rehabilitation areas (Michael Comfort pers. comm.). Due to the insulating effect of plant material, well vegetated areas are seldom effected by frost heave.

Frost heave occurs wherever climates are cold enough, and undoubtably was more intense and producing larger features during the glacial maximum. However, even under the present relatively mild interglacial climate, needle ice on the Central Plateau has been observed to:

- break an intact soil surface into crumbs (Figure 20A and B),
- exhume roots of established plants and uproot seedlings, (Figure 20B and C)
- disturb gravel erosion pavements on degraded sites, so that fine material is continually brought to the surface where it can be erodedand any seedlings are uprooted (Figure 20C)
- lift rocks of considerable size (Figure 20D)
- mix the surface centimetres of soil to form mini stone polygons (particularly in very shallow soils), and
- cause down slope frost creep resulting in the development of gravel fronted lobes (Matsuoka, 2001) or terraces of material (Figure 20E).

Frost heave is perhaps the most important primary erosion process on the Plateau. In any one event, it does not cause a large retreat in eroding soils, or move eroded material a large distance. However, it is very pervasive, occurring frequently over very large areas of the Plateau. It occurs on bare ground right up to the boundary with intact vegetation, and so is capable of damaging roots and undermining those plants. Most importantly, it can break a cohesive, erosion resistant soil surface into particles that can readily be transported by any other erosion processes. For example, frost heave has been found to be partially responsible for high rates of fluvial erosion along Ripple Creek Canal (Prosser *et al*., 2000). Also, because frost heave can uproot seedlings, it is very effective at preventing revegetation of eroded soils.

The intensity with which needle ice develops appears to depend upon a number of environmental conditions. It requires temperatures at the soil surface to fall below freezing, and so is seldom observed where there is a full insulating cover of vegetation or where soils are covered by standing water. It forms from soil moisture, and so does not occur in very dry soils, even when temperatures fall below freezing. The intensity also appears to vary with soil type, with the largest needle ice development usually seen in the dolerite based mineral soils typical of much of the Plateau. It occurs with lesser frequency in the sandy soils of lunettes, possibly because these soils are very well drained.

Sheet flow

Water is a major erosion agent on the Plateau. The area is very prone to overland flow, because it is seasonally very wet, can receive moderate to high intensity rainfall events, and often has large areas of saturated soils, shallow soils, and bare rock, thus limiting the potential for infiltration. Under natural conditions, a dense sward of vegetation would slow and filter such overland flow. In the absence of vegetation, there is wide spread erosion from sheet flow, a thin layer of flowing water (see Figure 21). Interestingly, no signs of rill erosion were observed in areas of sheet flow. It is thought this is because frequent frost heave obliterates any shallow channels created in this way.

Figure 20. A. Close up of soil crumbs lifted by needle ice. Needles are approximately 7 cm long. B. Soil surface with soil crumbs and lifted roots after needle ice has melted. C. Seedlings uprooted by needle ice in erosion pavement near Talinah Lagoon. D. A rock weighing at least 5 kg lifted over 1 cm by needle ice. E. A gravel fronted lobe of soil on a sloping bedrock surface near Wild Dog Tier.

Sheet flow appears to have a limited ability to erode intact soils particularly where there is a complete vegetation cover. However, this increases somewhat where flow is locally concentrated. It also depends on the soil texture, with cohesive organic and clay rich soils being more resistant to erosion than sandy and gravelly soils. Sheet flow is most damaging as a secondary agent of erosion, mobilising soil particles created by other processes such as frost heave, desiccation or animal disturbances. Also, by regularly disturbing areas of bare and loose soil, sheet flow is a potential contributing cause of slow rates of regeneration.

The effects of sheet flow are most obvious in the periglacial landscape of the eastern Plateau. Here, broad areas have been denuded of top soil, and the resulting stony lags are still disturbed by sheet flow. However, sheet flow processes are likely to be important contributors to erosion wherever sloping bare ground is present.

Figure 21. A degraded area near Lake Fanny subject to disturbance by sheetflow.

Channelised flow

Channelised flow has greater flow depth and velocity than sheet flow, and so has far greater power to erode and transport sediment than sheet flow. Both primary and secondary erosion by channelised flow are very common. Forms include gully erosion (ie headward extension of the drainage network), stream incision, bank erosion and floodplain stripping, and partial avulsion (development of new channels). In reality, many of these forms occur in combination. The resulting effects and form depend on catchment size, local topography, vegetation and the depth and character of local soils and sediments.

Stream erosion has been observed on the Plateau for many years (eg Mitchell, 1962; Edwards, 1973a). Its frequency is probably related in part to the effect of fire and erosion on catchment hydrology. Catchment scale fire and erosion reduces surface roughness, and storage of precipitation in vegetation or soil, making runoff far more efficient. This is combined with reduced resistance to erosion along drainage lines, and the result widespread erosion.

Gully erosion is found in very small headwater catchments where there would previously have been no channel. It is frequently associated with areas of sheet erosion upstream. It is not clear how common this type of erosion is, or what volumes of sediment may be liberated by it, as the channels are often small and masked by vegetation.

Stream incision occurs commonly on moderate stream slopes, and small to moderate catchments. In this context, the channel is surrounded by a build up of organic and fluvial sediments that can be incised if the stream has sufficient power. This form of erosion is frequently seen on streams in small valleys, where it usually takes the form of a series of headcuts on the dominantly single thread channel. Incision may extend through the modern peat into the underlying mineral soil or moraine. The result is significant channel enlargement. However, in the Plateau environment there is usually very limited potential for these headcuts to travel any great distance, as bedrock or boulders form very frequent controls on bed level. Most of the headcuts observed had either reached a natural bed control, or were within meters of doing so.

Incision also occurs on relatively steep tributary streams where they flow through small alluvial fans on reaching a broad flat valley floor. It is likely that prior to disturbance, channel capacity greatly decreased at this point as water and sediments dispersed across the plain. Channels often appear disorganised and difficult to follow. It is now common to see suites of headcuts on a messy network of channels (see Figure 22A).

