Water Quality Centre Publication No. 19

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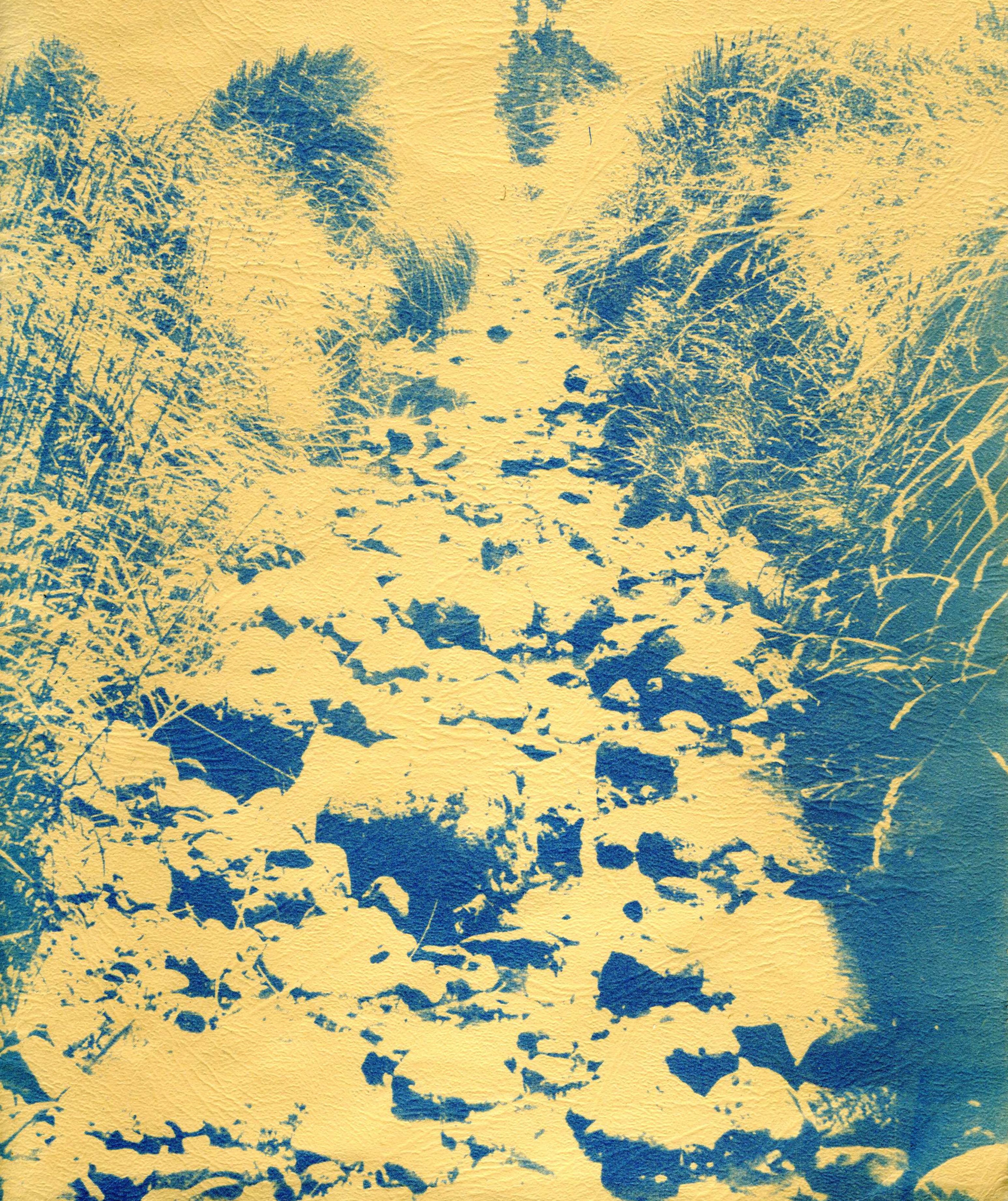

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by

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SUMMARY

The effects of grazing animals on stream margins and the benefits of riparian retirement to streambank erosion and aquatic habitat were assessed through the survey of 6 streams and rivers in Southland, New Zealand. Effects and benefits were assessed by comparing morphological and vegetation data between grazed and retired reaches, and making inferences about channel erosion processes and the effect on those characteristics that benefit aquatic habitat.

Grazing was found to have relatively little effect on channel morphology and bank stability of most streams. On the 2 larger streams, which had relatively active channels, grazing damage was slight and appeared to be playing little part in overall streambank erosion or characteristic morphology. Past effects, if they occurred, would have been obliterated by shifts in channel position. In the other smaller streams, the channel was far less active and localised damage to streambanks was highly variable ranging from 0 to 25 % of the channel length. The worst damage seemed to be associated with a combination of factors: a relatively high stocking rate with cattle and an exceptionally wet streamside soil. The least damage was observed on the smallest stream surveyed, demonstrating that the the large potential for damage to such small streams is only realised under the appropriate conditions. In most other streams the damage was highly localised, in some cases leading to wider, shallower sections, but not significantly changing the average dimensions of the channel. Only in the most damaged situation had significant channel widening occurred.

We attributed the relatively low degree of grazing damage in most streams compared with that observed overseas to the relatively dry stream-side soils, moist temperate climate, high inaccessible banks and possibly better stock management.. Benefits of retirement were thus limited to the retention of remnant native shrubs and tussock along stream margins, protection against man-made channel alterations and the prevention of localised, stock-induced streambank damage in small streams. In the larger actively migrating streams, retirement by itself would have little effect on the dominant erosion processes. The lack of recolonisation by native species, particularly larger shrubs or trees that might stabilise banks and enhance instream habitat, leads us to suggest that greater benefits would accrue if the retired zones were planted in appropriate tree species. This would seem to be a particularly attractive option in larger streams where an improvement in trout fisheries and a reduction in erosion is required.

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1. INTRODUCTION

Riparian retirement has been widely recommended for improving aquatic habitat and water quality in agricultural catchments in New Zealand (e.g. Evans 1979, Young 1980, Southland Acclimatisation Society 1981, Riddell & Sutton 1983, Williams & Brickell 1983, Watson 1986, Dungey 1990). These recommendations have been made in response to a deterioration in water and habitat quality, chiefly from nutrient and fine sediment enrichment and loss of trout and native fisheries. Grazing stream margins is perceived to lead to a loss in riparian vegetation cover and trampling of banks. This in turn could lead to a decrease in shade and bank stability, and an increase in bank erosion and fine sediment inputs. Retirement is expected to prevent or reverse these effects. However, there has been no rigorous scientific testing of its benefits to the aquatic habitat or to bank stability in New Zealand. Most of the evidence for its effectiveness comes indirectly from accepted soil conservation practices in New Zealand or more directly from studies on riparian retirement in the rangelands of the western United States.

In New Zealand, retirement coupled with appropriate tree planting is widely used for streambank erosion control (Dixie 1983, Rowell 1983). There seems to be little doubt as to its efficacy, but few quantitative evaluations have been reported, either on the effects of grazing or on the benefits of retirement. In the Western USA, there is ample evidence documenting benefits of protecting stream channels by retirement from grazing (e.g. Platts 1979, Skovlin 1979, Platts & Rinne 1985). These studies provide evidence that long term grazing has changed the stream environment to wider, shallower streams with little vegetative cover and shade. Channel changes are thought to be due to increased erosion resulting from removal of protective vegetation and trampling of banks. Fencing of stream channels produces a rapid improvement in riparian habitat, mainly in response to vegetative changes, while stream morphology improves slowly. Fish populations may or may not be improved (Platts & Rinne 1985).

The lack of New Zealand data prevents us predicting whether the USA findings are applicable to New Zealand conditions. As a contribution to meet this information gap, this study examines the effects of stream berm retirement in a number of Southland streams and rivers. This particular region of New Zealand was chosen because of the local importance of berm retirement. Through the 1970's and 1980's, the Southland Catchment Board encouraged a number of agricultural land developers to retire berms for erosion control, flood control, water storage and water quality enhancement. Some of the most graphic evidence in support of retirement has been photographs of stream channels taken before and after development published by the Southland Acclimatisation Society (1981), who are concerned about a deterioration in the region's trout fisheries, an important recreational and tourism resource (Riddell and Sutton 1983, Watson 1986, Rodway 1987). These photographs show large changes in stream morphology. Anecdotal evidence of this kind suggests a serious problem and added considerable impetus to the need to address the effects of streambank grazing in New Zealand and the potential benefits of stream berm retirement. In this report we examine the effect of grazing on channel morphology. In companion papers we also describe the effects of channelisation on streambank stability (Williamson et al. (in prep.)), and the effects of grazing and channelisation on invertebrates (Quinn et al. (in prep.)).

2. CATCHMENT DESCRIPTION

2.1 Site Selection

The study area is located in northern Southland (Fig. 1). Some 26 streams and rivers containing protected reaches were visited and appraised for their suitability for this study. Most had to be rejected because of complicating factors, such as lack of a suitable unprotected comparison, large changes in land use or differences in geomorphology. One common complication was channel straightening and deepening to increase drainage efficiency. The selection attempted to minimise differences between protected and unprotected pairs, but it was impossible to find the perfect matched pair that only differed by presence or absence of protection.

Six streams were selected ranging in catchment area from 3.3 to 55 km^2. Catchment details are summarised in Table 1. In all, 7 reaches which had been retired from grazing were surveyed and compared with 8 reaches that were still grazed to the water's edge. The latter were either downstream from a retired reach or in an adjacent catchment.

2.2 History and Land Use

Before European settlement the dominant vegetation near the streams was red tussock (*Chionochloa rubra*) or a mixture of red tussock and wetland communities, including wire rush (*Empodisma minus*), sedges (*Carex sp.*), inaka (*Dracophyllum sp.*) and woody shrubs (mainly *Coprosma sp*). Red tussock grows 1-2 m tall in its native state. The land surface was very rough and hummocky, slowing runoff on all but the steepest slopes, hence upland bogs were common and in general the land was poorly drained.

During the middle of the 19th century, the land was settled as large pastoral sheep-grazing properties (known in New Zealand as stations). This was accompanied by seasonal burning of the tussocklands to encourage more palatable new growth. Initially sheep, and later mixed cattle and sheep were grazed. Some blocks became infested with large numbers of wild deer. Although overall stocking rates were low (typically 1 - 5 stock units[1] per hectare (s.u./ha)), berm areas were favoured grazing sites, and some were top-dressed and oversown with exotic grasses. The change to more intensive grazing occurred in relatively recent times (Table 1), with subdivision of the stations into smaller farms.

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[1] One stock unit is equivalent to an adult cow.

