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Soil Erosion in Auckland's Hill Country

A Survey of Fresh and Recent Erosion in 1999

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Soil Erosion in Auckland's Hill Country: A Survey of Fresh and Recent Erosion in 1999

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1 Executive summary

1.1 Background

This contract report presents findings from a survey of erosion on hill country soils in the Auckland region. The survey was commissioned by Auckland Regional Council, to help meet its statutory responsibility for monitoring state of the environment (Section 35, Resource Management Act, 1991).

The survey has been designed as a sample, to ascertain extent of erosion in the hill country; not as a regional over-view to identify all sites where erosion currently occurs. Instead, it identifies land uses, which currently experience erosion on particular soils.

Survey results could be used by the Council, as evidence to help justify regulatory control of certain land uses by the proposed Land and Water Plan. However, the Council may achieve better erosion control in Auckland's hill country if the survey's findings are widely publicised, so as to encourage landowners to make the transition to uses which can be sustained without damaging the land.

1.2 Method

A point sample network was established, at one kilometre intervals on hill and steepland soils. This entailed approximately 2500 points. 1:10,000 enlargements of ARC's aerial photographs, taken by Air Logistics in summer and autumn 1999, were used. Points on the NZMS 260 one kilometre map grid were overlaid on each enlargement. Where-ever a point fell on hill country:

- presence/absence of active erosion,
- presence/absence of recent erosion,
- land use,

were visually interpreted from the photograph. Soil types were ascertained subsequently, by overlaying the NZMS 260 grid on DSIR Soil Bureau maps.

Erosion and land use have been recorded in a database in such a way that, should ARC wish to adopt the Ministry for Environment's preferred indicators, they can be derived from the point sample data.

Data have been stored in a format which can be compared with future re-survey data obtained by alternative methods, in the event that spatial information technology improves sufficiently in the next ten years.

Technical information has been documented in appendices, so that ARC will be in a position to repeat the survey. This can be found in the report Methods Used to Survey

Auckland's Soil Erosion in Hill Country, Sand Country and Rural Land Use (Hicks 2000d).

1 Statistical considerations in survey design

2 Survey procedure

3 Extraction of MfE's preferred state-of-environment indicator from survey data

4 Ways to compare survey data with fresh data obtained by new technology

1.3 Findings: erosion under different land uses

In Auckland's hill country, fresh erosion has been widespread within the year preceding survey (1998):

- It is least under wetland vegetation; here, none has been recorded.
- It ranges from 3.9% - 4.6% of sample points for natural scrub and forest, to 9.0 - 10.0% for exotic scrub and forest. Topsoil erosion associated with vegetation clearance or tracking accounts for just a small proportion of the higher figures for exotic scrub and forest; most of the difference is attributable to landslides in standing vegetation.
- On grazed hill country, fresh erosion is least under dairy pasture at 3.4% of sample points, higher in improved pasture grazed by beef cattle or sheep at 10.9%, and higher again in unimproved drystock pasture at 12.3%. About a third of the erosion in grazed hill country is topsoil loss where pasture is depleted; the balance is due to landslides or earthflows.
- In the few places where hill country is intensively cultivated i.e. cropland, outdoor vegetable production or orchard, more than 10% of sample points are at risk of fresh topsoil erosion by sheet-wash or wind-blow; though its actual incidence is likely to be less, due to crop growth before rain or wind strikes.
- Where hill country is disturbed by earthworks i.e. farm tracking, forestry tracking, house sites, road construction, 100% of sample points are at risk of fresh topsoil erosion; although its actual incidence is likely to be reduced, by sediment control measures before rain or wind strikes.

Large areas of soil are currently revegetating after erosion in recent years (1990-1997):

- 8% of wetland of sample points are revegetating after sedimentation.
- From 7.4 to 11.9% of sample points under scrub and forest have revegetating landslide or earth-flow scars.
- For pasture, the percentages range from 8.1% up to 26.3%.
- For the few places where hill country soil is intensively cultivated, over 20% of sample points are revegetating after exposure to risk of topsoil erosion.

