RABBIT CONTROL IN THE PARWAN VALLEY AND ITS VALUE FOR CATCHMENT MANAGEMENT

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ABSTRACT

The highly eroded slopes of the White Elephant Hills provide ideal harbour for a rabbit population which can disperse readily into the surrounding farmlands. The nature of the terrain makes eradicating rabbits from these sites extremely difficult. Rabbits are implicated in the major soil erosion problems of the area. Rabbit numbers fell to very low levels during the 1982-83 drought, and the opportunity was taken to intensify rabbit control measures. It was recognized that the problem would be much more difficult to address when rabbit numbers were high.

Maintenance of very low rabbit numbers has been achieved by fencing off small areas and then targeted poisoning at sites of rabbit activity. Consequently, there has been a dramatic increase in the regeneration of trees, shrubs and grasses, and particularly in the survival of tree and shrub seedlings over much of the White Elephant Reserve. Experimental equipment already in place has identified a 20% decrease in average annual surface run-off, attributed to the greater biomass with increased infiltration and evapotranspiration.

This increase in pasture production corresponds in general terms to an improvement in the gross margin of approximately 1 DSE/ha. The implications of rabbit control for catchment management both in the Parwan valley and more generally are examined.

1. INTRODUCTION

Some fifty years ago, interest in the Parwan valley was initiated by two processes, erosion and sediment transport. It was recorded that Melton reservoir was rapidly losing its water capacity as it filled with sediment. The high sedimentation rate was the result of excessive soil erosion, predominantly from the Parwan Valley. The Parwan Creek catchment occupies only 17% of the total catchment area above Melton reservoir.

The Parwan experimental area was established in 1953 by the Soil Conservation Authority. It is located within the White Elephant Reserve, now owned by the Victorian government (figure 1).

The objectives in establishing the project were to gain a greater understanding of the hydrological processes operating in an eroded catchment, to determine the relationship between rainfall and run-off, and to evaluate the effects of remedial land use and pastoral practices.

While certain management factors have been deliberately manipulated, rabbit infestation has varied across the experimental catchments. The length of record enables some assessments to be made of these changes.

2. DESCRIPTION OF THE SITE

2.1 Location

The White Elephant Reserve covers some 300 ha, and is located about 16 km south-west of Bacchus Marsh, 53 km west of Melbourne, Victoria (figure 1). The Parwan experimental area covers 94.5 ha and is located within the Reserve. Coordinates of the area are latitude 37°41' south, longitude 144°20' east. There are seven reference subcatchments within the area. The orientation of the subcatchments is shown in figure 1, and some characteristics are given in table 1.

2.2 Instrumentation

Climate data is collected at a meteorology station located within the area (figure 1). There is a continual record of the key climatic factors (rainfall amount and intensity, wind speed and direction, temperature and humidity and pan evaporation). Surface run-off from the six small subcatchments is recorded through a 300mm H-type flume connected to a stilling chamber. Surface run-off from the main channel is estimated by a 120° broad-crested weir and float recorder. In 1978, a sharp-crested weir was installed. Water level is recorded on L & S type A35 recorders. A more detailed description of the instrumentation is given in Wu (1980) and Wu *et al.* (1986). The average annual rainfall is approximately 530 mm, while average annual evaporation is 1540 mm, a deficit in the annual water balance of 1010 mm.

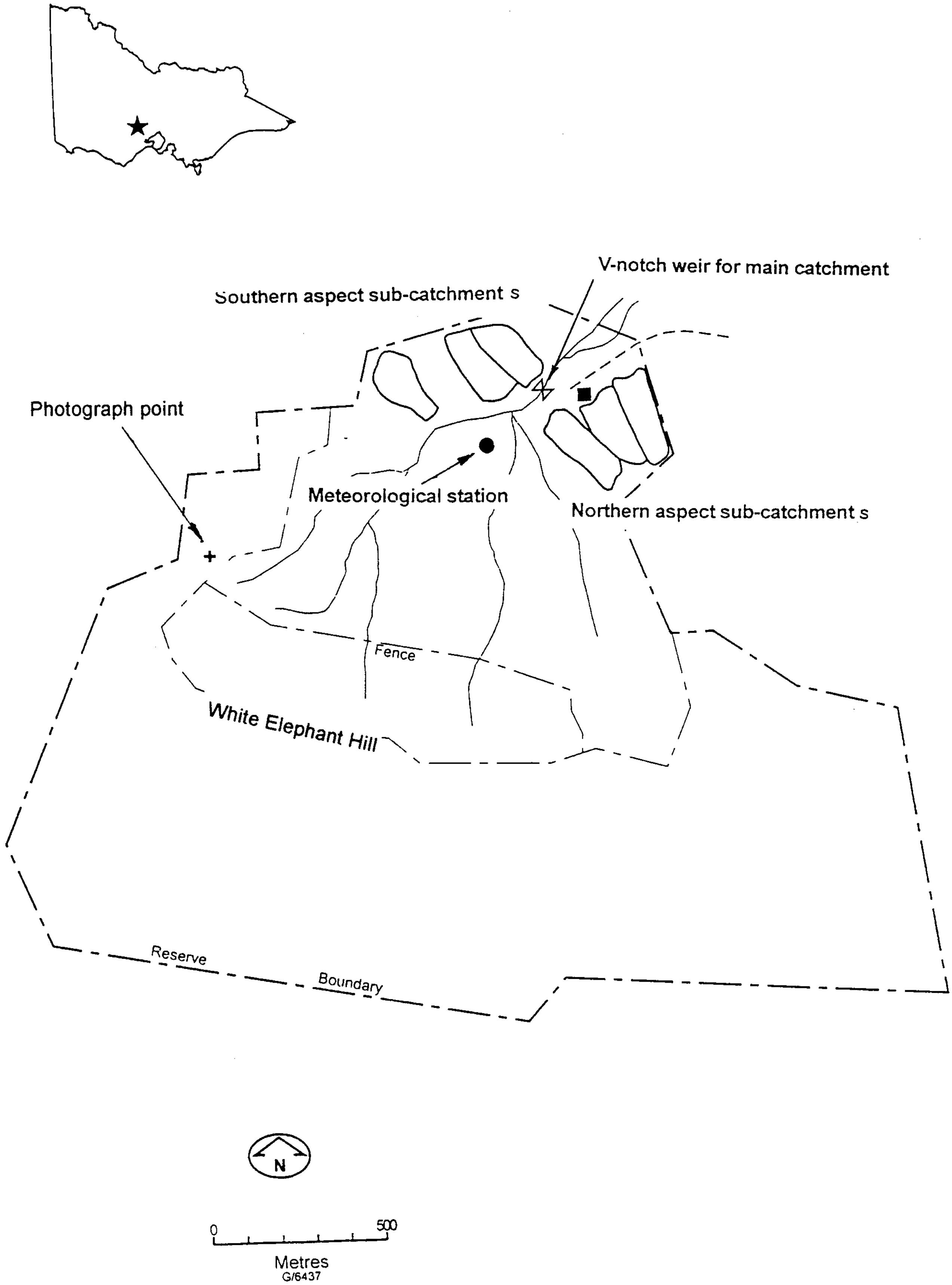

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Figure 1. Location of study site showing relationship of experimental area and White Elephant Reserve