Stream incision also occurs in low slope sections where the bed level has been controlled by swamp vegetation including species/lifeforms such as cushion plants, S*phagnum* and *Gleichenia*. In these sections, it appears that the natural stream form is anastomosing, with multiple channels and frequent tunnel sections. Once disturbed, these sections appear to develop multiple headcuts on each branch of the channel. In one small tributary in a section of cushion plant bog near Lake Fanny, six headcuts occur within roughly 30 m (Figure 22B). After incision, tunnel sections appear to collapse, creating a greater proportion of open channel. Possibly there is also a reduction in the number of active channels. It is likely that channel incision in such environments has the potential to effectively drain the surrounding bog, causing changes to the vegetation, although it is not clear from the limited field work to date how often this occurs or the lateral extent of vegetation effected.

Bank erosion and floodplain stripping is very common, particularly on relatively low gradient streams. This may be initiated by stream incision. While the channel is relatively narrow, stream processes may drive bank erosion. However, as the channel becomes wider it appears that the stream is probably operating mostly as a secondary erosion process, removing material broken from bare but intact soil by frost heave. This results in massively over-widened channels (Figure 22 C and D). As this process is not primarily driven by the stream, it is not limited by the usual controls on stream width, and could potentially continue to erode indefinitely.

On some valley flats of the eastern, periglacial parts of the Plateau, new stream channels have formed roughly parallel to the original stream. New channels are typically different in form to the old. The old channel is typically deep, narrow and convoluted, winding through and between the boulders that underlie the modern plain of organic and stream sediments. In contrast, the new channels are typically wide, shallow and extremely rocky. They are formed by a combination of incision and bank erosion of the modern organic and stream sediments, but are perched on top of the underlying boulders and clay matrix. Active soil erosion often occurs along one bank, as the channel gradually migrates into the lowest part of the valley. Both channel types are very inefficient, which may explain why both persist. It appears that the base flow typically remains in the original channel, but flood flows that would once have been dispersed across the floodplain are now accommodated in the new channel. The new channel may also capture a considerable volume of overland flow from the neighbouring slope. On wide valley floor, a network of such new channels can develop, eroding a large portion of the soil from the valley flats (Figure 22E).

Wind

The lunettes and dunefields of the eastern Plateau are evidence that significant wind erosion, transport and deposition (ie aeolian processes) have occurred in the Holocene, probably during the last 4,500 years (Bradbury, 1994). Aeolian processes are less active under present climatic conditions, but they do still occur. The decrease in aeolian activity is possibly a result of increases in vegetation cover and steady lake levels stabilising sediment sources, rather than by a decrease in wind strength. Where large areas of bare ground occur, evidence of aeolian processes can often be seen. For example, Bradbury (1994) found evidence of modern dune formation downwind of the Lake Augusta Impoundment, which provides a sand source because the regularly fluctuating water levels create a large area of bare ground.

Figure 22. A. A complex network of headcuts, bank erosion and sheet erosion at the toe of a slope on the upper Thomsons Rivulet. B. Two of the six headcuts in multi-channelled swamp section of a small tributary of Lake Fanny. C. Over widened channel near Lake Fanny. D. Natural section of channel immediately upstream of C. E. Multiple eroded channels in the Thomsons Rivulet catchment. Note also the sheet erosion in the foreground.

Under modern conditions, it is likely that wind erosion is dominantly a secondary erosion process, moving soil fragments that have been produced by frost heave, animal disturbances or desiccation. Wind erosion and deposition is widespread where soil is bare. It can be identified by sand and granule deposits trapped against vegetation on the downwind side of bare ground (Figure 23). Presumably, any finer material entrained by the wind is completely removed from the area. It is not clear what volumes of material may be transported in this way. Small erosion patches on the Plateau often form closed depressions, and it is likely that wind erosion is responsible for scouring these hollows.

Figure 23. Deposition of wind transported sand and fine gravel on wild Dog Tier.

Impacts of grazing mammals

Animals have the potential to initiate or maintain soil erosion through intense grazing and soil disturbances such as the development of tracks, burrows and scratching (eg Figure 24). On the Plateau, the main herbivores are rabbits, wallabies and wombats. Rabbits have been blamed for causing severe land degradation (Scott 1955 in Shepherd, 1973; Cullen, 1995). Cullen (1995) found that rabbits were strongly associated with areas of the Plateau where grazing and burning were most prolonged and intense, and erosion problems most severe. However, it remains unclear to what extent rabbits were an initial cause of erosion, rather than simply following a preference for eroded areas. Grazing by rabbits and native mammals appears to inhibit vegetation recovery (Bridle *et al*., 2001). In particular, observations made during this study suggest that rabbits have a distinct preference for grazing and scratching in eroded areas. Grazing pressure, in combination with creation of new bare ground by scratching, is likely to be a significant influence on recovery rates.

Figure 24. Rabbit grazing and scratching near Cristys Creek creating a large patch of bare ground.

Drought

Seasonal drought can act as a primary erosion processes, as desiccation can cause bare but intact soil surfaces to fragment, creating particles easily moved by wind or water. It also potentially plays an important role in suppressing vegetation recovery. As many eroded areas have remnant soils only centimetres thick, they are very prone to drying, creating a very hostile environment for seedling growth and survival.

Seasonal drought is particularly strong in the eastern part of the study area, where rainfall is lowest. Bureau of Meteorology records from Liawenee, just east of the study area, suggest that average evaporation can exceed average rainfall between November and March. Prolonged strong winds in dry conditions will also promote rapid drying of soils.

Recreational impacts

Recreational activities such as four wheel driving, walking and trampling by horses will damage vegetation and create areas of bare ground that can then be a focus for erosion. Work by Jennie Whinam and others (Whinam *et al*., 1994; Whinam and Comfort, 1996; Whinam and Chilcott, 1999) have shown that the effect of trampling is influenced by the type of trampling (human or horse), the number of passes and the vegetation type. Damage of prostrate shrubs was particularly notable. These shrubs may be important colonisers of bare areas. Breaking a single stem leads to the death of a significant part or all of the shrub. Whinam and others also found that both the area of bare ground and the depth of soil loss sometimes continued to grow in the year following the initial disturbance, suggesting that even small scale damage by trampling can initiate ongoing erosion.