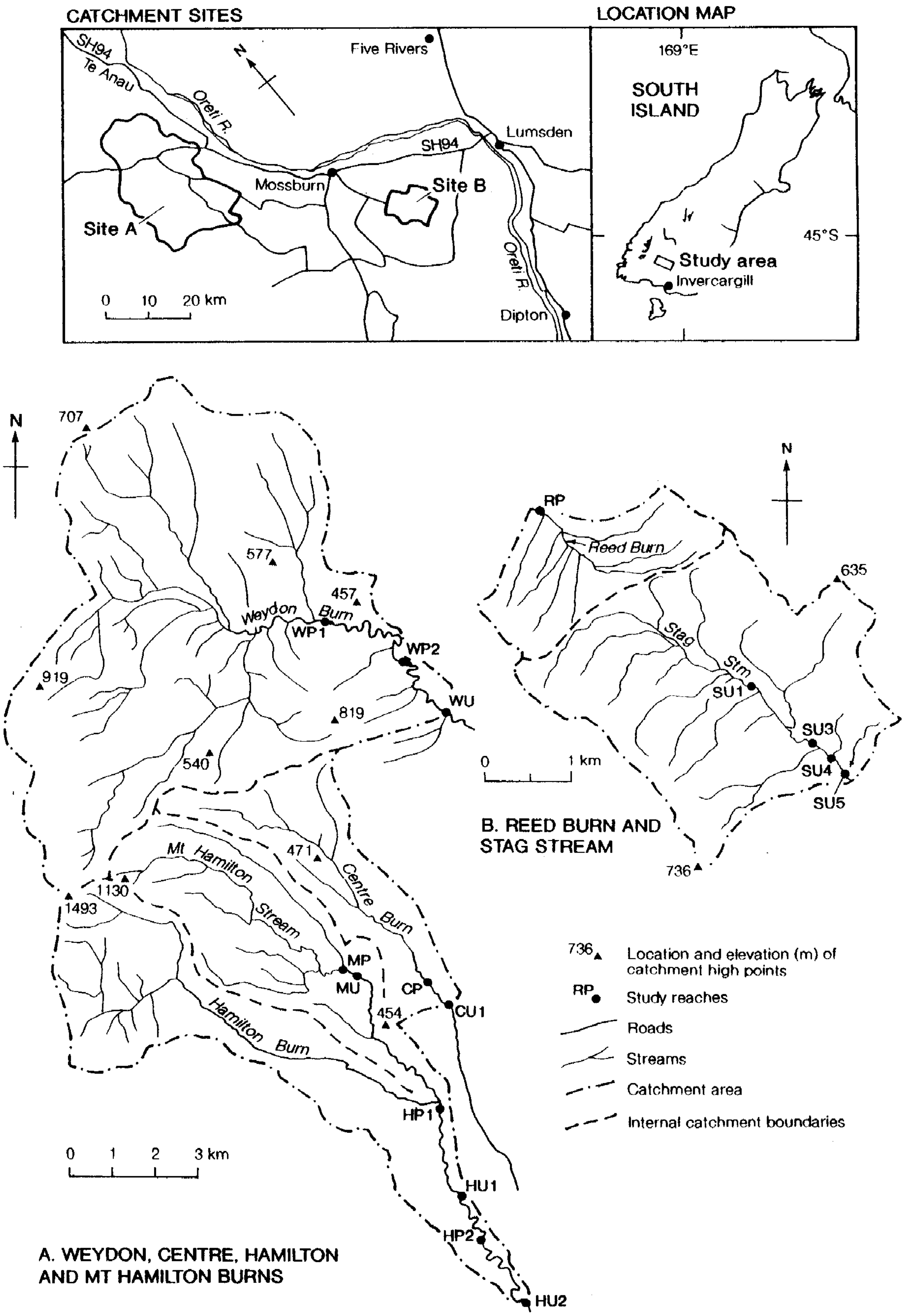


Fig. 1 Study area location maps.

Table 1. Catchment details. Land use: IP = improved pasture, OT = oversown tussock, EG = extensively grazed tussock, M = mountain lands, B = bush, R = tussock reserve.

Reach [1]		Date land improved	Berm land use[3]	Retired width (m)	Date berm retired	Catchment							
						Area (km2)	Max. height (m)	Land Use [2] (%)					
								IP	OT	EG	M	B	R
Reed	RP	1980	EG	20	1980	3.3	665	50.0	50.0	0	0	0	0
Stag 1	SU1	1982	OT	0	-	4.5	736	46.0	54.0	0	0	0	0
Stag 3	SU3	1981	OT	0	-	7.3	736	34.0	66.0	0	0	0	0
Stag 4 [2]	SU4	1979	IP	0	-	9.5	736	37.0	63.0	0	0	0	0
Centre	CP	1975	EG	>50	1975	10.3	700	54.0	29.0	17.0	0	0	0
Centre	CU	1965	IP	0	-	10.9	700	51.0	27.0	21.0	0	0	0
Mt Hamilton	MP	1975	OT	>50	1975	10.0	1136	00.0	64.0	18.0	18.0	0	0
Mt Hamilton	MU	1974	OT	0	-	13.6	1136	00.0	47.0	36.0	17.0	0	0
Hamilton	HP1	1967	IP	20-50	1975	32.8	1487	54.0	15.0	0	31.0	0	0
Hamilton	HU1	1967	IP	0	-	37.4	1487	60.0	13.0	0	27.0	0	0
Hamilton	HP2	1950	IP	≥20	1973	39.0	1487	61.0	13.0	0	26.0	0	0
Hamilton	HU2	1950	IP	0	-	41.0	1487	64.0	12.0	0	24.0	0	0
Weydon	WP1	1966	OT	>50	1982	55.0	1487	10.0	26.3	5.3	17.4	21.9	19.1
Weydon	WP2	1966	OT	>50	1982	58.0	1487	7.4	26.5	5.5	18.0	22.9	19.8
Weydon	WU	1966	IP	0	-	60.0	1487	7.4	25.5	5.8	19.0	24.2	18.1

1. U = unprotected (grazed) P = protected (retired).
2. Includes reach SU5.
3. Landuse in paddock surrounding reach, at present (grazed reaches) or before retirement (protected reaches).

Intensification took 2 forms. On steeper land oversown tussock (i.e. a mixture of tussock and improved pasture species) was produced by burning, intensive cattle grazing and top-dressing with fertiliser and exotic grass seed. This produces a less hummocky surface and the gradual replacement of tussock by grass. On flatter areas, improved pasture was formed by discing and replanting with exotic grasses. In some cases (Hamilton Burn) the ground was ploughed to the stream edge, and cropped before planting with grass. In others (Centre, Mt. Hamilton Stream, Weydon), less accessible land has been left in tussock, which often includes the stream margin. Improved pasture in the Hamilton P2 reach was planted in pines in 1975. In poorly drained areas, such as the improved pasture in Centre Burn catchment, extensive tile and mole drainage has been installed.

In the smaller farms, stocking rates of up to 10 stock units (s.u.) per ha are maintained on the oversown tussock, and 15 s.u./ha on improved pasture. Rates on extensively grazed or oversown tussock on some of the larger blocks are difficult to assess because some of these blocks are less preferred for grazing and only used seasonally or intermittently at 5-10 s.u./ha. All unprotected reaches had mixed sheep and cattle grazing, except for the unprotected Weydon reach (WU) which was grazed by sheep alone. Maintenance superphosphate dressings equivalent to 20-35 kg P ha^{-1} yr^{-1} are used.

In addition to the above land use categories, the Hamilton, Mt Hamilton and Weydon catchments contain mountain lands (scree, native bush - predominantly *Nothofagus sp.*, silver tussock (*Poa laevis*) and hard tussock (*Festuca novae-zelandiae*). All land above 500 to 600 m elevation has been retired for erosion control and headwater protection or other specific conservation purposes.

2.3 Soil Profiles

Profiles exposed on streambanks (Fig. 2) showed recent soils, mostly clay to silt loams, formed from coarse alluvium. In some cases, soils were stony or peaty. The underlying uncohesive alluvium varied widely in the amount of fine material and particle size, but most profiles contained at least one layer which disintegrated under mild abrasion. These layers normally occurred above the low flow water level in most streams except Reed Burn and Stag Stream. The overlying soils had enough cohesion to form overhangs of typically 0.5 m (and up to 1.2 m) when underlying alluvium had been removed through erosion.

Fig. 2 Bank soil profile showing soils overlying coarse alluvium (Weydon Burn grazed site).

2.4 Drainage and Channel Developments

Apart from development of the adjacent land, a number of the study reaches had undergone some form of development in the stream channel or had land drainage efficiency improved by mole and tile drains. Downstream from the study sites in the Centre Burn (500 m), the channel has been excavated and straightened, and has undergone subsequent bank erosion and back-cutting (headward incision).

The farmer whose land ajoins Hamilton Burn (including HU1) has observed that the stream has widened since he took possession of the property. He sprayed and cleared gorse and broom in the channel, which may have been one factor in its widening.

The Weydon Burn has been used as a source of road shingle for some time. Shingle was extracted from just upstream of the reach WP1 during highway construction. In 1975, most of the berm area was covered in gorse and broom which was removed by spraying. From 1950 to 1970, shingle banks were removed for erosion control to prevent re-direction of flow into banks.

2.5 Climate

Northern Southland has a relatively low average rainfall for New Zealand. The closest long term station (located at West Dome 10 km to the east) recorded a mean for 1949-1980 of 969 mm, and range of 708 - 1222 mm (New Zealand Meteorological Service 1980). During summer, the upper soil horizons tend to dry out and droughts occasionally occur. Winter frosts are common, but average winter temperatures (July) are about $4^{o}C$. Snow fall can occur during winter, but does not stay long on the ground. Winter temperatures are cold enough for patches of very thin anchor ice to form on the streams. Average specific flow for Mt Hamilton Stream measured near the study sites was 29 $l\ s^{-1}\ km^{-2}$ for 1978-80. For Hamilton Burn, some distance downstream from the study sites (where catchment area had increased to 188 km^2) average specific flow was 19 $l\ s^{-1}\ km^{-2}$ for 1975 to 1980.

3. METHODS

The reaches were surveyed on 3 occasions: December 1987, November 1988 and July 1989. Most reaches needed to be revisited at least once for additional information. All information was pooled as there were no indications that any of the parameters measured had changed during this time.

A total station survey instrument (Geodimeter 140) was used to record the channel shape in 5 or more cross-sections in each reach. Cross-sections were chosen to demonstrate reach characteristics, and adequately sample local variability in channel geometry. In addition, a long section was recorded to obtain the channel slope. In the incised streams (Reed, Stag, Centre, Mt Hamilton Stream) these data were complimented by tape measurements of channel width and depth at bank-full depth and water level. In the Hamilton and Weydon Burns, surveyed reaches were 5 to 20 times median widths, but were considerably more than this in the smaller streams. The width, depth and width/depth ratio at bank full height (e.g. see Fig. 3) are frequently used to characterise channel dimensions (Beschta & Platts 1986). Bank full discharge was defined as that where the width/depth ratio associated with the active flood plain is at a minimum (Hey & Thorne 1986). This was easily identified in the smaller streams which had well defined channels. In the largest stream (Weydon Burn), it was often difficult to identify the active flood plain because of multiple terrace levels or the absence of an identifiable discontinuity in the bank slope.

Stream reach characteristics were assessed using some of the methods of Platts et al. (1983). The methods used are listed in Table 2. Simple random sampling was achieved by choosing cross-sections at regular intervals. Some of the measurements made are illustrated in Fig. 3. In addition to the semi-quantitative vegetation surveys at each cross-section, a quantitative survey was carried out on Mt Hamilton Stream and Centre Burn. Vegetation cover enclosed in a 0.25 m^2 area was measured every 10 metres along the reach and converted to % frequency of occurrence.

The proportion of bank undergoing active erosion was measured by a longitudinal survey of the length of bare soil, collapses and stock crossings. Active erosion was defined as that which would contribute to a lateral shift in the bank, a change in channel dimension or shape (widening, shallowing, undercut collapse) or a change in aquatic habitat (overhang collapse). We did not include bare banks edging terraces higher up the bank (false banks) which were only accessible by extreme floods, or past collapses which had become stable and well vegetated. Stock crossings were easy to identify, although we did not include

Table 2: Riparian assessment methods (adopted from Platts et al 1983, Platts et al 1987)

Parameter	Method	Explanation
Pool quality	Measurement	Index reflecting width, depth and cover. 1 (lowest) - 5 (highest)
Pool/riffle ratio	Measurement	Glides = pools, runs = riffles
Shore water depth[1]	Measurement	On vertical line from bank outer-most point
Streambank angle[1]	Measurement	Angle between 1.5 m pole lain on bank with water surface
Bank undercut[1]	Measurement	Deepest recess from vertical line from bank outer-most point
Vegetative overhang[1]	Measurement	From bank outer-most point
Streamside cover[1]	Recorded	Type, height, cover
Streambank alteration[1]	Subjective evaluation	% of bare soil, broken, eroded or badly pugged banks
Bank Profile	Visual assessment	Type, depth of horizons

1. Measured on line of cross section on bank.

stock tracks along banks which, apart from a possible source of suspended sediment, were otherwise not contributing to streambank instability. Stock-induced slumping or collapses were inferred when tracks or hoof marks were associated with cracking behind slumps or collapses. This survey differed from the streambank alteration index (Platts et al 1987) which measured all bare soil on the streambank, including stock tracks and false banks.

Characteristics of the stream bed sediments were assessed at 3 cross-sections at each reach. Sediment samples were collected using the Wolman method (Wolman 1954), and all pebble or greater sizes were measured on the long, intermediate and short axes, using vernier callipers. Particle roundness was assessed from charts (Powers 1953) and by the method of Cailleux (1947). Mean size, sorting, skewness and kurtosis were calculated using the formulae of Folk (1965). Bed permeability was measured in the Hamilton and Weydon Burns using the method of Terhune (1958). The coarseness of bed sediments or bedrock prevented its deployment at most other sites.