Table 1. Some characteristics of the Parwan subcatchments

Number	1	2	3	4	5	6	7
aspect	north	north	north	south	south	south	north
area (ha)	1.5	1.5	1.5	1.6	1.6	1.6	80.9
land cover	woodland	permanent pasture	native pasture	woodland	permanent pasture	native pasture	see Table 6

2.2 Landscape

The landscape of the experimental area has two dominant features; the north face of the White Elephant Hill (27 ha), which has slopes of 20° to 30°, and the lower slopes (54 ha) which are relatively flat (5° to 10°').

The development of the Rowsley fault line has removed any stable base point in the stream system. Consequently, the Parwan Creek continues to down cut, disturbing the side slopes of the Parwan Valley. The combination of a geomorphic instability, basalt capping and highly unstable substrate has resulted in a range of land degradation problems, including gully erosion, sheet erosion and mass movement.

2.3 Soils

The soils of the experimental area are of Miocene origin. The surface soil horizon has compacted following removal of vegetation. Raindrop action has produced a widespread crusty surface layer. The lower soil horizon has very poor structure and quickly loses stability when wet (Hexter *et al.* 1956). Consequently, sheet and gully erosion are widespread on the White Elephant Hills. The major problem is the extensive tunnel erosion, which in places has developed into gullies up to 5 metres deep (Hexter *et al.* 1956). These sites provide harbour for rabbits. Where the surface layer of soil has been eroded, the ground cover degrades until eventually, only lichens survive (Forbes, 1948).

3. STRATEGY FOR RABBIT CONTROL WITHIN THE RESERVE

The strategy for rabbit control started when the response of the experimental plot to fencing was observed in 1982-83 (Section 3.1). This prompted more fencing (Section 3.2) and poisoning (Section 3.3). The results lead to development of the plan. The effects have been monitored by surveys of rabbit numbers (Section 3.4), and by assessment of the change in biomass following rabbit exclusion (Section 3.5).

3.1 Reclamation at Western end of White Elephant Hills

An experimental plot of 1.6 ha at the western end of the White Elephant Hills was fenced for rabbit exclusion in 1958, and 344 trees of 19 species were planted with tree guards. However, the exclusion fence was not maintained, rabbits reinfested and the condition of the plot deteriorated. By 1975, the fence had been undermined to a large degree, and gave only minimal protection. A vegetation survey at that time showed that there were 250 survivors from the original planting. There were 120 additional shrubs of *Acacia pycnantha* (Golden Wattle), which regenerate profusely and appear to be less palatable to rabbits, but there were no other species (Soil Conservation Authority, unpublished data). In 1982, rabbits were excluded from the plot by repair of the fence, by poisoning and by lack of food caused by the 1982-83 drought. The effectiveness of attempts at revegetation was examined, and the importance of maintaining the fences was recognised as a key factor in excluding rabbits. This lead to the development of the rabbit control strategy. By 1984, an estimated 3000 seedlings had germinated in the experimental plot, with most of the original 19 species being present. Since 1984, there has also been extensive regeneration of understorey native grasses and shrubs.

Table 2. Application rates of poisoned carrots on sites of rabbit activity

Year	86	87	88	89	90	91	92	93	94
Application rate (kg/ha)	7	7	7	7	4	4	4	2	1

The complexity of the challenge is well illustrated by an example. An eroded area with extensive gullies at the west end of the White Elephant Hill was earmarked as a problem area, and was fenced off and poisoned in 1986 (figure 1). At the time, the Reserve perimeter fence was not in good condition, and needed repair. Rabbits quickly returned following the poisoning, because the fence was low in places and rabbits were able to jump over it. The low sections occurred for two reasons. Firstly, cows from the adjoining farm were pushing between the rabbit-proof wire and the barbed wire to graze the phalaris, and were bending the rabbit-proof wire. Secondly, there were low spots across an eroding gully. An extra height of 30 cm of rabbit-proof wire was fitted in the low sections, which stopped the cows but not the rabbits. A guard of barbed wire 10 cm from the top of the fence was needed to finally stop the rabbits entering the area. Overall, approximately 12 months elapsed between when the area was fenced off and when there were visible signs of recovery by the vegetation. The condition of the area in autumn 1989 is shown to the right of the fence in Plate 1. The area to the left of the fence is the experimental plot described in the previous paragraph. The photograph was taken facing south-east, approximately 10 m from the fence junction. The site is marked in figure 1.

3.2 The fencing plan

When the Reserve was established in the 1950s the existing exclusion fence was renewed around the perimeter. This fence linked with the boundary fence of the experimental catchments (figure 1). Fences around the lower slopes section of the experimental area were maintained from 1975. Rabbits were excluded from subcatchments 1 and 4 from 1978. Little maintenance was carried out on the Reserve fences until 1982, when all fences were repaired by renewing rusted sections along the bottom.

The fence around the 1.6 ha experimental plot was repaired in 1982 (figure 2). At the time, it was noted that requirements for fencing maintenance slowly reduced after a period of continual breaches of the netting fence, which indicated that rabbits were dispersing under the harsh conditions.

As noted above, the experimental plot regenerated rapidly following repair of the fences. This had two consequences. Firstly, a high priority was placed on keeping the fences in good condition by regular patrolling and maintenance. Secondly, the findings indicated what could be expected by fencing out further areas of the White Elephant Hill. In 1985 and 1986, an additional 14 ha of the worst infested sites were fenced off into exclusion plots. This is marked in figure 2. Fenced areas were then incorporated into design for detailed poisoning described in Section 3.3.

3.3 The development of targeted poisoning

Poisoning with sodium monofluoroacetate (1080) in carrots is the preferred method of rabbit control. A review of the properties of this compound is given in Atzert (1981). Up to 1985, the standard procedure for poisoning rabbits in the White Elephant Reserve was to lay a trail along a defined track using a bait layer, as shown in figure 2. Two poison-free feeds were given with a three day interval, and then poison was laid. From 1978 to 1984, an additional trail was laid along the ridge of the White Elephant Hill (figure 2), because it was recognised that rabbits were using the eroded face of the White Elephant Hill to reinfest the lower slopes. Poison was laid twice along the trail over the summer of 1982-83. In 1984, there was some additional poisoning by hand along the gullies. In 1985, poisoning along the standard trail was augmented with aerial poisoning, with further poisoning by hand along some gullies.