3.2.2. The condition of soils across the Central Plateau

The many forms and features of soil erosion

Fieldwork for this project has shown that the processes of soil erosion on the Plateau create a distinctive suite of features. As erosion is seldom complete over large areas, degraded soils have a very uneven microtopography, with patches of remnant soils like miniature mesas and buttes interspersed with eroded areas partially or completely lacking A horizons. In plan view, this creates a very complex pattern of eroded ground and remnants (eg Figure 25). This patchy distribution of erosion has implications for how sites are identified, prioritised and treated, as clear boundaries between intact soils and eroded areas are rare. It massively increases the area of land potentially effected by erosion. Also, as the scarp between soil remnants and eroded areas is a focus for erosion and therefore needs to be a focus for rehabilitation, it increases the complexity and intensity of the task of rehabilitation. For example, in the small (2,000 m^2) area shown in Figure 25 there is 754 m of erosion edge. The planform of erosion also has positive effects. Vegetation recovery has been observed to extend out from soil remnants (Bridle *et al*., 2001), so eroded areas with frequent areas of remnant soils have a higher potential for recovery than broad areas lacking remnant soil patches. Also, where bare patches are small there is potential for eroded material to be trapped by vegetation within a short distance, and so not be removed from the area.

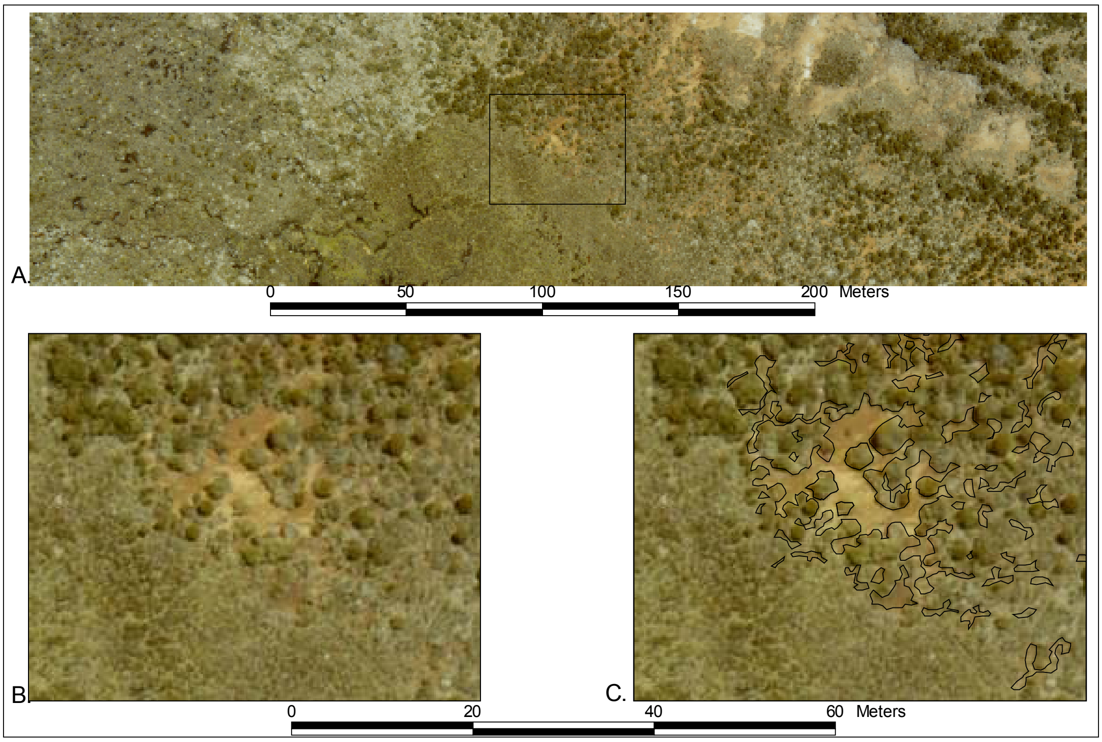


Figure 25. An example of the patchy nature of soil erosion. A. An area near the Bernacchi rehabilitation trial site, showing variable levels of erosion. B. An enlargement of the approximately 50x40 m area within the box in A. C. Digitised erosion boundaries within the enlarged area. It contains 276m^2 of eroded patches, and 754 m of erosion boundary.

Remnant soils are typically partially or fully vegetated. Eroded areas are often covered by a gravel lag, described by Cullen (1995) as an erosion pavement. There is however, a large variety of forms within this general pattern. The depth of soil loss, boundaries between remnant soil and eroded areas, nature of remnant soils, character of the eroded area, planform of erosion, and the presence of depositional areas all vary. Predicting the precise character of erosion at any one site is not easy.

The elevation difference between intact and eroded soil surfaces is variable, from a few centimetres to almost half a metre. This can represent partial or complete loss of the A horizon, and in some cases the B and C horizons as well. An erosion pavement tends to develop in gravelly soils, appearing as a layer of loose gravel and rocks over the remaining soil profile. This pavement appears to act to slow ongoing erosion by protecting the remnant soil (Cullen, 1995). However, erosion pavements are not ubiquitous, and it is also common to see areas with bare truncated soil profile where no pavement has developed. In deep peaty soils along drainage lines, the base of the organic horizon may still be present as the surface of eroded areas. In contrast, particularly on shallow mineral soils, erosion can remove almost all the soil exposing large areas of bedrock.

The boundaries between soil remnants and eroded patches is also variable. This boundary can take the form of distinct scarps with a clearly identifiable top and toe with a classic undercut cross section. This is most common where the erosion is relatively deep (greater than 15 cm). However, erosion boundaries can also be anywhere on the continuum between undercut, vertical and gently battered over 50 to 100 cm. Perez (1992) and Grab (2002), working on turf exfoliation in alpine areas of Southern Africa and Venezuela respectively, both found that erosion boundaries retreated through undercutting and slumping of small terrace scarps. This pattern does occur on the Central Plateau, but it also appears that frost heave and other processes can cause the retreat of gently battered erosion boundaries while maintaining the cross sectional form.