Statistical comparisons used Wilcoxon's rank sum test (paired reaches) or analysis of variance of ranks (three reaches) (SAS 1982). Differences were evaluated at the 95% level of confidence.

The owners or managers of the farms adjacent to the streams were interviewed to obtain information on the history of development, farm management and riparian management. They were also asked for their opinions on the usefulness of retirement, the effects of stock grazing on stream margins and their observations of stream channel erosion.

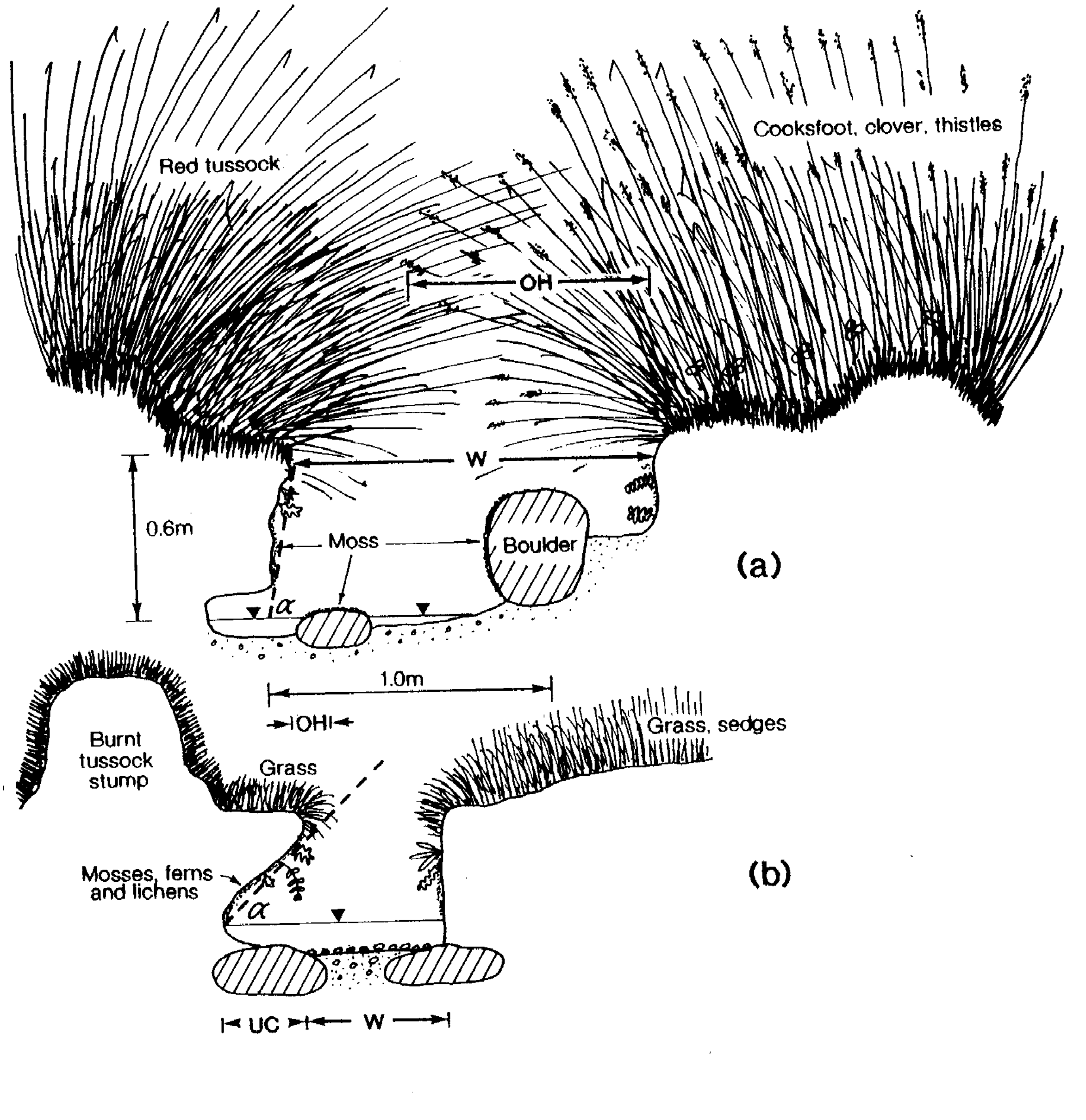


Fig. 3 Schematic representation of typical cross sections in the **(a)** Reed Burn (RP) and **(b)** Stag Stream (SU1). Undercut (**UC**), vegetation overhang (**OH**), and stream bank angle (α) are as indicated.

4. RESULTS

Channel dimensions, sediment size and erosion surveys are reported in Table 3. Other channel characteristics are reported in Fig. 4. Examination of streambed sediments did not find any evidence of changes due to riparian management, except in SU4. Here there was a greater amount of fine silt covering the bed in pools than upstream (Quinn et al. (submitted)). Elsewhere, differences were sometimes observed between reaches, but these appeared to be due to geomorphological factors (e.g. erosion through to bedrock or a higher proportion of boulders). Measurements of shingle bed permeability in Hamilton Burn (HP1, HU1) and Weydon Burn (WP2, WU), showed highly permeable material in both reaches, with no evidence of silting.

4.1 Reed Burn/Stag Stream

Reed Burn and the adjacent Stag Stream were extensively grazed until 1980. At this time, the Reed Burn channel and surrounds were retired and the land upslope converted to improved pasture. The flood plain surrounding Stag Stream was converted to oversown tussock. This flood plain is continuously grazed for 1 month in summer by cattle and rotationally grazed by sheep the rest of the year.

Our survey shows that there is little difference between the 2 streams. Both streams are small and stable, with vertical-sided or undercut, incised channels (Fig. 3, 5), that would be susceptible to stock trampling. None of the indices that measure channel shape (undercut, streambank angle, width) or stability (Table 3, Fig. 4) indicate stock damage has occurred in this part of Stag Stream. The vertical or overhung sides on both streams were sparsely covered with roots, moss and small ferns, and there was only slightly more freshly exposed soil in Stag Stream, perhaps indicating a slightly more erosive environment. The main difference between the 2 reaches was in vegetation growth on top of the bank, an obvious grazing effect (Fig. 4). Reed Burn was completely overhung by tall cocksfoot (1-2 m tall) and the occasional red tussock (2 m tall), whereas the Stag 1 reach had a mixed pasture/sedge/wire rush association (0.3 m tall) near the surveyed channel.

4.2 Lower Stag Stream

Visible stock damage to stream margins was noted further down Stag Stream. As this was the worst damage we had observed in our investigations which could be attributed to stock,

Table 3. Channel dimensions, habitat quality and erosion surveys for surveyed reaches. Median widths and median depths are at bank-full level, - = not measured. Significant differences ($p<0.05$) between comparisons are identified by letters a , b.

Reach		Width (m)	Depth (m)	Width/depth	Pool Quality (1 - 5)	Pool/Riffle ratio	Mean particle size (mm)	Water width (m)	Erosion survey: Length (m)	Erosion survey: Total (%)	Erosion survey: Stock Involved (%)
Reed protected	RP	1.3 a	0.6 a	2.1 a	-	-	Note 2	-	-	-	-
Stag 1 grazed	SU1	0.74 b	0.4 b	1.7 b	-	-	17	-	-	-	-
Stag 3 grazed	SU3	1.35 b	0.5 b	2.6 a	-	1.6	14	1.25	60	7	6
Stag 4 grazed	SU4	1.9 a	0.55 b	3.3 a	-	1.2	11	1.59	220	30	25
Stag 5 grazed	SU5	1.4 b	0.8 a	1.8 b	-	0.6	-	-	160	8	6
Centre protected	CP	4.0 a	0.91	5.2	4.5	0.69	45	3.0 a	135	≤3	0
Centre grazed	CU1	2.93 b	0.98	3.1	4.5	0.66	27	2.0 b	70	18	12
Mt Hamilton protected	MP	6.4	1.8 a	5.1	4.7	1.9	63	3.7	155	16.5	0
Mt Hamilton grazed	MU	5.85	1.35 b	5.4	4.5	1.6	34	3.6	107	11.6	3.4
Hamilton protected 1	HP1	15.9	1.22	15	4.3	0.33	38	6.8	472	28	0
Hamilton grazed 1	HU1	25.7	1.58	16	4.2	0.76	31	9.3	505	28	≤6
Hamilton protected 2	HP2	20.5	1.34	14.7	4.2	0.33	22	9.5	387	37	0
Hamilton grazed 2	HU2	21.3	2.22	10	5.0[1]	0.24[1]	24	9.3	250	19	<3
Weydon protected 1	WP1	15.4	1.15	13.4	4.6	0.89	70	8.9 a	590	25	0
Weydon protected 2	WP2	22.9	1.51	15.1	3.6	1.25	25	7.4 a	385	31	0
Weydon grazed	WU	24.8	1.16	21.3	3.0	0.5	22	5.0 b	500	45	0

Notes
1. One pool only.
2. Silty clay substrate overlain with interspersed cobbles and gravel.

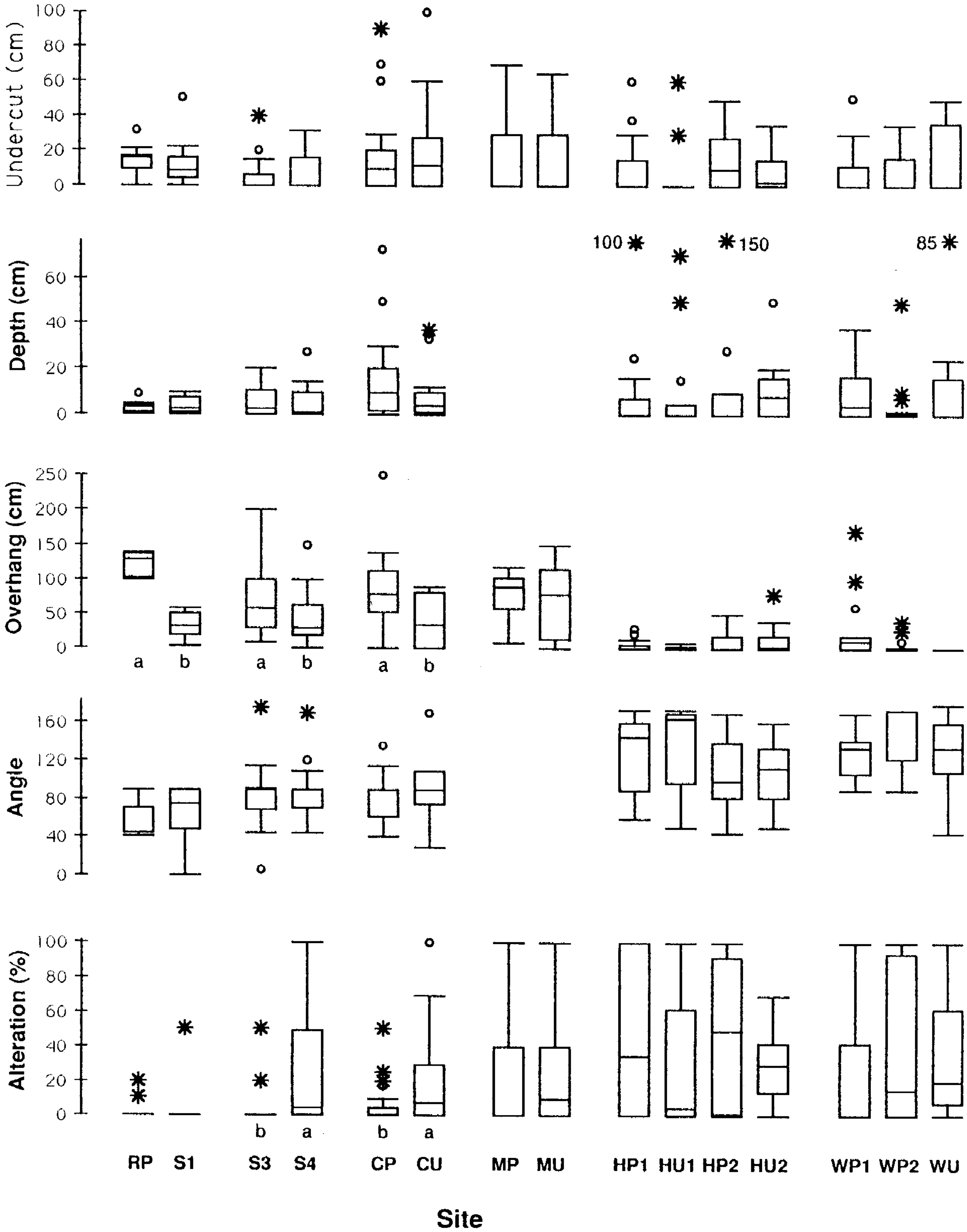


Fig. 4 Bank undercut, shore water depth, bank alteration, bank angle, vegetation overhang. Box indicates the class interquartile range, the bar the medium value, the whiskers 1.5 X interquartile range, with outliers (o >1.5 X interquartile range) and extreme outliers (* >3 X interquartile range). Significant differences (P<.05) between compared reaches are indicated by different letters a,b (e.g. widths for SU4 > SU3=SU5). Alteration is the percentage of the stream bank that is eroded, broken down or bare soil.