From 1986 to 1993, there was only hand poisoning at all sites of rabbit activity (scratches, dung hills and feeding sites) throughout the Reserve. The interval between hand applications was increased to seven days. Application rates were progressively reduced as rabbit numbers declined from levels present prior to fencing. Application rates on sites of rabbit activity are shown in table 2.

Fencing and targeted poisoning together reduced rabbit numbers dramatically while rabbits were in plague proportions throughout the Parwan Valley. Spotlight surveys made within the Reserve on completion of targeted poisoning in 1989 and 1990 located only two rabbits.

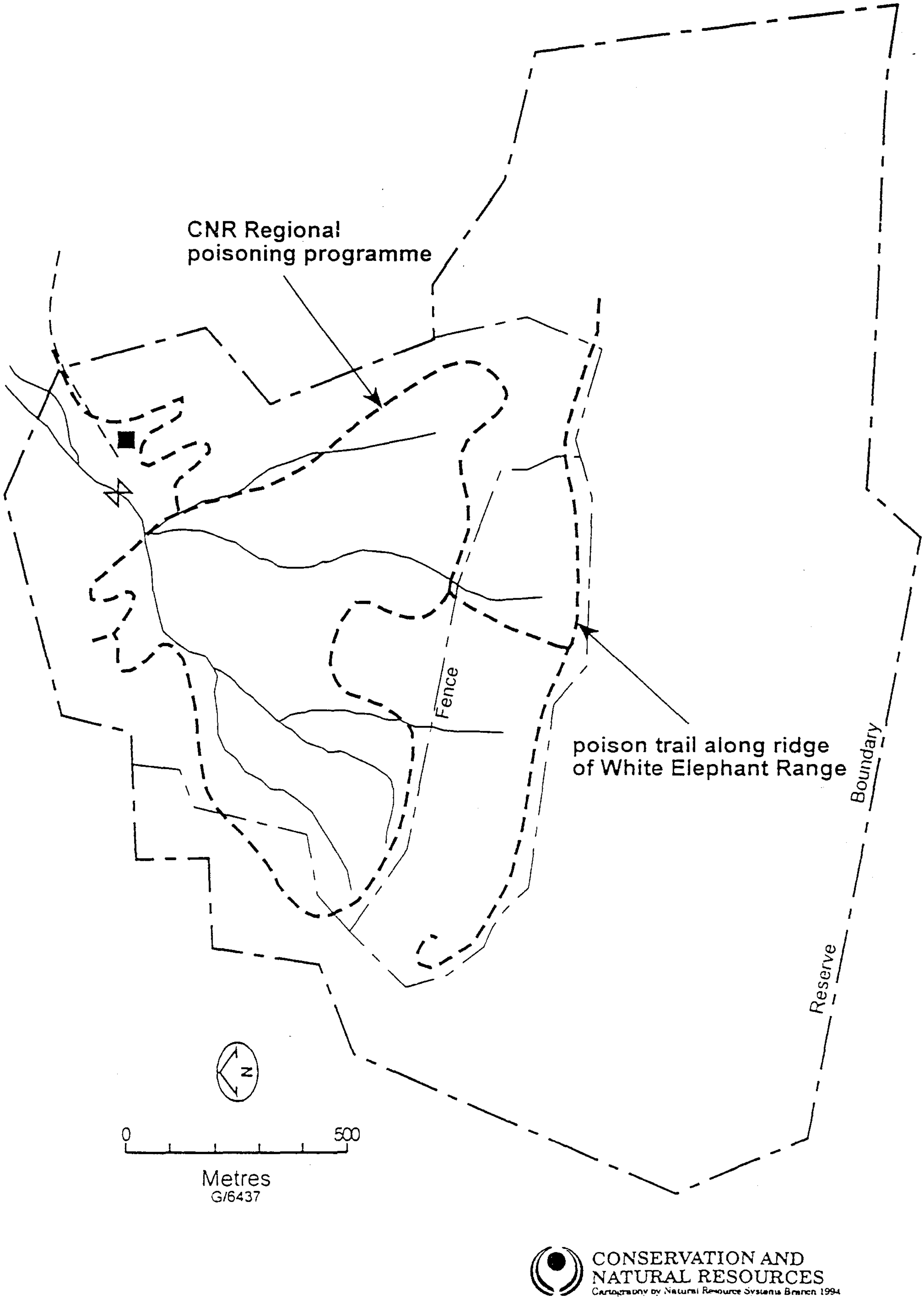

Figure 2. White Elephant Reserve showing poison trails

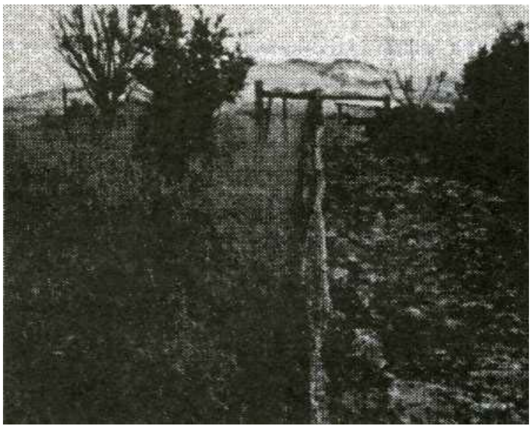

Plate 1 - Photograph taken in autumn 1989 illustrating effects of rabbit exclusion. Full details are given in the text.

3.4 Rabbit number surveys in the Parwan Valley

Rabbit numbers in the Parwan Valley have been surveyed by the Department (D. McPhan[1], unpublished data). Thirteen surveys were made in different seasons from 1985 to 1989. The data from these rabbit surveys have been used to find where the rabbits are located on the landscape, and their density.

Surveys were made in the early evening, starting after dusk. Rabbit numbers were observed by spotlight from a vehicle driving slowly along a 9 km transect in the Parwan valley. Estimated range of the spotlight is 50 metres. The location of the transect is shown in figure 3. Rabbits were counted on both sides of the vehicle path. Counts were recorded at 0.5 km intervals from a stationary vehicle. The mean number of rabbits along the transect over the period 1985 to 1989 is shown in figure 4. To illustrate the extreme situation, results are also shown of the survey on 18 January 1988, when rabbit numbers were high. Rabbit numbers tend to be higher near preferred habitat or where it is difficult to poison, e.g., at the foot of steep slopes.

Science Officer, Department of Conservation and Natural Resources, Bacchus Marsh Numbers are lower where maintenance is done and conditions are harsher, e.g., near the road with the rabbit proof fence. Survey points 15 to 18 give the closest approximation to the landscape within the experimental area.