1.4 Findings: erosion on different soils

Fresh erosion ranges from 1.8% to 12.7% of sample points on different soil groups.

- On foothills it generally declines, moving from slightly weathered, through strongly weathered, to leached or podsolised soils. As the proportion of clay increases, susceptibility to surface erosion processes - sheet-wash, wind-blow, rilling or gullying - becomes less.
- On hill faces, fresh erosion declines in a similar fashion, moving from slightly weathered to leached soils. The slightly-weathered soils occur on steep faces, more susceptible to landslides (soil slips); the strongly-weathered, leached and podsolised soils on successively lower-angle slopes. As clay content increases, so does susceptibility to earthflows (slumps); hence a slight increase in erosion on podsolised hill soils (H3b2).
- Fresh erosion is least on stony steepland soils, affecting 1.8% of sample points. It is greatest on shallow steepland soils, where it affects 12.7%; and similarly great where locally steep slopes occur on lowland soils (H3c, 12.6%). The differences are largely explicable in terms of soils' parent material and slope - hard and unweathered beneath S2 soils; slightly weathered on steep slopes, beneath S3 soils; weathered but unconsolidated on steep slopes, beneath H3c soils.

Recent erosion ranges from 7.6% to 15.3% of sample points on different soil groups.

- On footslopes the same trend (for erosion to decrease as soil weathering increases) is found, reflecting annual exposure of footslopes to surface erosion by winter rains throughout the region.
- On hill faces the trend disappears, over-ridden by variable accumulation of revegetating mass movement scars, as storms have struck different parts of the region between 1990 and 1997.
- Recent erosion appears greatest on stony steepland soils, affecting 15.3% of sample points, but the figure may be inflated by interpreting naturally sparse vegetation as recently eroded. Recent erosion on shallow steepland soils is genuinely high at 10.7%, clearly identifiable as revegetating landslide scars. Recent erosion is slightly greater where locally steep slopes occur on lowland soils (H3c at 12.6%); again clearly identifiable as revegetating landslide or gully scars.

1.5 Findings: soil groups where erosion is unusually high or low

There are several soil groups where statistical analysis indicates that erosion is less than expected under certain land uses. These are:

H1a	-
H1b	Natural cover (forest, scrub, wetland)
H2a	-
H2b	-
H3a1	Natural cover
H3a2	Natural cover
H3b1	Natural cover
H3b2	-
H3c	-
S2	-
S3	Natural cover

For many other land uses, erosion is statistically no greater or less than can be expected, given the natural level of erosion on a soil group:

H1a	Natural cover	Pasture	-	-	-
H1b	-	-	-	Cultivated land	-
H2a	Natural cover	Pasture	Exotic forest	-	-
H2b	Natural cover	Pasture	Exotic forest	-	-
H3a1	-	-	-	-	-
H3a2	-	-	-	Cultivated land	-
H3b1	-	-	Exotic forest	-	-
H3b2	Natural cover	Pasture	Exotic forest	-	-
H3c	Natural cover	Pasture	Exotic forest	-	-
S2	Natural cover	Pasture	Exotic forest	-	Earthworks
S3	-	-	Exotic forest	-	Earthworks

On some soil groups, a few land uses clearly have greater levels of erosion than could be statistically expected:

H1a	-	-	-	Cultivated land	-
H1b	-	Pasture	-	-	-
H2a	-	-	-	Cultivated land	Earthworks
H2b	-	-	-	Cultivated land	Earthworks

H3a1	-	Pasture	Exotic forest	Cultivated land	Earthworks
H3a2	-	Pasture	Exotic forest	-	-
H3b1	-	Pasture	-	-	Earthworks
H3b2	-	-	-	-	Earthworks
H3c	-	-	-	Cultivated land	-
S2	-	-	-	-	-
S3	-	Pasture	-	-	-

1.6 Conclusions

The survey's findings convey three messages:

- That erosion is a natural phenomenon in Auckland's hill country, even under natural vegetation cover,
- That the incidence of erosion is higher where certain land uses are being practiced on certain hill country soils,
- But that most of the hill country land uses are not causing significantly higher erosion than can be expected, and some of them have levels of erosion that are close to those of natural vegetation cover.