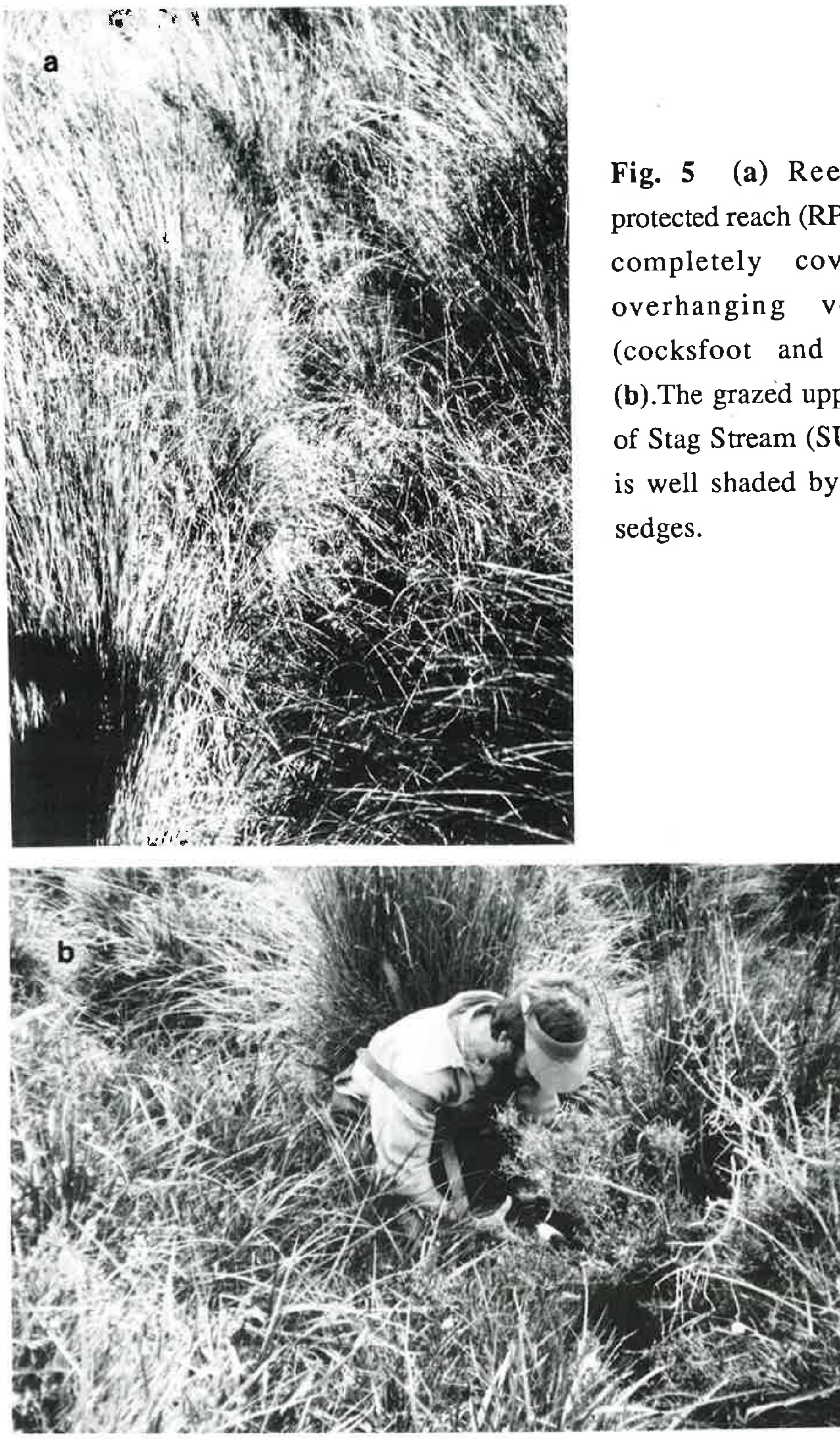


Fig. 5 **(a)** Reed Burn protected reach (RP), which is completely covered by overhanging vegetation (cocksfoot and tussock). **(b)**.The grazed upper reaches of Stag Stream (SU1), which is well shaded by grass and sedges.

we included its survey. For comparison we used moderately grazed banks upstream (SU3) and lightly grazed banks downstream (SU5). The damaged reach (SU4) and SU5 are in a paddock which is grazed by cattle for 4 months (Aug-Dec). SU3 is in a paddock grazed similarly to SU1 (cattle for 1 month per year). In these 3 reaches, shrubs are important bank side vegetation (predominantly *Coprosma sp*. 1.5-2.5 m tall) whose roots and trunks form a significant proportion of the streambank. Downstream, SU5 is so densely covered by shrubs that they prevent stock access to the channel.

Fig. 6 shows damaged and undamaged parts of the stream channel. The 400 m stretch SU4 is regularly used for stock crossing, or access along the stream channel, and this is reflected in soil alteration ratings (Fig. 4). A longitudinal survey (Table 3) showed stock crossings, stock-induced incipient bank collapse, and severe pugging damage had taken place along 25% of the banks. At major crossings the shrubs had been up-rooted, undermined or pushed into the stream channel. Downstream in the shrub protected reach, such damage was much lower (6%), while in SU3 it also occurred on 6% of the bank. As a result, the channel was significantly wider in SU4 compared to SU3 or SU5 (Table 3).

The reach SU4 was suffering from grazing pressure because the soils on both sides of the channel were perennially saturated. The excess moisture turned the pasture into a lush meadow attracting cattle which in turn trampled the soft wet soils on the banks. Besides the trampling damage, increased pore water pressure could also enhance bank collapse (Thorne 1982).

Pool/riffle ratio was highly variable. In SU4 pools were formed behind collapsed shrubs and stock crossings. These were wider and deeper than those in the undamaged sections. Therefore, in these respects, the pool quality was much higher in SU4.

4.3 Centre Burn

The upstream reach (CP) is only lightly grazed and undeveloped, except for a period around 1975 when the adjacent swamp was drained, and some channel works were carried out. The unprotected reach 200 m downstream (CU1) flows through land that has been converted (1966) to improved pasture with oversown tussock near the stream channel. An earlier survey (1972) of channel widths found a median width of 2.9 m and depth of 0.91 m just downstream of CU1 (Williamson et al (in prep.)). Aerial photographs do not show any change in the channel position between 1944 and 1982, indicating that both reaches are relatively stable.

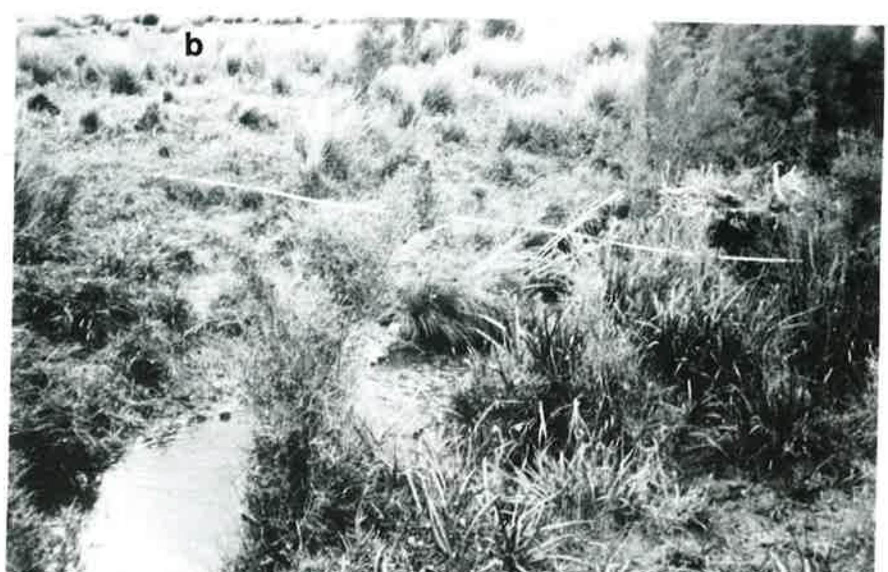
Our surveys show that the 2 reaches (Fig. 7) were fairly similar in channel shape and fish habitat quality (Table 3), the ungrazed reach actually being wider than the grazed reach. There was no change in channel width between 1972 and 1988. Differences were found in channel stability (Table 3, Fig. 4) and vegetation (Table 4).

Table 4. Bank vegetation (% of total vegetation) of unchannelised reaches. Vegetation within 5 m of channels edge, except for Mt. Hamiltom Stream where separate surveys were conducted on top of the bank and down the bank.

Reach	Exotic Pasture Plants	Tussock	Sedge Wirerush	Shrubs	Flax	Ferns	Thistles	Gorse	Toi-toi
Reed RP 1	67	33			M	M	M		
Stag SU1	73		18			7			
Stag SU3	50			50			M		
Stag SU4	75			25		M	M		
Stag SU5				100		M			
Centre CP	33	37	M	28					
Centre CU1	68	27	7						
Mt Hamilton MP top	53	19	12	15	1	M	M		
Mt Hamilton MP bank	22	11	10	38	8	11			
Mt Hamilton MU top	22	42	22	5					
Mt Hamilton MU bank	22	16	18	22	9	9			
Hamilton HP1	D	SD					M	M	
Hamilton HU1	D	SD	D						
Hamilton HP2	87							13	M
Hamilton HU2	100		M				M		
Weydon WP1	D	SD	M	SD					M
Weydon WP2	D		M				SD		
Weydon WU	D	M					M	M	

Notes:
M = minor component, frequently noted but low proportion of cover D = dominant component
SD = subdominant component .

Fig. 6 Stock damaged and undamaged portions of the lower Stag Stream. **(a)** SU3. Note the significant bank cover by shrubs. **(b)** Stock crossing SU4. Note the wider, shallower channel and damaged shrubs.



Quantitative surveys of vegetation showed that red tussock was the predominant plant in the ungrazed reach, and although it was still important in the grazed reach, exotic pasture formed the largest proportion here. Of more interest is the proportion of native shrubs (28 %) in the ungrazed reach which were almost completely absent in the grazed reach. These, together with the ungrazed tussock, accounted for the much larger vegetation overhang (Fig. 8) in the ungrazed reach.