Rabbit numbers have been averaged along the survey transect for a given land use classification, as defined in Hexter *et al.* (1956). Results are shown in table 3. Simple arithmetic then gives the expected density of rabbits for that land use class throughout the Parwan Valley. Results are shown in table 4.

3.5 Measurements of biomass

Two sets of plots were studied to quantify the changes in vegetation following rabbit exclusion. The first set was in pastured land of the main catchment; the second on the ridge of the White Elephant Hill. The site in the pasture had a north-west aspect and was near rabbit activity. Grasses present are mostly *Danthonia* species. The site on the ridge had little rabbit activity since 1986. Grasses are *Danthonia* species, with a small amount of *Poa labillardieri.*

The method was the same at both sites. An area of 1 m^2 was harvested from the exclusion plot and from the adjacent area. Material was dried at 45°C for 4 hours and weighed to determine biomass. Results are given in table 5. Because the vegetation is mostly native grasses and mosses, the overall ground cover has been subdivided to show their relative contributions. These values are included in table 5.

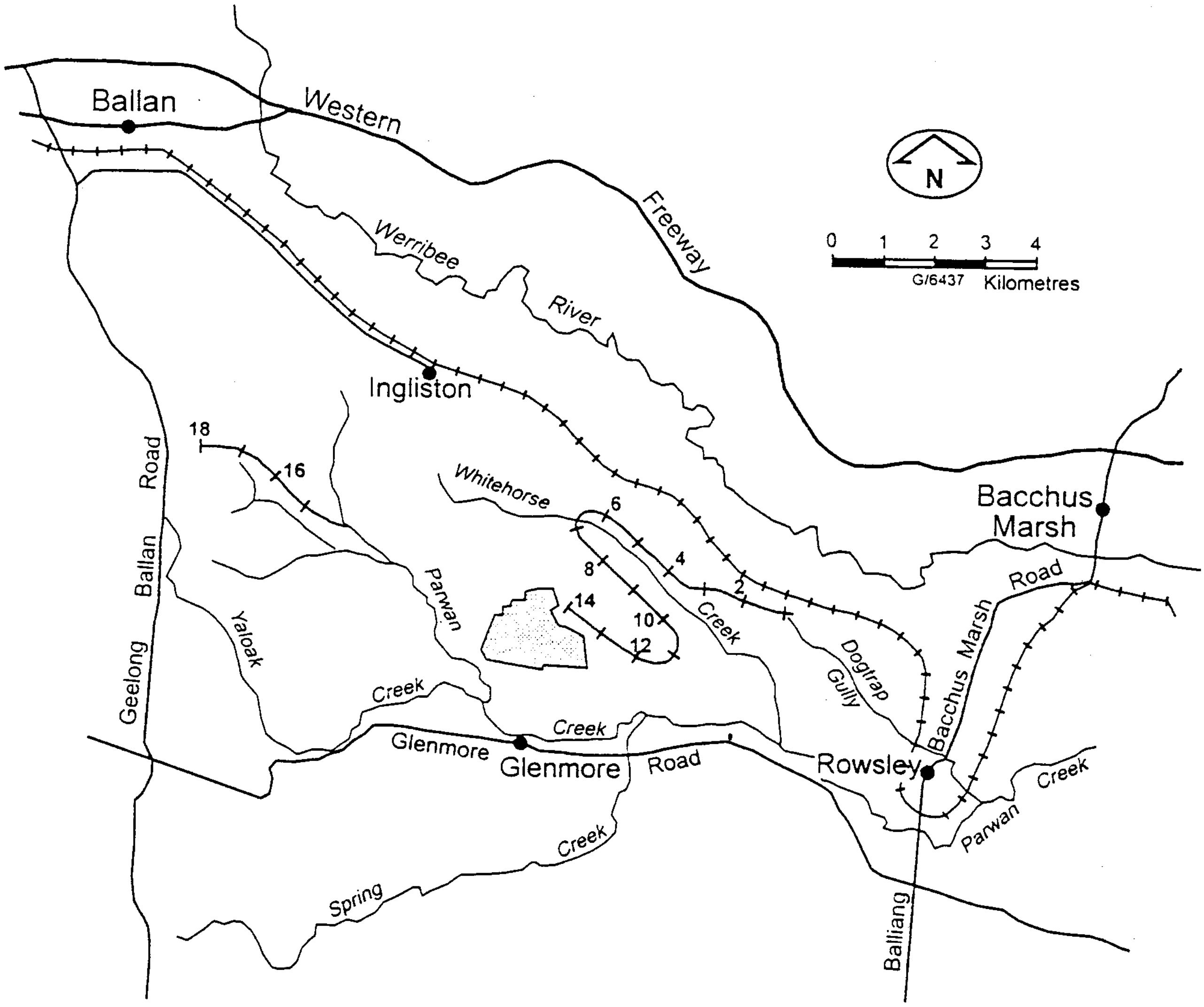

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Figure 3. Location of transect in Parwan Valley for rabbit surveys, and survey points