Remnant soils in degraded areas are typically partially or completely vegetated. They may occur in partially sheltered locations, such as adjoining large boulders, or may be surrounded by erosion. Close examination of these remnants often (although not always) reveals that they have also undergone some erosion, and have lost part of their A horizon. This is suggested by their uneven surface topography, the highly variable depth of A horizons, and by comparison with intact soils in surrounding areas, where these are comparable to the eroded patch.

Eroded patches can be anywhere on the continuum between exposed bedrock and deep soil. Where some material remains, it may be the in-situ lower section of the original soil profile, or it may be a highly disturbed gravelly material with few soil characteristics. Erosion pavements are common. These are created from a lag of gravel clasts left behind when finer fractions of the soil have been eroded. The character of the erosion pavement depends on the grain size of the gravel in the original soil, and varies between less than one centimetre to greater than 10 centimetres diameter.

In degraded areas there is typically a complex network of eroded patches and soil remnants. Patch margins are often convoluted. This planform is also highly variable in terms of the size of erosion and remnant patches, which might be tens of centimetres or tens of metres. Degraded areas can be dominated by remnant soils, which surround small and discrete eroded patches, or by erosion which surrounds small islands of soil remnants. Where remnant soil dominates, erosion patches form small enclosed basins, that may hold water for part of the year depending on the nature of the substrate and local water table. In this situation net erosion rates area likely to be relatively slow, because detached soil particles can easily be trapped in surrounding vegetation. Removal of soil material from the area will be dominated by wind erosion. However, once eroded patches enlarge sufficiently to interconnect, any small pools are drained and overland flow can efficiently remove eroded material from the area. It is likely that this increases the rate of erosion.

Erosion features and processes are influenced by the slope and drainage of the site. On slopes, erosion tends to form a series of terraces like scarps. These scarps then erode up-slope. Coarse eroded material accumulates on the down-slope side of the erosion patch. Similar patterns were found by Perez (1992) and Grab (2002). Where eroded materials are deep, they can form distinct gravel fronted lobes that are transported by frost heave (Matsuoka, 2001). The nature of drainage at the site also influences the forms of erosion. These are described in the Channelised flow section above.

Soil erosion on the Plateau is accompanied by some deposition of eroded material. Evidence of this is less common than erosion, probably because a significant proportion of eroded material is either transported considerable distances or is widely dispersed. The potential sediment sinks on the Plateau are discussed below. However, in some rare cases deposition of sediment is followed by revegetation and stabilisation. In these cases the soil profile is developing rather than eroding.

Forms and features of intact soils

An important discovery during the field component of this project is that the features indicative of erosion are commonly also found under complete vegetation cover (eg Figure 26). This suggests that active soil erosion has been more widespread than is presently the case, and that many areas have recovered soil stability. Potentially, over 180 years of land use and altered fire regimes, there have been multiple waves of soil degradation, followed by partial recovery of vegetation and soil stability. In particular, with the exception of wetlands, most areas inside the 1961-62 fire boundary are likely to show some signs of erosion, regardless of their present vegetation cover.

A B

Figure 26. A. Erosion microtopography with almost complete vegetation cover near Talleh Lagoons. Dotted line highlights the top of an erosion scarp. B. A fully vegetated erosion pavement around the exposed roots of a dead eucalypt near Great Pine Tier.

This conclusion has significant implications for the identification and mapping of soil condition. It is apparent that Cullen's work is <u>not</u> a map of all areas effected by soil erosion over the last 200 years, but only those areas that were bare or actively eroding in 1990 when the aerial photography was flown. In this sense, Cullen's estimates of area effected by erosion, and of total volumes of soil lost, are likely to be significant underestimates of the total impact of European land management on the Plateau.

In an effort to describe the appearance of intact soils, short field visits were made by helicopter to several areas on or outside all known fire boundaries, including Lake Nutting, Clumner Bluff, Fisher Bluff and Taranna Bluff. Signs of soil erosion were present at all these sites, although with far lower frequency and intensity than typical of sites within the fire boundary. Without further work, it is not possible to establish the extent to which such erosion is natural, in response to soil disturbance by animals or natural fires, and the extent to which erosion induced by European land management is all pervasive. This question could potentially be answered by studying lake sedimentation rates since deglaciation. Development of such a project is being discussed with Hydro Tasmania and the University of Tasmania.

Patterns of erosion across the Plateau

The section above described the highly variable nature of erosion on the Central Plateau. At this stage, it is difficult to predict the extent and form of erosion at any one site. However, some general patterns in the form and extent of erosion can be identified. These largely reflect the influence of topography and geomorphic history on the susceptibility of soils and drainage lines to the different erosion processes. Three regions have been identified where there are trends for different forms of erosion to dominate.

1. The ice cap area of the northern and western Plateau. Here the hummocky topography and frequency of large surface rocks means that long continuous slopes are rare. In this area, eroded patches tend to be smaller and less interconnected than in the eastern Plateau.
2. The periglacial eastern Plateau. Here the landscape is broad and rolling, and includes lots of long slopes. There is a notable tendency for broad scale erosion, where eroded patches are large and interconnected, and patches of remnant soils small and isolated. There are also large areas where it appears shallow soils have been entirely removed, revealing bedrock.
3. Aeolian areas. These soils are prone to wind erosion to a far greater extent than other soils of the Plateau. However, they also seem to revegetate faster.

3.2.3. Sediment sinks

Cullen estimated that approximately nine million cubic meters of soil has been lost from eroded areas of the Central Plateau (Cullen, 1995). This raises the question of where that soil might have gone. The following potential sediment sinks have been identified during this study.