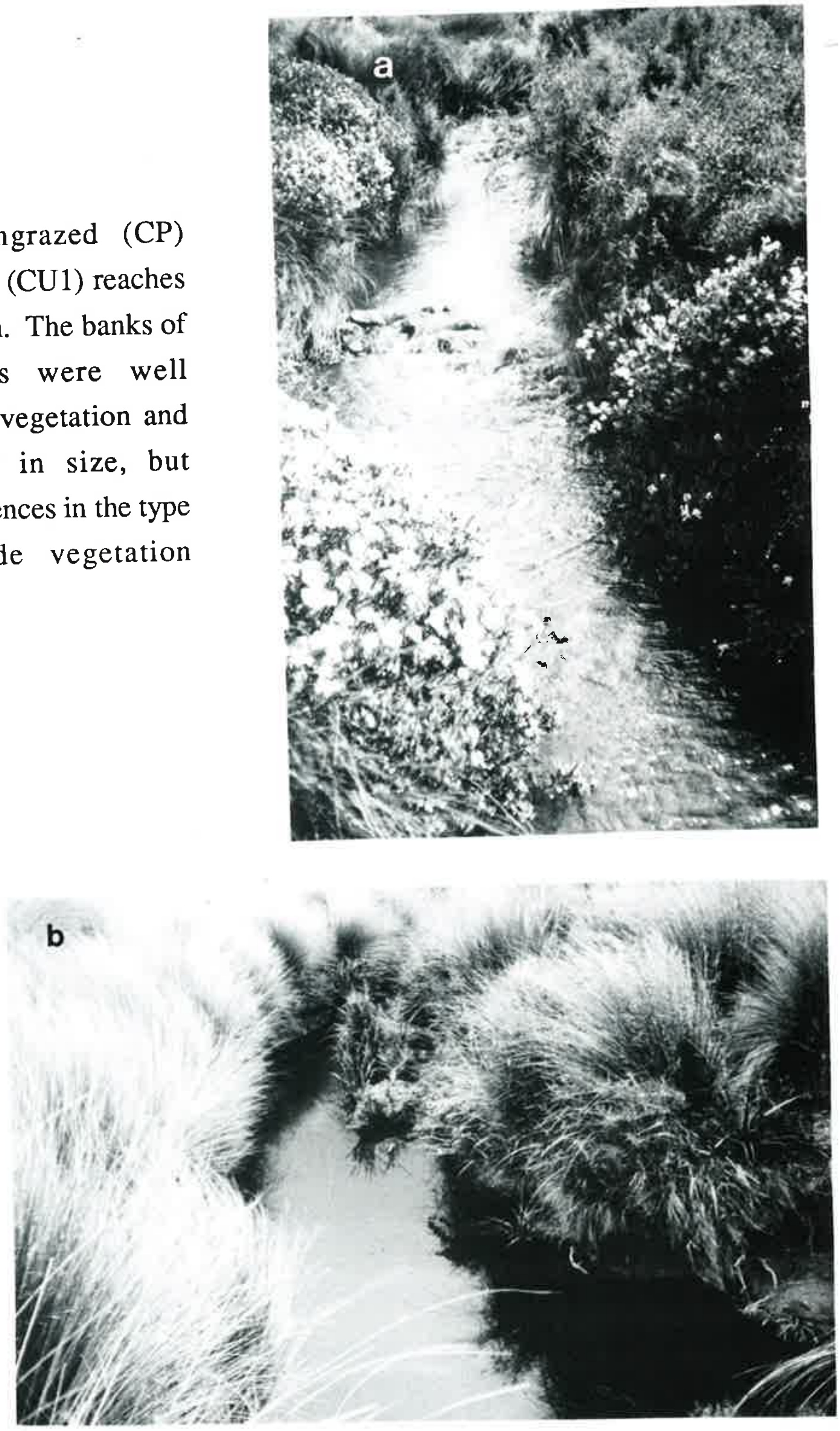
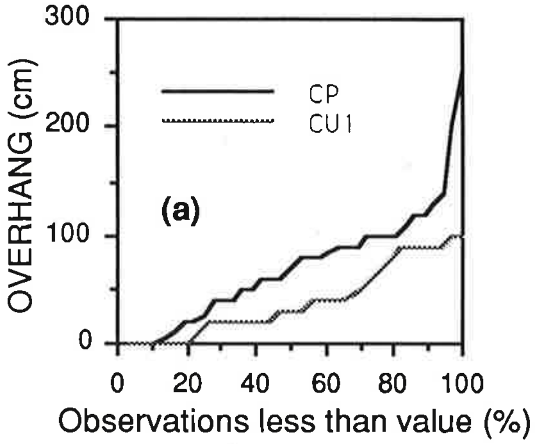


Fig. 7 **(a)** Ungrazed (CP) and **(b)** grazed (CU1) reaches of Centre Burn. The banks of both reaches were well covered with vegetation and were similar in size, but showed differences in the type of streamside vegetation cover.

The number of collapses and bare banks (from recent collapses) was significantly greater in the unprotected reach, as reflected in the soil alteration index (Fig. 4). Some of the collapses appeared to result from 'natural' undermining of the stream bank, and did not appear to be induced by stock as judged by the lack of pugging or stock tracks behind the collapse. This 'natural' undermining may, of course, have been accelerated by the downstream channel works (Williamson et al. in prep.).



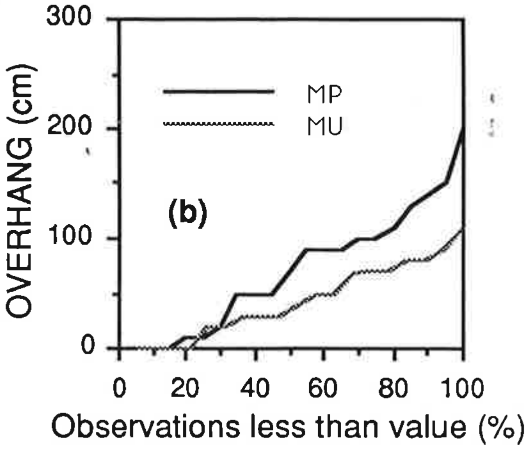


Fig. 8 Distribution of vegetation overhang in the **(a)** Center Burn and **(b)** Mt Hamilton Stream. Overhangs are plotted with increasing size against cumulative observations.

Longitudinal surveys (Table 3) showed that about 12% of the unprotected streambank was suffering visible stock damage, mostly at well established stock crossings (Fig. 9). Other causes accounted for about 6%, which is more than observed in the protected reach (<=3%). This difference due to stock damage was highly localised and easily visible. However, it has not (yet) been translated into significant change in the channel width (Table 3) or led to shifts in channel position.

Fig. 9 Stock crossing on the Centre Burn (CU1).

4.4 Mt Hamilton Stream

The retired and unprotected reaches on the Mt Hamilton stream were separated by 100 m and Mt Hamilton Road (Fig. 1). Aerial photographs taken in 1944 show a narrow channel with well vegetated banks in both reaches. There has been little change in the stream position between 1944 and 1979 (Fig. 10) again suggesting a relatively stable stream.

The channel was generally narrow and steep-sided, well overhung by banks and vegetation (Fig. 11). There were many deep, high quality pools (Table 3). In places the stream was actively migrating, exposing long sections of bare, cracked bank; this was more prevalent in the protected reach and therefore not a result of recent grazing.

A major difference between the 2 reaches was due to a major stock and vehicle crossing point in the unprotected reach, where there were many signs of pugging and hoof damage. This part of the unprotected channel was wider, with shallower banks and fewer undercut banks. Elsewhere, and on average, the reaches were similar in channel shape and size (Fig. 4, Table 3).

Vegetation also differed between reaches, but in an unexpected way. On the flood plain on top of the banks, exotic pasture plants were far more dominant in the protected than the unprotected reach (Table 4). It almost appeared as if the cocksfoot grasses were preventing any recolonisation by other species. On the steeper banks native shrubs (koromiko, hebe, coprosma) were more prevalent in the protected reach, and these together with the ungrazed tussock and flax provided a greater vegetation overhang (Fig. 8).

A longitudinal survey of both reaches showed 16.5% and 11.6% active erosion in the protected and unprotected reaches, respectively. In the latter, stock damage (chiefly crossings) contributed 3.4% of the erosion (Table 3).

4.5 Hamilton Burn

Hamilton Burn is mostly an unstable, meandering stream, except in its lower reaches (containing study reach HU2) where it has become more incised in the flood plain. Aerial photographs taken in 1944 before development to improved pasture, show a river channel that is similar in form to what it is today, so its unstable nature is not due to recent land development. Fig. 10 shows the position of the Hamilton Burn and Mt Hamilton Stream near their confluence in 1944 and 1979. Mt Hamilton Stream remains mostly unchanged, while Hamilton Burn displays shifts of 50 metres or more on meander points.

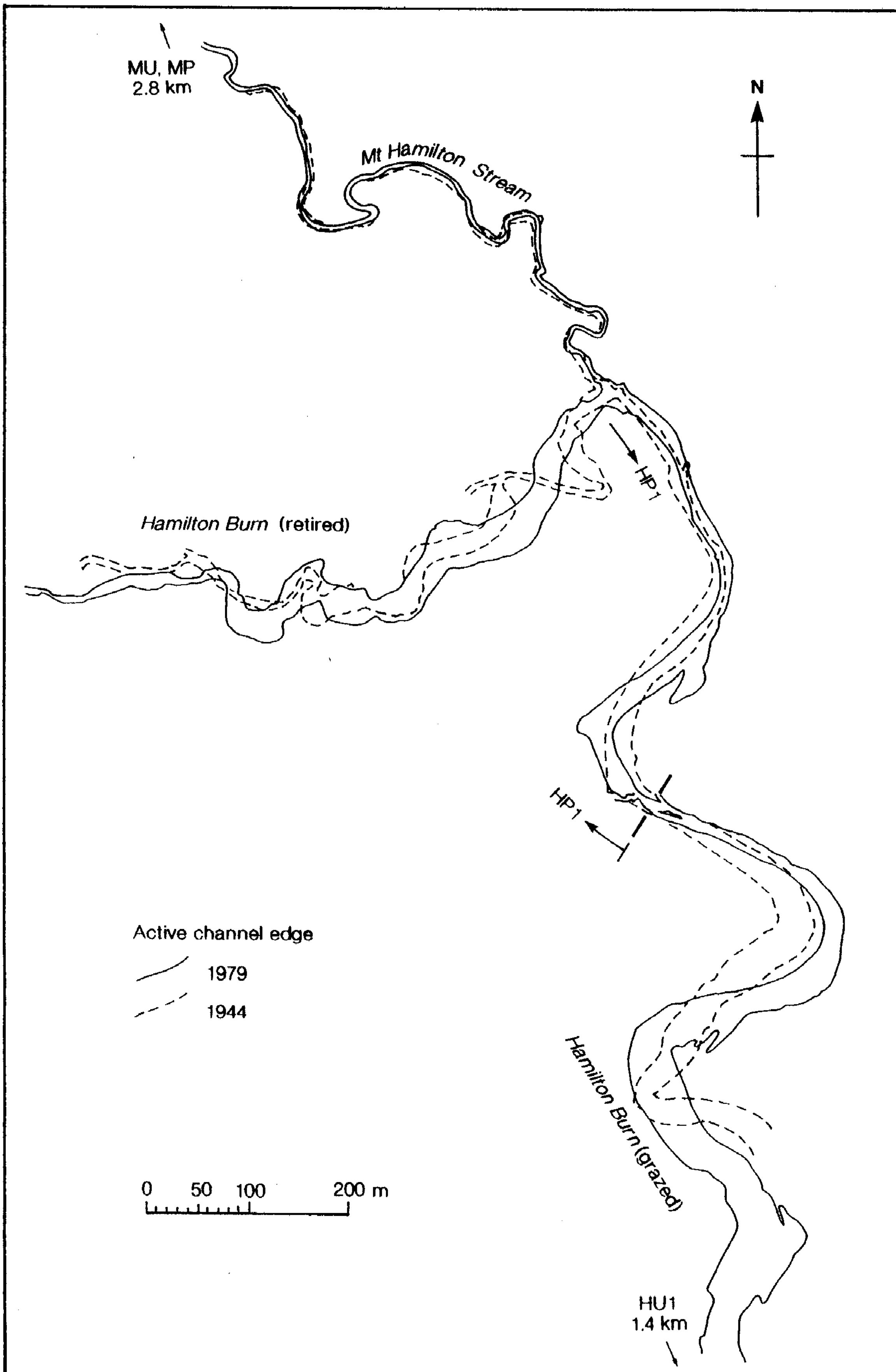


Fig. 10 Active channel edges of Mt Hamilton Stream and Hamilton Burn at their confluence. Information was directly taken from aerial photographs taken in 1944 and 1979. Note the relative instability of Hamilton Burn compared with Mt Hamilton Stream.