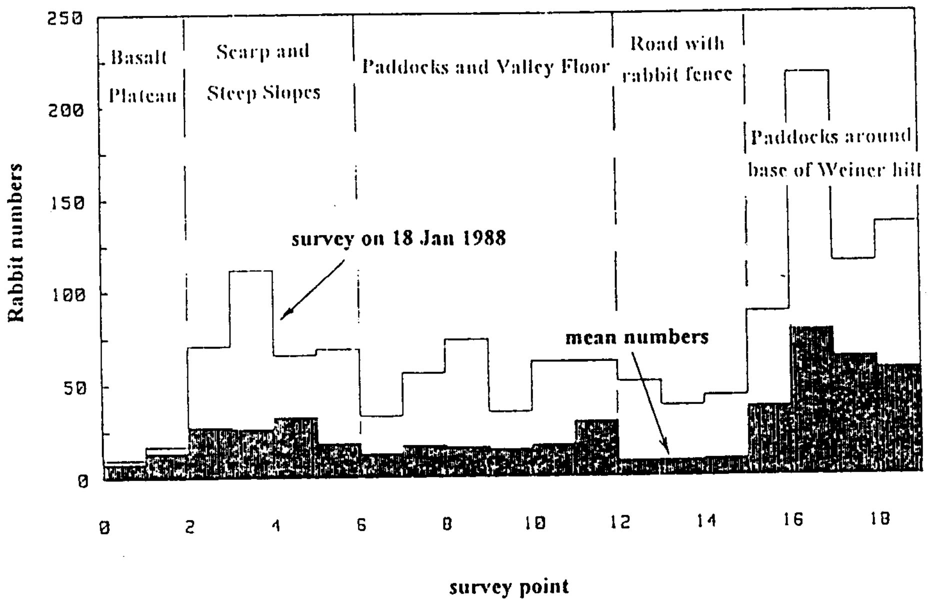

Figure 4. Results of rabbit surveys, 1985 to 1989

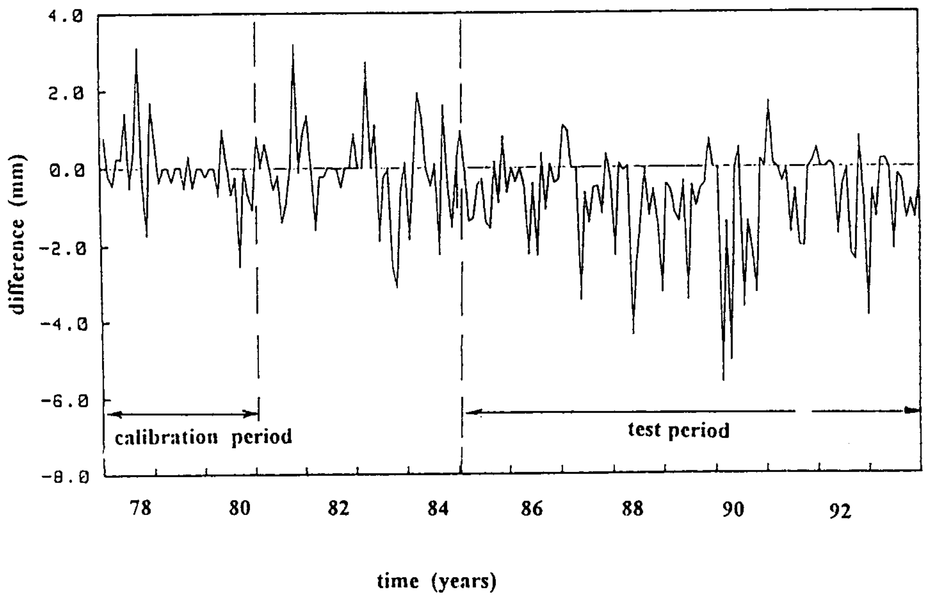

Figure 5. Water Balance Model.
Difference between Observed and Predicted Values (mm)

Table 3. Mean rabbit numbers observed on homogeneous landscape

Landscape unit	Basalt plateau	Scarp (steep slopes)	Paddocks on valley floor	Road with rabbit proof fence	Paddocks around base of hill
Land use class	2A	5	4B	4B	5
Mean	11	26	18	9	59

Table 4. Mean rabbit density for surveyed land class in Parwan Valley

Land class	Area (km^2)	Number/km^2
2A	67	700
4B	37	400
5	42	1500

Table 5. Characteristics of biomass at given sites

Site	Year established	Dry biomass (kg/m^2)	Ground cover (%)	Proportion: native grasses	Proportion: moss and litter
	1954	0.958	100	0.5	0.5
Pasture (a)	1991	0.386	90	0.5	0.4
	No exclusion	0.098	50	0.35	0.15
Ridge	1954	0.428	80	0.4	0.4
	No exclusion (b)	0.133	60	0.3	0.3

(a) Note that plant numbers are similar in the three plots.
(b) little rabbit activity was observed at this site.

4. RABBIT EXCLUSION AND HYDROLOGY

Previous sections have shown that the rabbit control strategy was successful in controlling rabbit activity, and consequently allowing the vegetation to regenerate. It would be valuable for management purposes to know if there has been a detectable change in run-off associated with this rabbit exclusion. The north face of the White Elephant Hill is of particular interest, because it is the most degraded part of the landscape. The estimation of run-off from the north face is described in section 4.1. A simple water balance model is applied to the north face in section 4.2 to test for changes in run-off. Findings are presented in section 4.3.

4.1 Estimation of surface run-off from the north face of the White Elephant Hill

The stream gauge in the main catchment (figure 1) measures combined drainage from the north face of the White Elephant Hill and from eroded and vegetated areas. This can be expressed as -

$$Q_{mc} = Q_{nf} + Q_{ea} + Q_{ls} \qquad \text{(I)}$$

Table 6. Components of landscape of the vegetated area on the lower slopes in 1978

Landscape	Representative subcatchment	Proportion of lower slopes vegetated area (A)
Savannah woodland	1	0.29
Native pasture north aspect	3	0.42
Native pasture south aspect	6	0.29

where,

Q_{mc} is run-off from main catchment,

Q_{nf} is run-off from the north face,

Q_{ea} is run-off from the eroded areas,

Ql_s is run-off from the lower slopes.

Run-off from the north face and eroded areas is estimated by subtracting the contribution due to the lower slopes from the total run-off, because there is no stream gauging at the break of slope. In turn, the contribution from the lower slopes is estimated by the weighted sum of run-off from the individual reference subcatchments, thus –

$Ql_s = A_1 Q_1 + A_3 Q_3 + A_6 Q_6$ (2)

where Q_i is run-off from subcatchment i,

A_i is proportion of the main catchment represented by subcatchment i,

i = 1, 3, 6. Values of A are given in table 6.

Equation (2) is evaluated to give the estimated run-off from the lower slopes section. This is substituted in equation (1) to give estimated run-off from the north face and eroded areas by difference. Possible changes in runoff due to rabbit exclusion can now be tested using a water balance model. Details are given in Section 4.2.

The above derivation assumes that partitioning the land use of the main catchment is valid, and that summation of the surface run-off (weighted for area) from the subcatchments is a reasonable approximation of the actual processes. Routing of surface run-off and channel absorption effects between the break of slope and the gauging station are considered to be small and have not been included in the analysis. It is also assumed that the relationship of the reference subcatchments and the lower slopes section of the main catchment remains constant during the course of the study. This appears reasonable as the targeted poisoning design operated on both subcatchments and the main catchment.

4.2 Water balance model

A simple water balance model has been applied to the north face of the White Elephant Hill to quantify any change in surface run-off.

The daily water balance is expressed as:

$P = I + ET + Q$ (3)

where P is rainfall (mm),

I is interception (mm),

ET is evaporation/transpiration (mm),

Q is streamflow (mm).

For modelling purposes, this equation has been rearranged as:

$Q = P - I - ET$ (4)

Variables on the right of equation (4) can be estimated. Interception has been estimated empirically as the loss in rainfall before run-off commences. Daily values applied for a given month are shown in table 7. An empirical surrogate for the ET term has been developed, defined as the time in days needed to dry out the catchment. Rainfall is depleted daily by an amount equal to the number of days since rain fell multiplied by 0.64 (units: mm). The depletion continues until either the day value in table 7 is reached, or rain falls. If the day value is reached, a daily maximum of 14x0.64 = 8.96 mm is subtracted. When rain falls, the day counter restarts from unity. Output from the model is predicted streamflow (mm).