2 Introduction

This contract report presents findings from a survey of erosion on hill country soils in the Auckland region. The survey was commissioned by Auckland Regional Council, to help meet its statutory responsibility for monitoring state of the environment (Section 35, Resource Management Act, 1991). The survey has been undertaken by Dr. Douglas Hicks, a member of Ecological Research Associates N.Z. Inc., who has been based in the Auckland region for some years.

The survey has been designed as a sample, to ascertain extent of erosion in the hill country; not as a regional over-view to identify all sites where erosion currently occurs. It would be unfair to target an owner of eroding land simply because sample points have fallen on his/her property, when there are other un-sampled properties in the vicinity with equally severe - or worse - erosion. Therefore, the database to be supplied to ARC records each site's soil, land use, and erosion status; but not its location or ownership.

The survey identifies land uses which currently experience erosion on particular soils. Landowners who realise they are practicing such a use, may wish to consider implementing soil conservation measures, which can reduce future incidence of soil loss and sediment entry into waterways. Survey findings may also prove helpful for informing purchasers of property, about uses which may be safely practiced without risking undue erosion of their new land.

Survey results could be used by the Council, as evidence to help justify regulatory control of certain land uses by the proposed Land and Water Plan. However I suggest that the Council may achieve better erosion control in Auckland's hill country, if instead, findings are widely publicised. Informing the public about erosion's nature and extent within the region, will help correct some common misconceptions. Educating the rising generation, will help the transition to land uses which can be sustained without damaging the land.

3 Brief and methods

The Auckland Regional Council's brief dated 20 December 1999 was to develop and implement a method to measure hill country erosion in the Auckland region.

Following discussion with other Councils and MfE in March 1999, ARC's preferred indicator for 'soil intactness' in the hill country is area of recent erosion. 1:10,000 colour enlargements, from aerial photo coverage taken in 1999, provide an opportunity for up-to-date measurement. ARC has also requested that an estimate of current land use be made from the same photo coverage. Background information about the reasons for these decisions is given in ARC's brief. The rest of this section outlines how each objective in the brief has been met.

3.1 Objective 1

To recommend, document and implement a simple, practical and robust (scientifically and statistically defensible) methodology for monitoring the current state of the hill country environment of the Auckland region. Monitoring methodology must be able to be repeated in subsequent years and representative of the Auckland region where samples of areas are assessed

To meet this objective, a point sample network was established, at one kilometre intervals on soil groups H1, H2, H3a and H3b (hill soils at risk of erosion, as depicted on the map Susceptibility of Auckland Soils to Degradation, Hicks, Shepherd and Parfitt 1996). The point sample network was extended to include soil groups H3c (hill phases of lowland soils), S2 (stony soils) and S3 (steepland soils). Although the latter three are not hill country in the strict scientific sense, rural land uses impact similarly on their soils, so it makes sense to include them in the sample. This entailed recording erosion at approximately 1800 points in the hill country and 700 in the other terrains.

Reasons for proposing a point sample were that:

- It can supply the information required,
- It can be measured quickly and at low cost,
- It is repeatable,
- It provides estimates that are representative of each soil group, to within acceptable error limits.

Technical Appendix One contains design parameters, time and cost estimates, and statistical calculations which support these four assertions. In the second respect, a point sample remains superior to alternative methods such as area measurements of the entire hill country from aerial photographs, or digital computer classification of satellite images.