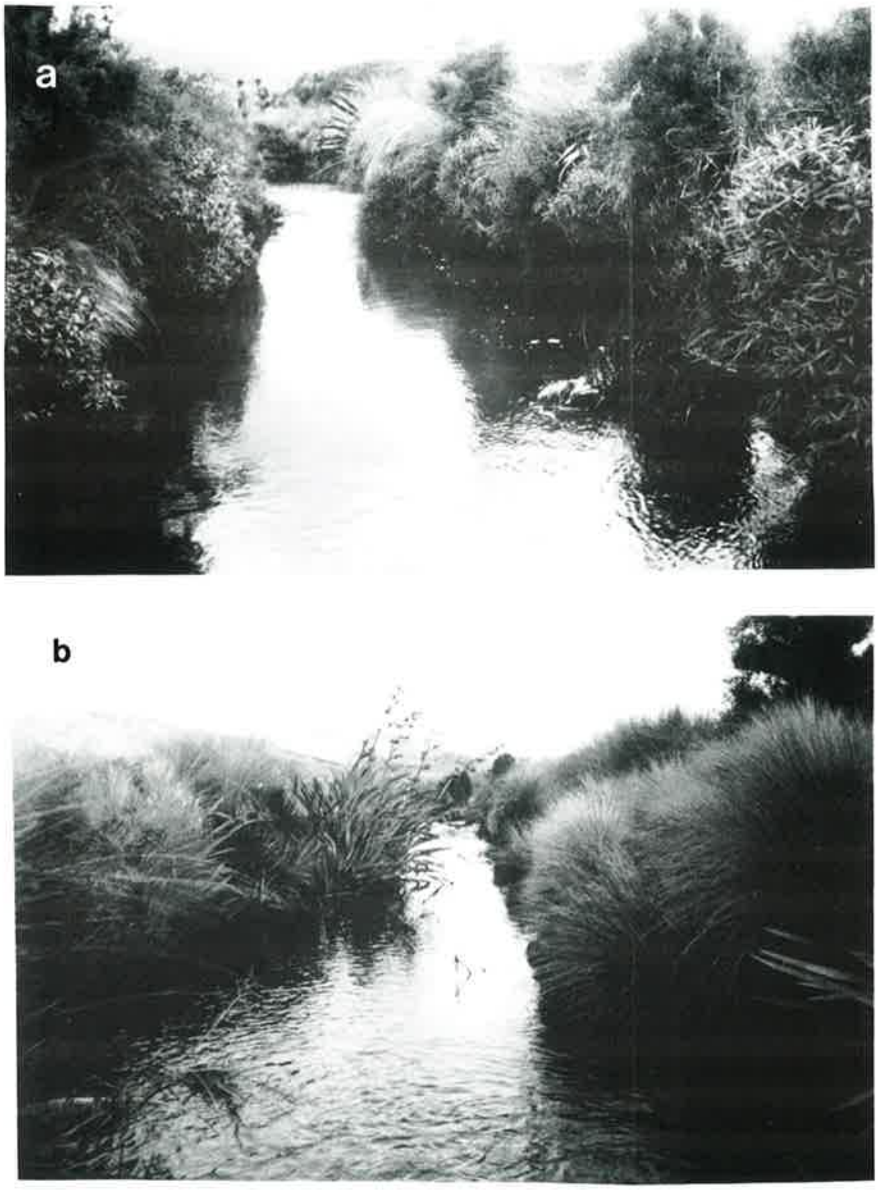


Fig. 11 **(a)** Protected (MP) and **(b)** grazed (MU) reaches of Mt Hamilton Stream. The reaches were similar in size, morphology and vegetation cover.

4.5.1 Upper Reaches of Hamilton Burn

The 3 upper reaches showed the typical pattern of an actively meandering river with steep eroding banks on the outside of bends and shallow shingle banks (point bars) on the inside of bends. The channel typically had deep pools at the meander points separated by long runs and riffles. There was very little noticeable difference in appearance between protected and unprotected reaches (Fig. 12). However, cattle damage in HU1 was particularly visible as trampled bare soil under false banks and accelerated collapse of undercut banks on the outside of active meanders (Fig. 13).

a

b

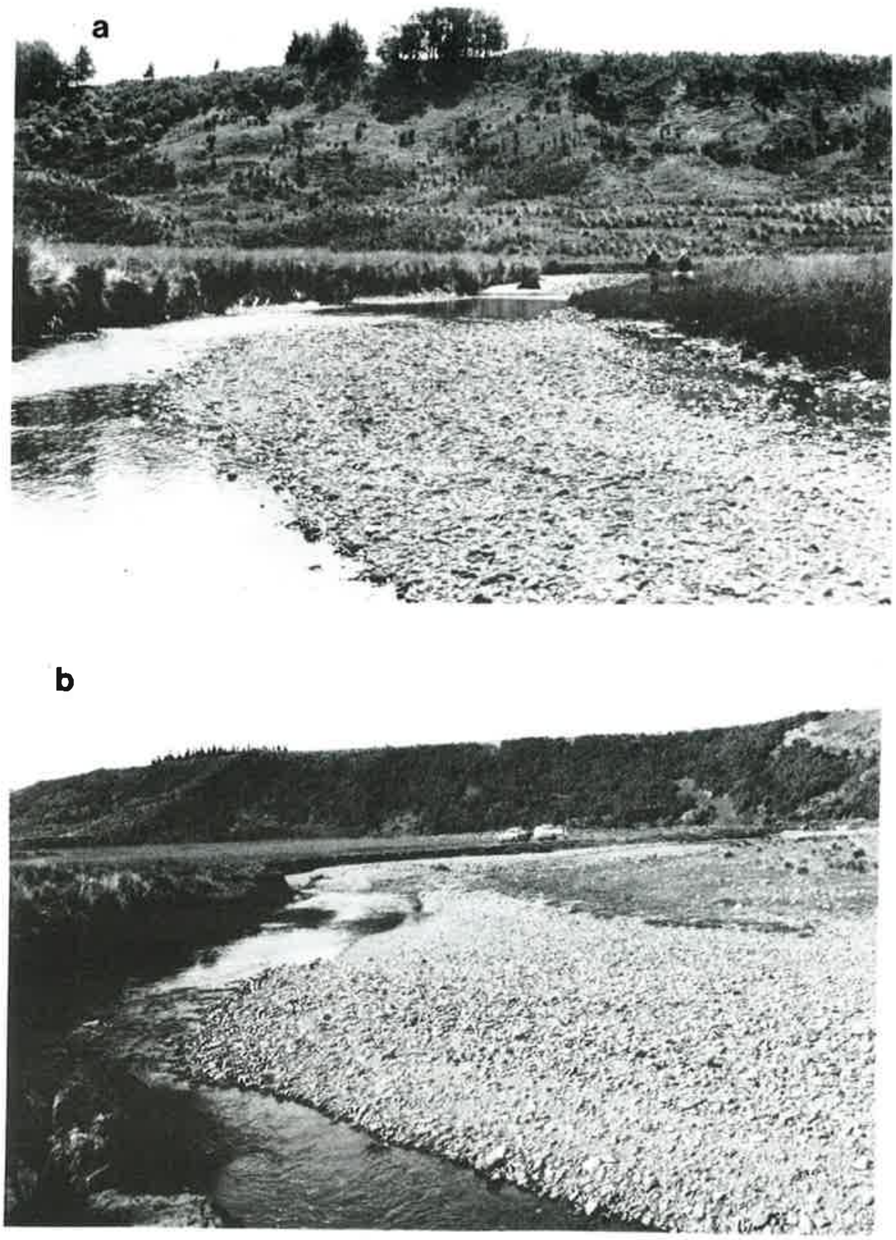


Fig. 12 (a) Protected (HP1) and (b) unprotected (HU1) reaches of Hamilton Burn looking upstream. Note the unstable, eroding right bank and aggrading left bank.

We were not able to discern any difference in baseflow habitat characteristics (water widths, streambank angle, shore water depth, pool riffle ratio, pool quality: Fig. 4, Table 3). The bank full width was greater in HU1 but the difference was not significant. Given the small number of measurements made, only a large difference could have been detected. Channel cross-sections are plotted in Appendix 1 for HP1 and HU1 and show that these reaches are fairly similar.

Despite the visually obvious cattle trampling damage, it only contributes a small proportion of streambank erosion (Table 3). The general lack of damage can be in part attributed to the well drained nature of the country, where trampling leads to compacted bare soils and not extensive broken, pugged soils. Cattle tracks along and across streambanks formed the most widespread visible damage, but contributed little to streambank erosion. The low shingle banks offered many convenient entry and exit points along the channel and therefore there were no wide, deep-slotted cattle crossings as found in the smaller incised streams.

Fig. 13 Cattle accelerated collapse of overhangs on an outside bend on Hamilton Burn. Here cattle are constrained by the topography to walk close to the bank. The instability of this stretch is worsened by wet soils from a seepage (draining from the right of the photo).

The recent collapse of undercut streambanks was the most dramatic feature of active eroding banks (in both protected and grazed reaches of Hamilton and Weydon Burns) and is conceivably accelerated by animals walking along the streambank (Fig. 13). If this is a common result of grazing, then it should be reflected in a lower incidence of undercut banks in grazed paddocks. Therefore, the extent of undercut was examined in detail along the vertical eroding banks in HP1 and HU1. This survey (which was independent of the that reported in Fig. 4) showed some larger undercuts in HP1 but failed to detect a significant difference (Fig. 14).

In both protected reaches, riparian vegetation was dominated by large cocksfoot plants, and occasionally red tussock. These provided little streamside cover (Fig. 4). The species re-vegetating shingle banks were confined to exotic pasture and weeds. In the grazed reach, poor soils on shingle banks and apparent excessive dryness on undercut banks lessened streamside plant vigour and their attractiveness for grazing.

In these reaches, collapses tended to maintain their integrity as large single clumps held together by a single cocksfoot or tussock plant, and many of these were seen intact in the channel where they probably provided important fish cover. Sometimes they redirected flows into banks, initiating new erosion.

The extensive survey of undercuts allowed us to compare the relative stability of parts of the banks which were topped by red tussock (0.8-1.0 m high) and cocksfoot (0.4-0.7 m high) in the upper protected reach (HP1). There was no significant difference in undercuts beneath the 2 species.

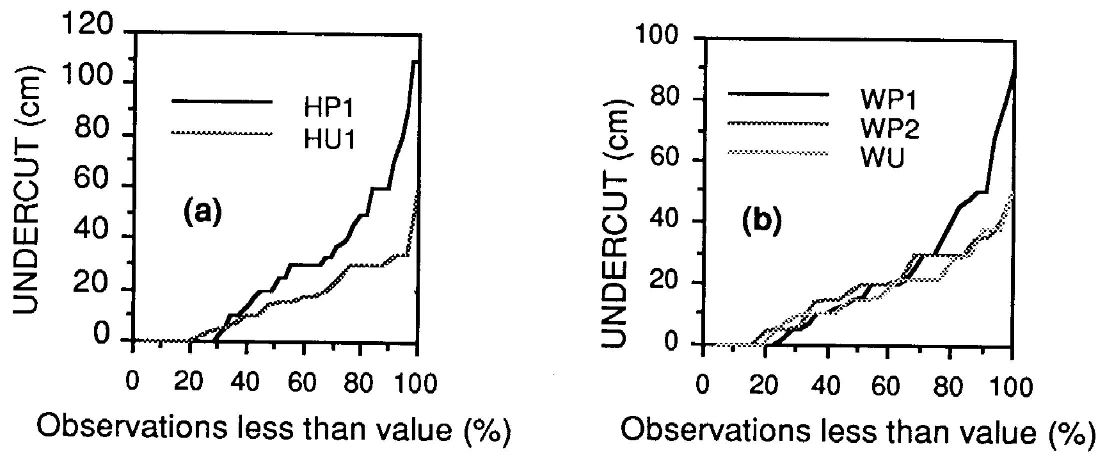


Fig. 14 Distribution of undercuts in actively eroding banks on the Hamilton Burn (a) and Weydon Burn (b). Undercuts are plotted with increasing size against cumulative observations.

Beneath actively eroding outer banks, there were deep pools with a moderate amount of cover from undercuts and sometimes collapsed bank material. Along the straight sections between bends, pools were few and these tended to be small with less cover. It was often difficult to classify these as either pools or runs, and this probably accounted for the differences between the reaches. The average pool quality was highly dependent on the inclusion or exclusion of these minor pools.