Adjoining patches of vegetation – in some areas, soil depths may be increasing because of material deposited in the area. A large scale example is downwind of the Augusta Lunette, where it appears that wind blown sand is being added to the sand sheet, and revegetation is quite active. More commonly, sediment may move a relatively short distance and be trapped in vegetation adjoining the eroded patch. This prevents soil being lost from the area as soon as it is detached. It also creates the potential for limited recovery in quite badly eroded areas, providing there is a source of soil material and some vegetation to trap and stabilise it. This process does not represent a net benefit, because for every area of increasing soil depth there must be an area of actively eroding soil.

Lower slopes – soil eroded from steep slopes and transported by sheet or channelised flow is often deposited at the margin of the slope and valley floor. These are natural depositional areas. Splays and bars of fresh sediment are frequently seen where tributary gullies discharge onto valley floors.

Waterbodies and wetlands – it is probable that large volumes of sediment have been trapped in swamps, wetlands, ponds and lakes. These occur with great frequency, particularly on the Upper Plateau Surface. A very rough calculation of the portion of the Plateau with frequent erosion (roughly the area north of Great Pine Tier) reveals some 13,095 waterbodies with a total area of 5,196 ha. If each lake and pond had received an average of 10 cm of sediment, that would represent over five million cubic metres of eroded soil. Until a study is done to map and date sediments of some typical lakes, it is not possible to estimate what volume of soil eroded since European settlement may be stored there.

The atmosphere – much of the soil lost on the Plateau would have had a high organic content. During intense fires, such as the 1961/62 fires, organic soils were burnt and converted to carbon dioxide. This includes the true peat soils that were found by Nicholls to be over 50% organic material (Nicholls 1958c in Pemberton, 1986), and also the A horizons of mineral soils that can contain a significant proportion of organic material. In this way, a huge volume of soil material was lost directly to the atmosphere.

Downwind landscapes– it has been observed above that wind erosion is active on areas of bare ground on the Plateau, and that aeolian landforms are actively forming where conditions are suitable (Bradbury, 1994). These dunes are accumulations of sand and granule sized particles. Silt and clay sized particles are lighter and once picked up by the wind can travel significant distances, and could easily have been transported out of the Plateau area. This is particularly likely to have occurred in the period after the 1961/62 fire, when the mineral component of burnt soils would have been exposed to the wind over very large areas of land.

3.2.4. The trajectory of degraded areas on the Central Plateau

The trajectory of degraded patches can be estimated in three ways. Current site condition can be compared to some previously measured baseline condition. Considerably less accurately, an assessment can be made of current rates of processes of recovery or degradation, based on impressions of a single site visit. Most accurately, a monitoring program can be developed to answer this question at specific sites.

Can Cullen (1995) be used as a base line for measuring trajectory?

The erosion mapping of Cullen (1995) does not comment on whether mapped areas are continuing to actively erode, are static or are recovering. However, it was considered to be a potential baseline against which to assess trajectory of eroded areas by making a comparison with modern conditions. Field work associated with the current study showed that the mapping was generally of a very high standard. However, there are several problems with using the map as a base line:

- The three categories of erosion intensity used by Cullen are very broad (10-40%; 40-70% and >70%). This means that the proportion of bare ground at a site can increase or decrease significantly, without causing the site to change category.
- There is sometimes an error in the location of mapped eroded patches. This occurs because the lines digitised from aerial photography were not orthorectified to remove the distortion that occurs when a three dimensional landscape is represented on a two dimensional photograph. This is mostly a problem in the more high relief areas of the Plateau.
- The large scale ground truthing component of Cullen's work took place before GPS's were in common use. Thus, it is not possible to relocate the sites where actual measurements of bare ground were made with sufficient accuracy to make it worth while repeating the measures. This is particularly true given the variability in erosion intensity at a local scale.
- In some cases soil erosion has exposed large areas of rock. These are correctly mapped by Cullen as bare ground (ie exposed rock and soil). However, they have neither the potential to erode further or to support revegetation. For this reason, these areas are no longer relevant to questions of rehabilitation and ongoing erosion on the Plateau. Ideally, the proportion of bare rock should be separated from bare soil.
- This mapping did not attempt to differentiate between naturally bare areas of soil, and areas where the erosion has been induced by European land management. The assumption was that all bare ground was a result of fire and grazing. This assumption is in large part likely to be correct, however it has not yet been tested.

Because of these issues, Cullen's mapping is not considered a suitable baseline for assessing site trajectory, except in cases where massive changes in site condition have occurred. For these reasons, there were only a few areas where a clear difference between the present proportion of bare ground and Cullen's mapped condition was identified. This should not be seen as a criticism of the Cullen's work, which was not designed to be used in this way.

Can long term trajectory be estimated from instantaneous evidence of erosion or recovery?