The main disadvantage of a point sample is that, while providing a statistically robust estimate of how much erosion exists on each soil group, it does not indicate exactly where the erosion is. This is not a problem because ARC's enlargements are, in themselves, first-class 'photo-maps' which show erosion's location relative to soils, vegetation and property boundaries in the year 1999. For site-specific environmental management, it is just as useful to look directly at them, as to refer to derived maps of percentage erosion by property. There is little gain from the time and expense that would be entailed in preparing the latter.

Technical Appendix Two describes the point sampling method, so it can be replicated by other personnel in future years if the survey is repeated. It includes definitions of terms used to describe hill country, soils, land use and erosion.

3.2 Objective 2

To measure the current area of active erosion (state/pressure indicator), using readily available aerial photographs as far as practical.

1:10,000 enlargements of ARC's aerial photographs, taken by Air Logistics in summer and autumn 1999, were used. Points on the NZMS260 one kilometre map grid were overlaid on each enlargement. Where-ever a point fell:

- presence/absence of active erosion,
- presence/absence of recent erosion,
- land use,

were visually interpreted from the photograph. Data were recorded manually on a check-sheet, then stored in an Excel-format spreadsheet to facilitate access and re-analysis by ARC staff in future years. Soil types were ascertained subsequently, by overlaying the NZMS 260 grid on DSIR Soil Bureau maps, and added to the spreadsheet. Soil types were assigned to the same groups as are depicted in the report Susceptibility of Auckland Soils to Degradation (Hicks et al op. cit.). A sub-set of data for the hill country soil groups was extracted and analysed.

Technical Appendix Two includes comments on map grid overlay, ease or otherwise of photo-interpretation, interpretation of soil maps, statistical analyses where needed to test representativeness and accuracy of the sample, and time taken to carry out each stage of the survey.

The main text of this report presents survey findings about erosion in hill country, together with summary tables and graphs.

3.3 Objective 3

To adopt and implement, as far as practicable, the preferred indicators for hill country erosion monitoring promulgated by the Ministry for the Environment i.e.:

- *Area of moderate erosion-risk land in pasture without soil conservation measures in place,*
- *Change in the area of moderate erosion-risk land in pasture without soil conservation measures in place*

Attaining this objective hinges on identifying moderate erosion-risk land, and also on recording soil conservation measures. For the former, MfE proposes Class VI and Class VII LUC units that are considered by regional councils as having 'moderate or greater' erosion risk. For the latter, it proposes such vegetation covers as are regarded by regional councils to be 'soil conservation measures'.

Erosion and land use have been recorded in the database in such a way that this can be done. Should ARC wish to adopt MfE's preferred indicators, they can be derived from the point sample data by:

- Storing point locations in ARC's Geographic Information System,
- Identifying LUC units at each point, by Arcinfo overlay of points onto the NZLRI,
- Deciding whether the LUC unit at each point is one of the units regarded as having 'moderate or greater erosion risk',
- Deciding whether land use recorded at each point corresponds with one of the vegetation covers regarded as 'soil conservation measures'.

In my response to ARC's project brief, I did not advocate doing this as part of the initial survey. The reason is that MfE's approach is conceptually unsound. It is 'do-able', but will definitely need to be changed, if it is to become scientifically defensible.

ARC's contract document requested that the report include advice on the steps needed to attain Objective 3. These are given in Technical Appendix Three. A critique of MfE's approach, together with suggestions for improving it, is included in the appendix.

3.4 Objective 4

To recommend feasible alternative methods of monitoring similar information in the event that spatial information technology improves sufficiently in the next ten years.

ARC's scoping paper Monitoring the Sustainability of Soil Resources (Hicks, 1994) compared methods which range from field mapping, through aerial photo interpretation, to analysis of satellite images.