Table 7. Empirical model parameters

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Interception loss (mm)	6	6.2	3.5	4	3	2	2	3	4	5	8	6
Time to dry the catchment (days)	6	6	8	10	10	12	12	10	10	8	8	6

The data set consists of daily rainfall and run-off records from January 1978 to December 1993 for the six reference subcatchments and the main catchment (figure 1). **During the calibration period** (January 1978 to December 1980), model parameters have been estimated by successive approximation to minimise differences between observed and predicted run-off. There is a period of no change from January 1981 to December 1984. **During the test period** (January 1985 to December 1993) parameter values from the calibration period have been used in the model to predict run-off. For a null hypothesis that there is no difference in run-off in the test period, only small differences between observed and predicted run-off are expected. Differences have been tested for statistical significance. Any significant differences are due to the effects of rabbit control.

4.3 Results

The difference between estimated run-off and the value predicted by the water balance model has been plotted fro the length of record considered in this study. This is shown in figure 5.

The aim of the analysis is to identify any major changes in surface run-off associated with rabbit control. With this in mind, the differences between estimated and predicted run-off have been averaged at monthly intervals over the calibration and test periods. Specifically, over the calibration period, the January 1978, 1979 and 1980 differences have been summed, and the mean has been plotted in figure 6. This procedure has been applied for the remaining months in the calibration period. Results are shown in figure 6.

The same procedure has been used during the test period (January 1985 to December 1993). Average monthly differences for the interval with rabbits excluded is shown in figure 6. Total monthly decrease in surface run-off over the 9 year test period amounts to 87 mm (figure 6). The average annual decrease is 87/9 ~10 mm, which is approximately 20% of mean annual run-off. This will be discussed further in section 6.

5. FINANCIAL ANALYSIS

The increased water use by the vegetation on site is reflected in increased biomass. The objective here is to quantify this change in practical financial terms. In the absence of any firm information, estimates have been made of the costs involved and benefits received to identify the major financial factors.

The analysis has aimed to normalize costs to the farm level, so that travel times and associated costs from Melbourne to the Parwan area have been excluded. Similarly, the off-site costs of sediment export (for example, costs incurred in removal of silt from Melton Reservoir) have not been considered. Costs of rabbit surveys have not been included.

The only benefit assessed in this analysis is that due to increased biomass using the data from the exclusion plots (table 5). Other benefits which have not been quantified include maintenance of productive land due to reduced soil erosion an improvement in native habitat on non-agricultural sites.

5.1 Costs

Costs arise in allocated time and in materials. Allocated time includes time spent by personnel in the field, i.e., for surveys, labour and supervision. Materials costs occur in purchase of fencing, repair of existing fences, transport and purchase of poisoned carrots.

5.1.1 Personnel time

One day per week is spent in the Reserve Tasks vary during the year. New fences were installed over the summer months, while repairs are a continual task. It is estimated that half the working day is spent on rabbit control measures. Time involved is 5 hours per day at $10.00 per hour (including on-costs) for 40 weeks per year. Total annual cost for personnel is 5 x $10.00 x 40 = $2000.00.

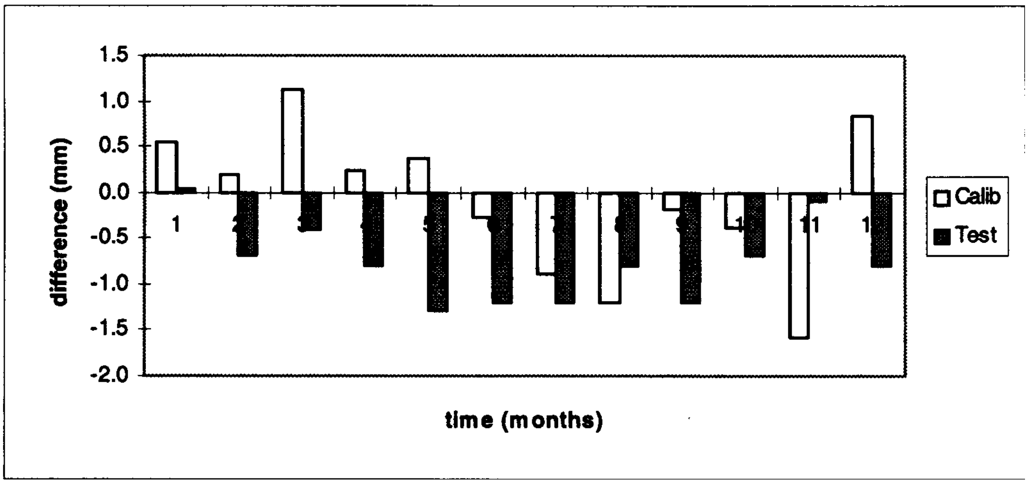

Figure 6 Mean monthly differences between observed run-off and values predicted from water balance model

Table 8 Costs for supply of poisoned carrots

Year	86	87	88	89	90	91	92	93	94
Number of 20 kg bags	60	60	60	60	47	47	47	30	18
Cost – free feed ($)	260	260	260	260	202	202	202	130	78
Cost 1080 feed ($)	180	180	180	180	144	144	144	90	54
Total Cost ($)	440	440	440	440	346	346	346	220	132

5.1.2 Cost of poisoned carrots

Carrots were purchased at bulk feed stores in 20 kg bags at prices varying from $2.50 to $6.00 per bag depending on season. Mean cost was $4.00 per bag. The number of 20 kg purchased are given in table 8. The Department charges $2.00 per 20 kg bag for 1080 poison, plus $0.50 Approximate cost of a 100 metre roll of rabbit-proof wire for a suitable bag to hold the poisoned carrots. There is a cutting fee of $2.50 per 20 kg bag. All up cost for supply of cut and poisoned carrots is $9.00 per 20 kg bag. The cost for a free feed is purchase and cutting only; a total of $6.50 per 20 kg bag. There are two free feeds given, and then poison.

Total annual costs for supply of carrots are given in table 8.

5.1.3 Cost of new fences

Items for new fences are wooden corner posts and supports, steel posts at 5 m intervals, rabbit-proof wire, support wire and barbed wire, and a gate with support. An approximate all inclusive cost for new fences including labour is $10.00 per metre.

Lengths of new fences and associated annual costs are given in table 9.

5.1.4 Cost for repair of existing fences kg bags

Approximate cost of a 100 metre roll of rabbit-proof wire is $250.00 for standard width (1 m) and $80.00 for narrow width (30 cm). Standard width is used for major repairs. Narrow width is used to repair breaches close to ground level, gaps where cows push through, and to increase fence height in low spots. Labour includes pegging down the wire, and the carting of stones for use as weights. An approximate all inclusive cost for repair of These existing fences including labour is $3.00 per metre.