4.5.2 Lower reach of Hamilton Burn

The lowest reach of the Hamilton Burn was incised into bed rock and relatively stable. We did not compare it with the upstream reaches because of its different characteristics. It was included in the survey because it had been continuously grazed by cattle (16 s.u./ha) since the 1960's, apart from a rare occasion when it was spelled for hay-making. The paddock has been able to sustain this grazing pressure because of fertile, very well drained soils and plentiful supply of water. We were particularly interested in the amount of streambank damage under these conditions.

Visible stock damage was confined to trampling of gravel bars, the occasional stock crossing (which had minimal impact on streambank morphology or stability) and abrasion of false banks on the edge of the flood plain (Fig. 15). The latter phenomena were the most noticeable bank erosion, but as it occurred 3-6 m away from the waters edge, it was deemed to have little impact on streamside habitat or bank stability. It appeared to be caused by animals rubbing against or walking under the banks whilst seeking shelter.

Fig. 15 Cattle grazed reach on the Hamilton Burn showing the bare false banks and relative stability of the channel and banks.

4.6 Weydon Burn

Weydon Burn (Fig. 16) was examined despite relatively recent retirement (1982) because it exhibits some large differences between protected and unprotected reaches, and these differences have been used to support riparian protection (Maturin 1985). Aerial photographs from 1944 to 1979 shows the lower Weydon Burn (containing the study reaches) to be a highly unstable river with very pronounced meander pattern. Just above WP1, the river exits from a gorge and commences its meander at the upstream end of WP1. WP1 was chosen because it contains the features that riparian protection is supposed to produce: deep pools, stable channel and banks, and a good vegetation cover.

We did find differences between WP1 and WU in stability rating, fish habitat quality (the pool quality index and pool/riffle ratio) and vegetation (Table 3, Fig. 4). WP1 contained deep pools, one lined with native shrubs providing greater overhanging vegetation than downstream. However below this, a longitudinal survey showed the development of an active meander with an increase in erosion. This persisted throughout the protected reach into the grazed reach , and was accompanied by a decrease in pool quality and absence of shrubs. The reason for these differences was probably that the channel in the upper part of WP1 was armoured by large cobbles and boulders (Table 3), rather than riparian retirement (it had not shifted its position between 1944 and 1989).

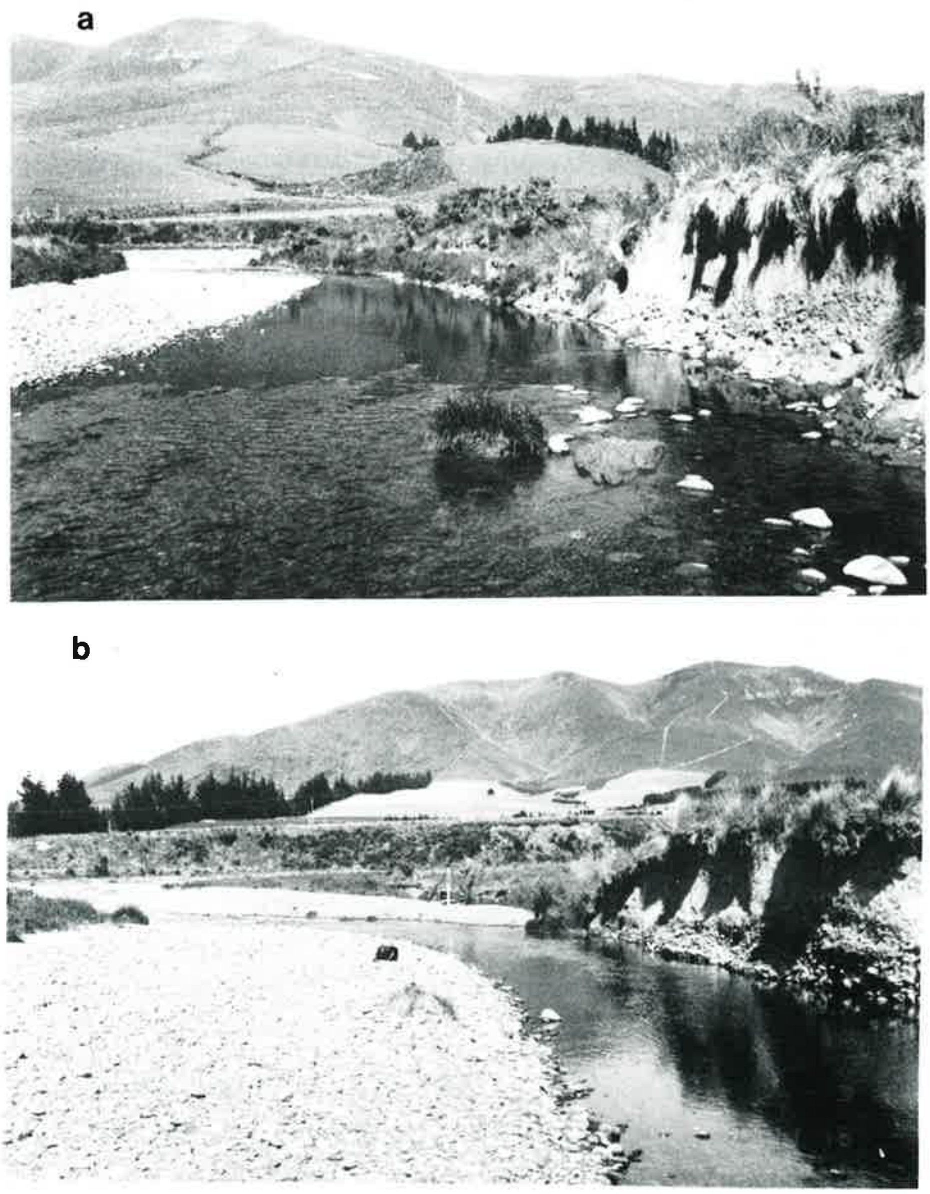


Fig. 16 Protected (WP2) (a) and unprotected (WU) (b) reaches of the Weydon Burn, showing undercuts, soil profile, as well as the ubiquitous cooksfoot grass in WP2.

Below WP1, the Weydon (Fig. 16) was similar to the Hamilton Burn both in channel morphology and the erosion mechanism (Table 3, Fig. 4). There was no visible stock damage to the banks of the grazed reach. This reach was grazed by sheep which are generally regarded as causing far less damage to riparian areas than do cattle. It was difficult to determine bank full depth so as to obtain channel dimensions, so only representative cross sections are reported in Table 3. Plots of channel dimensions of WP2 and WU show that the reaches are reasonably similar (Appendix 1).

As in Hamilton Burn, the unstable reaches tended to have deep pools at actively eroding sites separated by long runs and riffles. Pool quality deteriorated downstream, but unlike the Hamilton Burn where changes appeared to be related to difficulties in classifying minor pools, there was a distinct change in low flow habitat. The higher quality at WP1 was related to the inherent stability, but there was also a distinct change between WP2 and WU. The WU reach was narrower and very long riffles predominated with few high quality pools. The reasons for these differences were not clear.

As in Hamilton Burn, the extent of undercut was examined in detail along the vertical eroding banks. This survey (Fig. 14) found little difference between the protected and grazed reaches.

5. DISCUSSION

5.1 Channel form and dynamics

Natural channels are continually changing as they scour and fill, aggrade and degrade, bank-cut and deposit. Any assessment of the effects of riparian retirement, grazing or development has to be made against the background of these natural changes. The study reaches divide into 2 categories.

1. The incised channels which have changed little in the last 45 years (Reed, Stag, Centre, Mt Hamilton and the lowest reach of Hamilton Burn HU2).

2. The unconfined, actively meandering, shingle rivers (Hamilton and Weydon Burn) which consisted of the two largest streams.

The mechanism by which the streambank material was entrained by water flow or collapsed into the channel could be elucidated from the soil and bank profile. Stream banks were of the composite type with cohesive silty loams underlain by coarse alluvium. The particle size of this alluvium ranged from boulders to silts and the alluvium was rarely cemented. Consequently, most alluvium was weakly cohesive; clearly prone to erosion by fluvial entrainment during medium to high flows. At actively eroding sites, the results of this were seen as overhangs of cohesive soil above the undercut alluvium (Fig. 16). This mechanism has been described as cantilever erosion (Thorne & Tovey 1981) where corrasion of the alluvial layers leads to bank over steepening and eventual collapse of the overhanging 'cantilever' through gravity failure. This collapse was either of the whole overhang or by gradual upward erosion of the overhang. In this process, the rate-limiting step is corrasion of the bank.

The lateral movement of the stream will depend on the frequency of floods and the capacity of flows to scour the channel. Since European settlement, pasture development may mean that surface runoff now reaches the stream channel more rapidly than under tussock, causing more frequent and higher peak flows. This will be true where mole and tile drainage have been an integral part of land development, as at Centre Burn. Secondly, there has been an increase in high intensity rains in the last 10 years (Southland Catchment Board 1987), and this has been coincident with a number of severe erosion problems in the study area.

If a stream penetrates the surficial silts and clays into the coarse alluvium underneath, the channel has the potential to become very unstable. Of the streams surveyed, both the Reed and Stag had not eroded into underlying uncohesive layers and appeared relatively stable. In contrast, the other larger streams had cut deeply into underlying alluvium, with the 2 largest (Hamilton and Weydon) showing marked instability and lateral migration. Mt Hamilton Stream and the lower reaches of Hamilton Burn had eroded through the coarse alluvium and into the bedrock below and developed stable channels.

5.2 Effect of grazing and retirement on streambank erosion

Grazing can influence streambank morphology in two ways; directly through trampling damage or indirectly through destruction of stabilising vegetation. If either of these accelerates streambank erosion, then significant channel widening could conceivably occur. This has happened at major stock crossings in the unprotected reaches of Mt Hamilton Stream, Centre Burn and Stag Stream. However, with the exception of SU4, widening is always confined to a small length of channel and does not affect the overall stability of the reach nor its geomorphological form except at the crossing. It was not observed in the larger Hamilton or Weydon Burns, although any widening in these streams may have been masked by river migration.

Bank damage, as opposed to channel widening, was observed on most grazed reaches and depended on grazing intensity. Reaches within improved pasture paddocks, SU4 (25%), CU1 (12%), HU1 (6%) HU2 (<3%) generally had greater damage than those in oversown tussock or sheep grazing only, SU1 (0%), SU3 (6%), MU (3%), WU (0%).

In the smaller streams, grazing has a greater potential to cause damage, simply because streambanks are low, and animals have easier access at many points. Casual observations suggest that small New Zealand streams are severely impacted by grazing cattle. The fact that this has not occurred in the upper reaches of Stag Stream (SU1 and SU3) is probably due to low grazing intensity. Only in SU4 where high grazing densities occurred on wet soils did we find severe damage.

In the larger streams, high natural rates of erosion imply that cessation of grazing would only have a limited effect. At actively eroding sites, the banks are usually high and offer no stock access to the stream. Collapse of overhangs from stock wandering onto the edge of the bank may occur (e.g. our observation on the Hamilton Burn that local topography forced cattle to track along the outside bend of the river). This accelerated collapse increases the supply of bank material to the stream, but as this is not the rate limiting step

(Thorne 1981), no overall increase in the amount of erosion will occur. Elsewhere, the lack of significant difference between overhangs in grazed and protected reaches shows that stock collapse of overhangs is generally unimportant.

One of the key factors in the lack of stock damage may be the generally dry, well drained nature of streambank soils. This is particularly well demonstrated in the lowest reach on the Hamilton Burn (HU2), which is able to be continuously grazed throughout the year, with little damage to pasture or banks.

These results are in contrast to accepted wisdom amongst water managers, which anticipates severe grazing effects on channel stability. This prejudgement comes about from the published studies from the Western USA which have demonstrated deterioration of riparian margins and fish habitat from grazing. The reasons for the differences between these and our results are discussed later below.

Reduction of nutrient inputs by riparian protection has been demonstrated in other N.Z. studies (e.g. Smith 1989), but depends on the length of stream channel retired (Williamson & Hoare 1987). In some of the streams (Mt Hamilton, Hamilton) where a great deal of the upper stream channel is retired as class VIII land or riparian protected, there could be a substantial downstream benefit to water quality. However, there are still many small grazed tributaries and ephemeral channels which are farmed, and which still supply nutrients to the main channel, especially during storms. On other streams, where only a small proportion of the main channel is retired, improvements to water quality as a consequence of riparian protection are expected to be minimal.