Six years later, it is possible to assess whether spatial information technology has 'delivered the goods' during the past 6 years, and the likelihood of its providing a better delivery service within the next 10. Whether or not it has (or can), what is important is to ensure that data collected by conventional means now, can be compared with data collected by alternative methods in future. Technical Appendix Four:

- Up-dates observations made in the relevant section of the 1994 scoping paper,

- Discusses new technological developments, not envisaged in 1994, which are likely to be available by 2010,
- Outlines ways to compare point data with aerial photographic measurements or digitally classified satellite images, collected at different dates.

4 Definitions of hill country, soils, land use and erosion

Terms used when recording data, and the reasons for choosing them, are given in Technical Appendix Two so will not be repeated here, apart from details specific to hill country.

4.1 Hill country

'Hill country' is usually defined by geomorphologists in terms of its landforms - rolling to moderately steep slopes (between 15 and 30 degrees), formed from weathered rock, with low relative relief (usually less than 300 metres from valley bottoms to ridge crests). Clearly much of Auckland's region fits the definition:

- Almost all of Rodney District excepting river terraces, estuarine flats and sand country
- About half the land in Franklin District, mainly east of Papakura
- Likewise, much rural land in Manukau city east of Otara
- Small areas of rural land around the northern fringes of Waitakere City and North Shore City
- The inner Gulf Islands.

'Steeplands' is a term used by geomorphologists to define land with steeper slopes (between 30 and 50 degrees), and greater relative relief (usually 300 to 600 metres from valley bottoms to ridge crests), but not sufficiently high to be called mountainous. Some parts of Auckland's region fit this definition:

- The Hunua and Waitakere Ranges
- Scarps in the Kaipara Hills and Dome Hills
- Great Barrier and Little Barrier Islands.

Steeplands have been included in this survey along with Auckland's hill country; though data have been stored and analysed in a way which permits separate conclusions about erosion on steepland soils.

Hill country and steeplands can be identified in several ways:

- by field-mapping landforms,
- from contours on topographic maps,

- from digital terrain models,
- by stereoscopic examination of aerial photographs,
- from maps depicting geology or soils.

For this survey, the fourth and fifth options have been used. Sample points viewed on aerial photographs were classified as hill country where DSIR soil maps indicate a soil type found on hill country footslopes, hill country faces, steeplands, or locally steep slopes in lowlands.

The option proved satisfactory, except for points where a soil map indicates one of the above, but the aerial photograph clearly shows a floodplain, river terrace or undulating downland - or vice versa. These anomalies occur where NZMS 260 map grid intersections (used to locate sample points) fall close to a boundary between two soil types. Here, the soil group from the other side of the boundary was assigned to a point. Origin of such anomalies is discussed in Technical Appendix Two.

4.2 Soils

In 1995, Auckland's 132 soil types were consolidated into 19 groups with similar susceptibility to degradation (Hicks, Shepherd and Parfitt 1996). This was done to facilitate future survey of Auckland soils' condition for state-of-environment reports. Hill country soils fall into 11 groups out of the 19.

Grazeable footslope soils

H1a Susceptible to slight nutrient loss if intensively grazed

H1b Susceptible to slight nutrient loss, structural breakdown or surface erosion if intensively grazed

H2a Susceptible to moderate nutrient loss, structural breakdown or surface erosion if intensively grazed

H2b Susceptible to severe nutrient loss, structural breakdown or surface erosion if intensively grazed

Grazeable hill soils

H3a1 Hill phases of H1a; additionally susceptible to subsoil erosion

H3a2 Hill phases of H1b; additionally susceptible to subsoil erosion

H3b1 Hill phases of H2a; additionally susceptible to subsoil erosion

H3b2 Hill phases of H2b; additionally susceptible to subsoil erosion

Non-arable lowland soils

H3c Susceptible to severe subsoil erosion on account of locally steep slope

Non-grazeable hill soils

S2 Susceptible to severe structural problems on account of stony or rocky texture

S3 Susceptible to severe subsoil erosion on account of steep slope

Detailed accounts of each soil group, including the constituent soils, are given in the ARC's contract report Susceptibility of Auckland Soils to Degradation (Hicks et al op. cit.).