Lengths of existing fences which were repaired annually and associated costs are given in table 9.

$16.00/ha. Second, there is the current maintenance strategy, where annual running costs are approximately $2700/300ha =

$9.00/ha. The major item is the time and. effort made to ensure that rabbits are excluded. costs have been stable for seven years; there is a slight

Table 9 Costs of fencing

Operation	1982	1983	1984	1985	1986	1987 to 1994
Repair of existing fence						
Length (km)	2.0	1.0	0.5	0.2	0.1	0.1
Cost ($)	6000	3000	1500	600	300	300
New fencing						
Length (km)				0.3	0.2	
Cost ($)				3000	2000	

Table 10 Summary of costs

Year	Personnel ($)	Poisoned carrots ($)	Fence repairs ($)	New fences ($)	Rounded total ($)
82	2000	n.a.	6000		>8000
83	2000	n.a.	3000		>5000
84	2000	n.a.	1500		>3500
85	2000	n.a.	600	3000	>5600
86	2000	440	300	2000	4700
87	2000	440	300		2700
88	2000	440	300		2700
89	2000	440	300		2700
90	2000	346	300		2700
91	2000	346	300		2700
92	2000	346	300		2700
93	2000	220	300		2500
94	2000	132	300		2400

5.1.5 Summary of costs

The individual items described in the above paragraphs have been summarised in table 10 to give an indication of overall costs.

Prior to 1986, rabbit poisoning was done by regional Departmental staff, and included aerial poisoning. Costs were not available.

Table 10 shows two distinct phases. First, there is an interval of five years with relatively high costs due to requirements of new fences and repairs to existing fences. Costs in this period are greater than $4800/300ha or $16.00/ha. Second, there is the current maintenance strategy, where annual running costs are approximately $2700/300 ha = $9.00/ha. The major item is the time and effort

made to ensure that rabbits are excluded. These costs have been stable for seven years; there is a slight decrease with time as the quantity of carrots required for rabbit control has decreased.

5.2 Benefits

Consider that rabbits are controlled throughout the Parwan Valley in one year, and that the economic benefit becomes available in the same year. It is assumed that the increase in biomass corresponds to the values in table 5, (i.e., 0.386 - 0.098 - 300g/m^2). This has occurred over a three year period, so the benefit is -100g/m^2 annually.

In the absence of rabbit survey information within the experimental area (land use class 5), it is assumed that grazing pressure is similar to the values surveyed in the Parwan Valley in the same land use class (i.e., 1500/1=^{2}, table 4). Mean grazing pressure on pastures on the floor of the Parwan Valley (land use classes 2A and 4B) has been estimated from table 4 as 550/km^2. On the basis of relative grazing pressure by rabbits, an average improvement in pasture biomass would be expected of 550/1500 times the results observed in the exclusion plots, i.e., 37 g/m (= 370kg/ha) increase in biomass. For a nominal weight of 25 kg for a bale of dry feed costing $4.00, this converts to approximately 14 bales/ha of dry feed per annum, or $56.00/ha per annum. The financial benefit of this additional biomass exceeds the total estimated costs ($9.00/ha per annum, Section 5.1.5), so the method is financially feasible.

This gain can also be expressed in more practical terms. On the assumption that a wether eats approximately 1 kg of dry feed per day to survive (D Perry, pers. comm.), its feed requirements for a year amount to 365 kg. This is approximately equal to the annual improvement in biomass determined in the previous paragraph. Therefore, the gain in biomass due to rabbit control corresponds in general terms to an improvement in the gross margin of approximately 1 DSE/ha.

This is a broad indication only as no allowance has been made for variations in productivity of different pasture species or for varying site productivity. Preferential grazing by rabbits has not been considered. Nevertheless, these figures do indicate the value of a thorough strategy for rabbit control. This analysis has ongoing implications for the local industries of lucerne hay, dairy farming, beef and fine wool production.

6. DISCUSSION

6.1 The success of the rabbit control strategy

There was little vegetation on the White Elephant Hill when the experimental area was established in the early 1950s. Rabbit numbers were high enough to escalate land degradation, and their grazing pressure effectively suppressed regeneration (Section 3.1). The White Elephant Hill provided ideal rabbit habitat because the soils are highly erodible and the landscape is broken. Forbes (1948, page 29) described the study area and the upper Parwan Valley as having "fantastic numbers of the vermin". Rabbit numbers surveyed at this latter site are included in column 5, table 3.

The standard poisoning plan made little impact on the source areas of rabbits where vehicle access was impossible. Short migration distances from the deep gullies ensured that any depletion in rabbit numbers by the standard poisoning plan was only temporary. Rabbit migrations were also assisted by the lack of maintenance of fences.

An attempt was made to keep rabbit numbers low during the drought of 1982-83 by repairing the fences in the experimental area. The results from the experimental plot (Section 3.1) indicated that rabbit exclusion was an important factor in regeneration. Consequently, other areas were fenced off, in particular at the western end of the White Elephant Hill (figure 2) where erosion was severe. Fenced areas were then incorporated into a poisoning strategy which was targeted at sites of rabbit activity (Section 3.3). The major advantage of this development is in its effectiveness. Results show that low application rates at sites of rabbit activity maintain adequate control (table 2). The benefits are that the quantity of applied poison is minimised and that costs are reduced.

When this study was initiated, time constraints dictated that free feeding and poisoning could only be done at 7-day intervals. Results have shown that this interval was effective; both the technique and the findings have been validated in the literature. Cowan *et al* (1987) studied percentage of rabbits consuming baits at various distances from the warren. They found that 90% of rabbits consumed baits up to 25 metres from warrens up to 8 days after baiting commenced. This shows the importance of firstly applying baits close to warrens, and secondly of allowing sufficient time for all rabbits to browse the baits. Cowan *et al* (1987) conducted their study in England where the climate is cooler than in Victoria and the bait is likely to stay fresh for a longer period. In this study, much of the hand poisoning was carried out in autumn and winter when cooler conditions prevail.

The overall result of the fences and targeted poisoning has been that rabbit numbers within the Reserve have dropped from high values (figure 4) to close to zero. Surveys in 1989 and 1990 gave only two sightings over a 1.5 km course. This contrasts with numbers surveyed in the surrounding Parwan Valley (table 3). In the absence of any control measures, rabbit numbers similar to those in the valley would be expected, i.e., in the range 4001500/km^2 (table 4).

The maintenance of declining rabbit numbers from this point forwards can be related to the improved technique of bait feeding at sites of activity with an extended period between bait runs. Poisoning complements proper fence maintenance as a successful tool in rabbit control, in that the fence minimizes the dispersion of high rabbit populations and maintains areas of low rabbit density as less favoured sites.