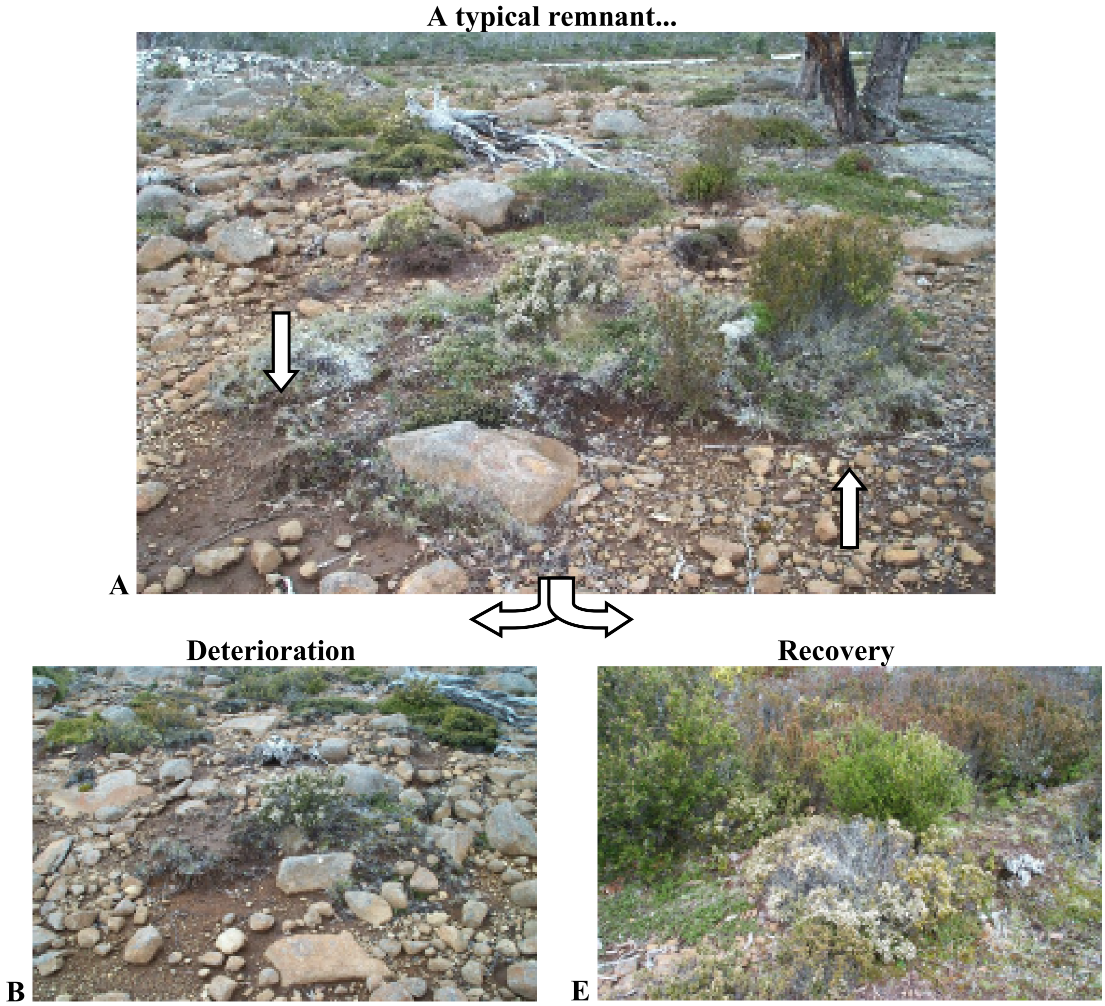
Estimates of site trajectory can also be made by looking for evidence of ongoing processes of erosion or recovery. For example, well established seedlings growing amongst gravels in an erosion pavement indicate that revegetation is occurring (Figure 27A). Alternatively, mature plants dying with roots exposed are a clear indication of ongoing erosion, and a negative trajectory (Figure 27B).

Unfortunately, this method of estimating site trajectory is extremely unreliable, as the processes of erosion and recovery are episodic. This means that the impressions of ongoing rates of changes are heavily influenced by the weather of the season and the preceding days. Frost heave and sheet flow may appear to dominate in a winter field trip, while desiccation and wind erosion may seem most important in summer. Plants that have expanded in a mild year may die back under heavy grazing or a harsh winter. Alternatively, rabbit populations may boom in mild years increasing grazing pressure, and crash after cold and wet winters.

A B

Figure 27. A. A healthy Grevillea australis expanding over active erosion pavement, indicating gradual recovery. B. A heavily grazed Coprosma with roots exposed indicating active erosion by frost heave and sheet flow. Both photos were taken near New Year's Lake.

Rates of recovery and erosion also vary spatially. It is not unusual to see evidence of vegetation expansion and ongoing soil loss within a meter of each other (such as Figure 28A). In this situation if the rate of erosion exceeds the rate of vegetation growth in the long term, the result will be a gradual reduction and final loss of the soil remnant and expansion of the unstable erosion pavement (Figure 28B - D). Alternatively, if revegetation rates exceed erosion rates, resulting in a secure patch of remnant soil surrounded by stabilised erosion pavement (Figure 28E). From a single site visit, it is impossible to say which end point is likely to occur. It is important to recognise that although there may be apparently clear and obvious signs of recovery or degradation at a particular site, these impressions are potentially very misleading and should not be used to make judgements about long term site trajectory.



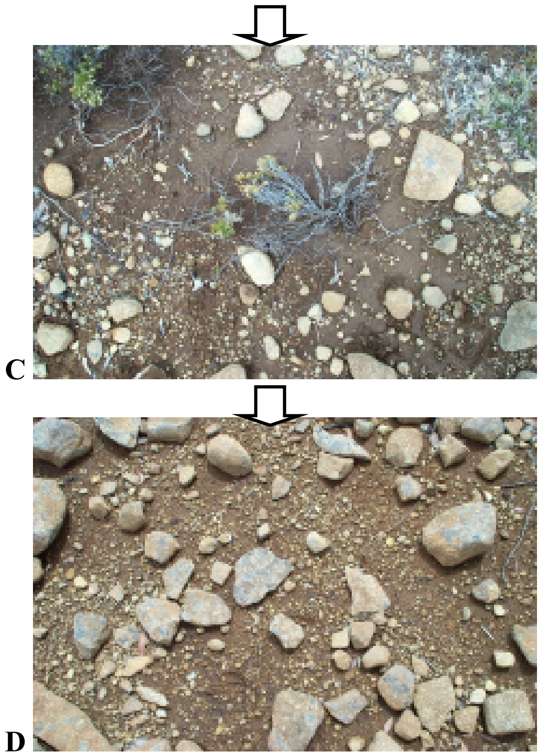


Figure 28. An example of the race between vegetation recovery and ongoing erosion. A shows a typical patch of remnant soil with active erosion in some areas (eg left arrow), and vegetation extending over erosion scarp in other areas (eg right arrow). B to D are the pessimists view, where the slow but ongoing loss of soil gradually reduces the size of the remnant until the area eventually becomes unstable erosion pavement. E is the optimists view of the future, where vegetation growth has stabilised the remnant soil and spread over the surrounding erosion pavement. All these images were taken within 10 m of each other.