5.3 Effects of retirement on streambank vegetation

Nearly all reaches were dominated by exotic pasture grasses along the bank. Retirement has resulted in dominance by cocksfoot and not in recolonisation by native species (at least not in the 8-15 years of retirement). These plants grew nearly as large as any surrounding tussock plants, and the rank decaying understorey appeared to prevent any colonisation or growth by other plants. The unsuitability of cocksfoot as riparian vegetation has been noted elsewhere (Purseglove 1988). Native vegetation (shrubs, flax and tussock) was only significant on the banks of three streams, Stag Stream (in SU3, SU4, SU5), Mt Hamilton Stream and Centre Burn. Here they formed important cover and shading. They were probably a surviving remnant of the original vegetation which had escaped fires, land clearance and grazing. Such remnants would not be expected to remain on the more mobile channels (Hamilton Burn, Weydon Burn).

California thistles prospered in many of the retired areas, but this reflected the situation in the surrounding pasture, and in these instances the strips could not be regarded as a weed-stock 'nursery'. Gorse and broom (other common noxious weeds in New Zealand) were present but not widespread.

Two streams that contained a large proportion of native species were examined more closely because of the palatability of these plants to stock. Accessible shrubs and flax had been cropped in Mt Hamilton Stream (MU) which has been in oversown tussock since 1982. Apart from a noticeable decline in the shrub koromiko, there was little difference between protected and unprotected reaches in the frequency and proportional cover (Table 4) of major species. In contrast, the Centre Burn unprotected reach contained very few native shrubs. This is probably due to the longer period of intensive grazing, although it may also be the result of past development (e.g. burning) or easier stock access.

Shading by overhanging vegetation was probably only of importance in the medium-sized streams (lower Stag, Centre, Mt. Hamilton). It was less important in the smallest streams because of the canyon effect of the incised channel.

One of the major water quality issues in Southland is the apparent loss of sports fisheries. One option that might improve this situation is the planting of trees along the open channels of the Hamilton and Weydon Burn. The use of willows is a well established soil conservation technique (Van Kraayenoord & Hathaway 1986), but other types of trees, including natives, are known to reduce stream bank erosion (Hicks, in press). Planting willows would also provide shade and cover (Green et al. 1989). Preliminary analysis of studies carried out in Otago and Nelson indicate the benefits to trout fisheries of moderate densities of riparian willows (Glova & Sagar 1990). In the absence of other practical options (e.g. to reduce quickflow from developed land) this seems the only way to reduce channel erosion in these unstable streams at a low cost.

6. CONCLUSIONS

In the Western USA, fencing and retiring grazed berms has always enhanced stream environments (Platts and Rinne 1985). There is always an improvement in streamside vegetation (and cover and shade), usually an enhancement in channel morphology (narrowing, deepening) and sometimes an improvement in fisheries (densities and size). In Southland, over a similar retirement period, improvements were constrained to retention of remnant shruby vegetation, greater vegetation cover in small to medium streams and the protection of small streams draining improved pasture from cattle-induced, streambank damage. The relative lack of measurable benefits reflects a relative lack of grazing effects in the study reaches. We speculate that the difference from the Western USA is due to:

1. A moist temperate climate which maintains grass growth for much of the year, so there is much less grazing pressure on streamside vegetation.

2. Cooler summer temperatures, so that animals are less attracted to wallowing in streams.

3. Removal of much native vegetation by land development, and the inability of native species to re-establish in competition with established exotic grasses, especially cocksfoot.

4. In larger streams, erosion by lateral migration of the stream occurs irrespective whether berms are retired or grazed.

The lack of recolonisation by native species, particularly larger shrubs or trees that might stabilise banks and enhance instream habitat, leads us to suggest that the retired zones would have to be planted in appropriate tree species if an improvement in trout fisheries and a reduction in erosion is required.

We anticipate that these results would be applicable to other parts of New Zealand with a similar geomorphology, in particular flood plains overlying coarse alluvial material (e.g. Canterbury Plains, Hawkes Bay). As in Southland, retirement by itself may or may not benefit channel erosion control or instream habitat, depending on geomorphology of the channel and the nature of the riparian vegetation. In order to obtain benefits, additional techniques such as tree planting may need to be considered.

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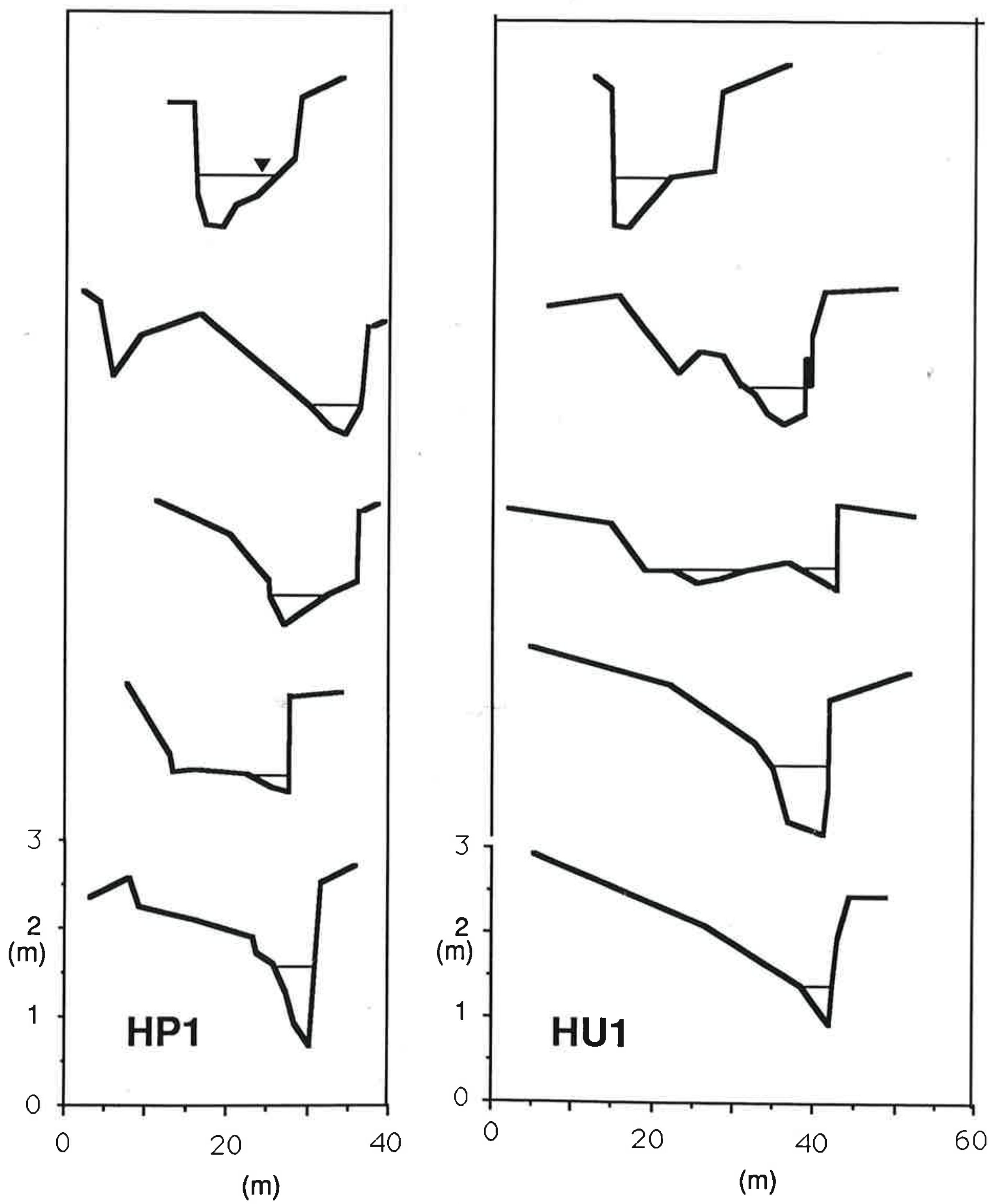
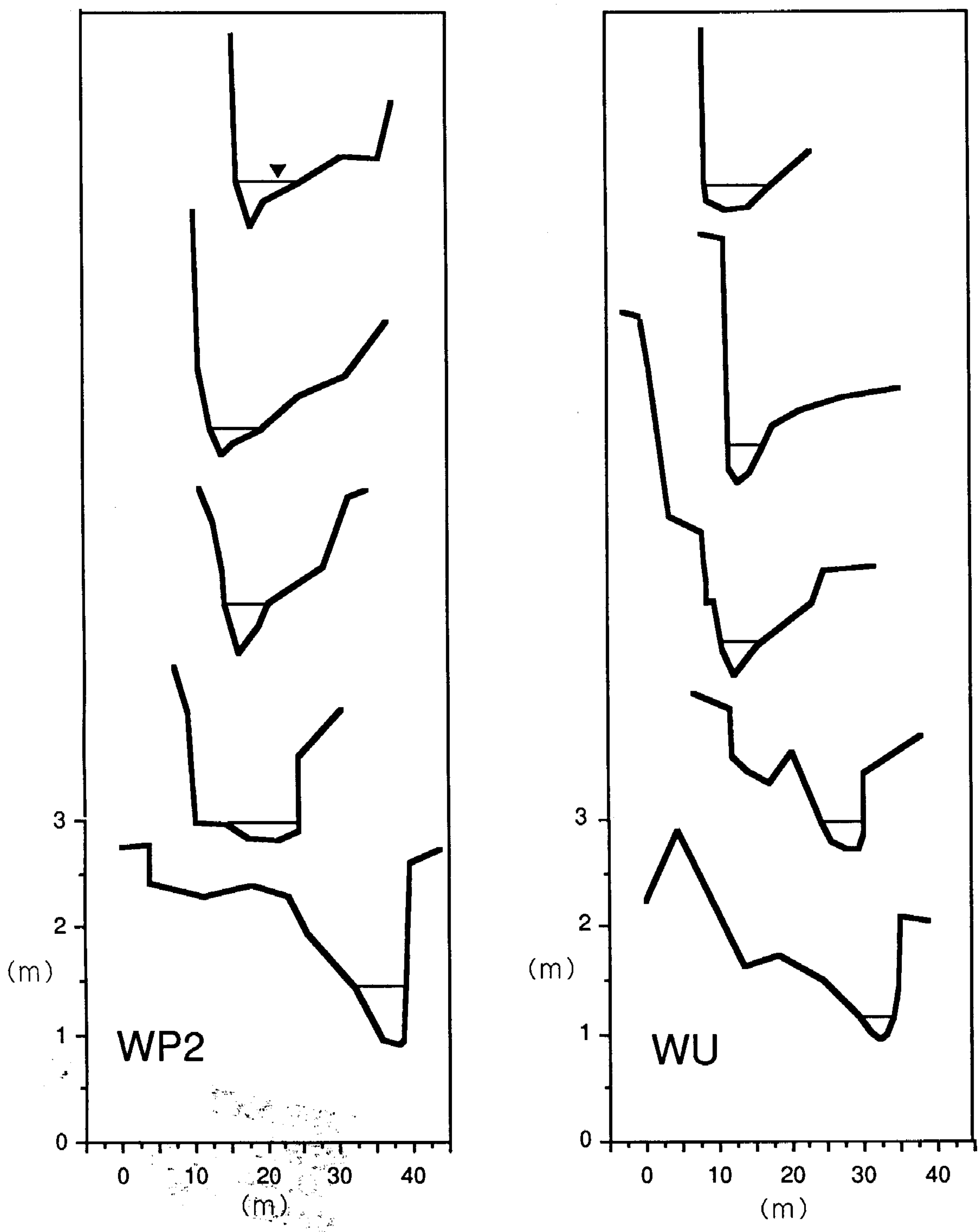
Appendix 1. Cross-section profiles of Hamilton Burn (HP1, HU1) and Weydon Burn (WP2, WU).




WP2
3
2
(m)
1
0
0
10
20
30
40
(m)
WU
3
2
(m)
1
0
0
10
20
30
40
(m)