6.2 The relationship of rabbits and run-off, and possible mechanisms

The broad scale damage caused by grazing rabbits and the consequences has been well documented in the literature (Stead, 1935; Forbes, 1948; Hexter *et al.* 1956; Hills, 1975; Williams *et al.* 1995).

The native grasses of the area (*Danthonia, Stipa* and *Poa* species) have a tussock habit of growth. As a result of an extended period of high rabbit populations these tussocks were closely cropped and continually harvested. They resembled a series of pads with low ground cover (30 to 40%) and low biomass (-0.1kg/m^2, table 5).

When the grazing pressure was removed, tree seedlings, understorey and grasses began to regenerate. The native grasses recovered to a tussock formation with 80 to 90% cover, biomass increased by a factor of approximately 4 times in 3 to 4 years, with the prospect of further long term improvement (table 5). It appears that there is minimal increase in numbers of native grasses, with the emphasis being in growth of existing plants. As the native grasses recover, interception increases and the microclimate under the vegetative canopy becomes less severe. These conditions favour growth of mosses, which is shown by an increase in ground cover (from 0.15 to 0.4, column 6, table 5). The growth of mosses retains surface moisture on site, and consequently increases infiltration. The growth pattern of mosses is seasonal, as they dry out over the summer months.

The reductions in run-off go through a cycle, with maximum reduction in mid-winter and minimum reduction over mid-summer (figure 6). In the absence of direct observation, this may be due to a combination of the increase in biomass and elevated infiltration. This would be consistent with the findings of Dunin and Downes (1962) and Dunin (1965), when poor native pasture was converted to annual improved pasture. May is the time of the autumn flush of growth, when temperatures are still elevated. In the calibration period, the rabbits would have continually cropped this biomass. However, the reduction in rabbit numbers has allowed the development of the understorey and a large number of acacias, which were not present in the exclusion plots. This has increased interception and provided shading and windbreak for the development of ground cover (table 5). Evaporation rates are reduced in the shade, and consequently surface soil moisture tends to be higher (Chow, 1964). These conditions remain favourable over the winter months for further infiltration and plant growth in the Spring. However, conditions change dramatically over the summer months. Low summer rainfall and high temperatures put all vegetation under soil water stress, and evaporation and transpiration are at low levels. High rainfall intensities still tend to compact any areas of exposed soil surface and produce surface run-off.

Although this explanation describes the overall findings, the details are tentative and require further study to clarify the underlying processes. In particular, experiments on the seasonal variation of infiltration and its relationship to ground cover and rainfall intensity would provide further insight into best practice.

As part of ongoing work, surveys of the main catchment have shown that the sheet eroded areas are rehabilitating very slowly, so that these areas now yield the greater proportion of the observed surface run-off. Therefore, the increase in interception and infiltration has occurred in areas with higher ground cover (pasture and/or acacias), due to exclusion of rabbits. Further decreases in run-off are expected as the sheet eroded areas rehabilitate. The possibility or feasibility of accelerating this rehabilitation warrants further investigation.

6.3 Future management recommendations

The landscape of the White Elephant Reserve is typical of the slopes of the Parwan valley. Deep gullies and sheet erosion on solodic soils occur throughout the Reserve, in the Parwan valley, in the adjacent Werribee River catchment and near Anthony’s cutting. The management practices which have been implemented in the Reserve have been effective in (i) reducing rabbit numbers to very low levels, (ii) enabling regeneration of vegetation to take place and (iii) retaining water on site and reducing run-off. As more areas have been fenced out and poisoned, rehabilitation of eroded areas has been commenced, mostly by extensive tree planting with straw mulch to retain moisture.

In principle, it should be straightforward to extend these management practices to the broader scale. Rabbit haven is made unattractive in two ways, by fences selected areas and by poisoning sites of rabbit activity. The method is financially feasible for the 300 ha reserve. The major costs are in the initial purchase of fences to exclude rabbits, and in ongoing maintenance: the benefits are in greatly increased biomass, reduced run-off and higher productivity from the selected area. These are important considerations for efficient management of low rain fall areas. In these situations, it is advisable to treat water as a resource which should be retained on site for use at critical times. Suggested measures to retain moisture include mulching, growing species which provide litter and by providing the environment to facilitate distribution of moisture through the soil profile.

The current practice of rabbit control has limitations because laying a poison trail does not address the source areas of reinfestation. Large kills are made in the vicinity of the trail, but rabbits breed in unthreatened areas and then disperse back into the farmlands. A continual cycle of depopulation and repopulation is almost guaranteed.

An alternative practice is to firstly appraise the land and appreciate that different land classes require different intensities of land management. The eroded slopes of the White Elephant Hill need fences to separate them from the flatter pastured areas. The preferred poisoning schedule is to poison at sites of rabbit activity with low application rates, and to allow sufficient time for baits to be accepted.

7. CONCLUSIONS

This study has shown that the policy of constructing fences around rocky or eroded hills and leaving these areas to the rabbits is not effective in minimising rabbit numbers, because these areas serve as sources of reinfestation. An effective method of rabbit control is to fence out the hillslopes from the paddocks, and if necessary, to even fence out critical areas on hillslopes. All areas are then carefully poisoned with attention being given to sites of rabbit activity. It is important to give rabbits sufficient time to take the poisoned baits. This study confirms findings that seven days should be allowed for high levels of bait acceptance. Rabbit numbers can be kept low only by continued fence maintenance and poisoning where breaches occur, so that rabbits are prevented from recolonizing a site.

In fact, this study has given rise to the interesting situation where low rabbit numbers have been maintained for approximately 10 years throughout an area of some 300 ha, and this is surrounded by an extensive area of farmland where rabbits are numerous.

The benefits of this method of rabbit control have lead to a decrease in run-off and an increase in pasture production. The increased pasture production corresponds to an approximate improvement of 1 DSE/ha in the gross margin. Management to decrease surface run-off is a positive step in erosion control and has special significance in low rainfall areas. Simultaneously, these practices increase interception and infiltration, and maximize water use on site. This involves the complete vegetative layer, including trees, shrubs, grasses, ground litter, macropores and soil microorganisms.

This study was initiated during a drought, when rabbit numbers were low. Psychologically, this is a stronger starting point than when rabbits are in plague proportions. The challenge now is to undertake this strategy at other sites where rabbit numbers are high and deep gullies and sheet erosion occur on solodic soils.

The results of this study have clear relevance to land of similar nature, e.g., the Parwan valley, the Werribee River catchment, the Pentland Hills area and near Anthony’s cutting. However, the basic principle of exclusion fences where there is ready reinfestation to replace poisoned populations holds in all parts of Victoria, while the relationship between streamflow, plant growth and rabbit control should hold for at least all dry (up to 800 mm annual rainfall) environments where there is significant surface run-off.

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