Existing monitoring of soil erosion and vegetation recovery

The most precise assessments of the trajectory of degraded areas can be obtained from detailed monitoring. There are three relevant monitored experiments presently running on the Plateau. All have significant limitations relating to their small sample size (ie only one to four replicate sites). Also, some work was designed to answer questions relating to the effect of grazing on vegetation recovery, rather than measuring natural recovery rates.

1. Grazing exclosures and vegetation growth monitoring

An existing monitoring program was established by Phil Cullen (Cullen, 1995) and has been re-measured by Kerry Bridle (Bridle, 1997; Bridle *et al*., 2001). This study is examining the influence on revegetation rates of grazing by rabbits and by rabbits and native animals combined. It consists of four sites established in severely eroded areas. Each site has two replicate plots of the two grazing treatments and two control plots. Each plot is subsampled by 10 half metre quadrats. The results of the study to date are described in Section 1.4. In summary, over a five year period, the study found an average rate of vegetation increase of just over 1% per year.

There are several concerns with this study. There are only four sites, which is probably not sufficient to characterise the variability across the different environments on the Plateau. Also, at each site, only two replicate plots of each treatment were used. Again, the highly variable nature of erosion on the Plateau means that this sample size may not be sufficient. Finally, the study has a strong emphasis on identifying the effects of grazing by rabbits and native mammals on rates of vegetation recovery. The quoted rate of vegetation cover increase is an average across all treatments. This means that the results from ungrazed plots probably influences the estimate of overall rates of revegetation. Unfortunately, however attractive the idea may be, excluding grazers from the 11,000 ha of degraded ground on the Plateau is not a viable rehabilitation option. As such, it is the control sites that have the most potential to inform the development of rehabilitation priorities. Further analysis of the control data may be useful.

Most importantly, this study focuses entirely on vegetation cover and does not measure rates of soil loss. This is not an oversight on the part of the authors, but a reflection of the difficulty of measuring soil loss in this environment. Erosion pins were installed at all sites when the quadrats were established, but these are regularly moved by intense frost heave. Many have now been heaved entirely out of the soil and lie loose on the ground. For this reason their measurement was abandoned.

It is also worth noting that the location of vegetation quadrats was marked with metal pins. Like the erosion pins, many of these have been heaved by frost, to the extent that relocating existing quadrats may be difficult. This is particularly a risk with the control sites, as they are not surrounded by a fence, which makes relocation easier. Establishing a more permanent method of marking these sites is a matter of some urgency.

2. Other long term vegetation monitoring

Bridle *et al.* (2001) report on several long term vegetation quadrats in the Eastern Central Plateau. After 23 years, these show a revegetation rate of between 1.2 and 1.3% per year. As with the grazing exclosures, the relevance of this study is limited by the very small number of sites and by the lack of measurement of soil loss.

3. The Bernacchi rehabilitation methods trial

In 2000 a trial of different rehabilitation methods was established in an extremely eroded area near Bernacchi. The results to date show extremely low rates of vegetation growth, typically less than 0.25% per year, measured over 6 years. As with the grazing exclosures study, it is only the control quadrats that can inform assessments of natural rates of recovery on the plateau. After 6 years, none of the control quadrats have any vegetation cover at all.

As with other studies, the relevance of this trial is limited by the lack of assessments of soil loss. It is also limited by the lack of replicate sites in other environments.

Concluding comments on assessments of trajectory

The long term trajectory of degraded sites on the Central Plateau has proven very difficult to assess. Some assessments of vegetation growth exist, but these are generally based on very small sample sizes and sample areas. Also, the rates of vegetation growth in control sites vary greatly, from zero to greater than 1% per year. This probably reflects variations in the initial conditions of the sites. With further work, it may be possible to differentiate between sites where natural revegetation will occur, albeit slowly, and those where it will not occur at all, prior to spending many years monitoring.

No assessments of ongoing rates of soil loss exist. This is largely because of the difficulty of making such measurements in this environment. Innovative monitoring techniques are needed to solve this problem. During this project, an initial attempt was made to establish a monitoring program (see Appendix 3) but this failed in the face of site variability and the difficulty of stable benchmarks. Other relevant work has included establishing a trial of the reliability of different types of erosion pins in different soil depths. This is a purely methodological trial, and may not report on rates of soil loss. It involves only one site, and is unlikely to be continued in the long term. The experiment was established in March 2006, and has not yet been resurveyed. Finally, an experimental set of low level aerial photography was flown, at 1:3,000 and 1:5,000 scale, to investigate the potential for using remote sensing to monitor the area of active erosion. No analysis of these photos has yet been completed.

The problem of measuring trajectory is compounded by the very slow rates of both improvement and deterioration. As changes occur very slowly, with many reversals, it is not easy to see differences even after many years have passed. The problem is further complicated by the need to somehow characterise the variability of the recovery rates, either by including very large sample sizes in the monitoring, or by incorporating some kind of landscape classification.

In this situation, it is not possible to comment on whether the condition of the majority of degraded areas on the Central Plateau has deteriorated, remained the same or improved. It is not possible to guess whether, in another 50 or 100 years, far larger areas will have been reduced to unstable erosion pavement, or if natural revegetation will have stabilised all the presently degraded area. In such circumstances, it is also impossible to say if active rehabilitation is required urgently, or not at all.

3.2.5. Potential controls on rates and limits of ongoing erosion

Cullen (1995) correlated the distribution of erosion with evidence of potential causes of erosion, namely fire history, rabbits and grazing history. However, although these influences may explain the initiation of erosion, other factors are likely to be needed to predict erosion rates, potential maximum extent, and recovery rates. These might include local temperature extremes, local topography including slope, drainage characteristics and catchment size; soil character including stoniness and moisture holding capacity; present degree of erosion, including depth, patch size and connectivity of patches; frequency of inundation; the present nature of erosion boundaries; and the erosion processes that operate at the site. During this project, an initial attempt was made to characterise some of these factors and to correlate them with apparent and measured rates of site recovery. However, there was insufficient time available to perfect methodologies and to collect the necessary data set. The draft data sheets and associated classifications are included in the Appendices.

3.2.6. What are the known tools and techniques available to land managers?

In Chapter 2, we stated that the highest land management priorities should be protecting areas that have conservation value because they retain their ecological integrity or because they include features of special conservation value. Protection of these areas may not require rehabilitation techniques, unless there is active erosion in the vicinity. Instead, it is important to prevent new disturbances that could initiate erosion. Cullen's work (1995) showed that erosion was initiated by one or a combination of fire and by grazing by feral and domestic animals. Accordingly, fire prevention is a priority. Also, domestic stock should continue to be excluded from the Plateau within the WHA. Finally, when possible efforts should be made to reduce rabbit numbers on the Plateau. These issues are discussed in the TWWHA Management Plan (Parks and Wildlife Service, 1999).

In many areas active rehabilitation will be required. Previous or existing rehabilitation works and experimental sites on the Central Plateau are described in Section 1.4. Briefly, these efforts have largely focussed on rehabilitation of mechanically disturbed ground and degraded lunettes, although two trials at Talinah and Bernacchi have investigated the efficacy of common rehabilitation techniques on sheet erosion.

In general, it appears that rehabilitation can be successful in increasing vegetation cover where significant soil remains, as is the case with many mechanically disturbed areas and the lunettes. However, even in these areas, plant growth is often slow, and rehabilitation often requires considerable maintenance. The rehabilitation approach must be flexible, and include re-treatment of the site or application of different techniques should earlier attempts be unsuccessful. Methods that have been at least partly successful are fencing, planting tubestock, seeding, fertilising and laying jute and slash in various combinations.

The experience from sheet eroded sites is less encouraging. Relatively little can be concluded from the Talinah trials, but at Bernacchi none of the methods trialed (jute, slash and fertilising) have resulted in large increases in plant cover. Failures in these areas are probably due to a combination of more extreme environmental conditions due to higher elevations, and to the far more extreme soil loss than has occurred at mechanically degraded sites.

Low soil fertility may also be a factor limiting rates of recovery. This is suggested by the success of Yates' trial where large quantities of fertiliser were applied for extended periods, and complete vegetation cover was achieved in only a few years. However, fertiliser applied at lower rates as part of more recent trials has not produced consistent significant results, and no soil testing has yet occurred to attempt to quantify soil fertility in degraded areas.

No rehabilitation has yet been attempted at sites on the Plateau where erosion is primarily driven by channelised flow.

Rehabilitating broad scale erosion on the Central Plateau is a challenge in part because of the harsh climate and the badly degraded soils, and the many interacting erosion processes. However, possibly the greatest difficulty is the huge areas involved, and the dispersed nature of the erosion. Internationally, most alpine rehabilitation projects tackle a relatively small area, where the source of degradation is often mechanical disturbance. In Australia, the very large rehabilitation program at Kosciusko began in the 1960's and cost over one million dollars (1960 dollars) tackled only 1,500 ha of degraded ground (Good, 2003). This contrasts with the 11,000 ha of erosion mapped on the Plateau.

A further restriction on rehabilitation on the Plateau are the conservation values that we are attempting to protect and restore. An initial review of approaches to alpine rehabilitation internationally has revealed similar approaches to those already trialed on the Plateau, with the addition of large scale drainage works, the use of cover crops, more emphasis on mulching often using materials from outside the area, direct seeding including hydromulching, and transplanting living plants with rootplates and soil attached. Many of these methods involve applying large quantities of soil or plant material. This cannot be sourced locally without damaging presently intact areas of the Plateau, and there are significant issues related to the introduction of weeds, foreign soil organisms or diseases should such materials be imported from outside the area. Similarly, high rates of fertiliser application may not be appropriate as they will cause the death of some native species. Other methods involve the use of heavy machinery, which is not possible in a wilderness area.

It is apparent that of the known successful rehabilitation techniques, most are not appropriate for very large areas. Fencing is a good example of this. It is also apparent from the contrasting results at Lake Augusta, Talinah and Bernacchi that the rehabilitation approach must be carefully designed to the specific environment where it will be used. At present, we do not have the knowledge to do this for most areas of the Plateau.

3.3. Conclusions to be drawn from field work

The field component of this project has produced a greater understanding of the present nature of erosion on the Central Plateau. However, this understanding has in general raised more questions than it has answered. Identifying rehabilitation priorities requires knowledge of the present condition, conservation value and trajectory of the area, and the cost and probability of success of appropriate rehabilitation techniques in the area. The results of field work are summarised below in these four areas.

1. The present condition of the area.
This is similar to the condition mapped by Cullen (1995). There are signs that some sites have improved their condition (as indicated by vegetation cover), whilst others have deteriorated, but signs of ongoing soil erosion are common and widespread. Erosion continues through many processes, including frost heave, sheet and channelised flow, wind erosion, grazing impacts, drought and recreational impacts. Typically, many of these processes occur in the same area. Frost heave is possibly the most prevalent of the primary erosion processes.

2. The relative conservation value of the area.
During fieldwork, efforts were made to identify large undisturbed areas that might be threatened by erosion. Because of their ecological integrity, such areas have high conservation value and are a high priority for rehabilitation. However, none were found as signs of historical soil erosion are frequent even in areas that are presently stable and well vegetated.

No systematic search for special conservation values has yet been made. This should be a priority for future years of the project.

3. The trajectory of the area.
As described in the discussion of trajectory in Section 3.2, with the exception of a few areas it is not possible to comment with any confidence on the rate of improvement or deterioration of broad scale erosion on the Central Plateau. There are signs of both ongoing soil loss and increases in vegetation cover at most sites, and at this stage we lack sufficient knowledge to estimate which areas will recover naturally, and which, in the absence of active rehabilitation, will continue to erode until soil loss is complete.

4. The cost and probability of success of rehabilitation.
Indications from existing trials indicate that the trialed rehabilitation techniques have a high chance of failure in sheet eroded areas. The development and trialing of techniques used interstate and internationally and potentially new techniques is required.