4.3 Land use

After some discussion of these issues with ARC's staff, it was decided simply to record land uses that ARC is interested in, from the point of view of their environmental impacts on soil. These are:

Outdoor vegetable production (market gardens)	H
Grain and greenfeed crops	C
Orchards and vineyards	O
Dairy pasture	D
Improved drystock pasture (beef cattle, sheep or deer)	I
Unimproved drystock pasture (beef cattle, sheep or deer)	U
Lifestyle blocks	L
Exotic scrub	X
Exotic forest	E
Natural scrub	S
Natural forest	F
Wetland vegetation	W
Coastal vegetation	M

This classification while basic proved practical when photo-interpreting land use. Comments about its ease of use are given in Technical Appendix Two. Three modifications were necessary:

- At many sample points, a secondary land use inter-mingles with the principal use. A lower-case letter has been added to indicate where this is the case. For instance, 'Is' denotes improved drystock pasture with clumps of natural scrub.

- Differentiation of lifestyle blocks from other land uses proved pointless. Some are under intensive horticultural use. The majority are under drystock pasture, both improved and unimproved. Many are in natural scrub or forest. 'Lifestyle block' describes property size, not land use; and for the purpose of this survey it is more sensible to amalgamate them with similar land uses on larger properties.
- A few points were surrounded by extensive bare earth, sand or rock. Here, the bare ground clearly could not be attributed to a surrounding land use. Such points were classified as 'bare ground' caused by some site-specific natural process or human activity. Examples are sand drifts, coastal cliffs, quarries, landing stages in harvested plantation forest, road re-alignments, and building construction sites.

4.4 Erosion

A point was recorded as *freshly eroded*, if the photo showed bare ground at or close to the point. Annotations on survey check-sheets indicate whether the bare ground is subsoil erosion due to natural processes:

- landslide,
- earthflow,
- gully,
- streambank collapse,

or surface erosion/deposition where vegetation is depleted by:

- sedimentation,
- cultivation, over-grazing, plant die-back,
- earthworks, tracking.

A point was recorded as *recently eroded*, if bare ground was visible at or near the point, but was already re-vegetating. The nature of recent erosion was annotated on check-sheets, using the same codes as for fresh erosion.

What has been recorded in this survey as fresh erosion, has occurred within the twelve months that precede date of photography. What has been recorded as recent erosion is at least 1 year old with an upper age limit somewhere in the range 5 to 10 years.

Technical Appendix Two discusses how the distinction between fresh and recent erosion is made, when examining aerial photographs. It also includes discussion about the contentious issue of whether for a point sample, erosion should only be recorded at a point, or for the area around a point; and if so, how far away.

5 Presentation of survey results

5.1 Analysis of sample

The hill country sample contains 2498 points. Codes stored in the spreadsheet enable it to be subdivided according to soil group or type; land use or vegetation structure and erosion status or form.

The purpose of this contract, which is simply to ascertain erosion's current extent under different land uses on hill country soils. This can be conveyed by a relatively simple presentation of summary data in four tables with accompanying graphs (sections 5.3-5.6).

A more detailed analysis of erosion's extent, on different soil groups and under different land uses, has also been prepared (Appendix A).

5.2 Representativeness

Representativeness of data, for hill country throughout the region, has been ascertained by applying three statistical tests (see Technical Appendix One). As the hill country sample size is large, the test based on standard error of a proportion has been used to calculate confidence limits for land use:

Land use	*Area of hill country*	*95% confidence limits*
	%	*+-%*
Orchards and vineyards	0.4	0.2
Outdoor vegetable production	0.2	0.2
Grain and fodder crops	0.7	0.3
Dairy pasture	9.4	1.1
Improved drystock pasture	35.3	1.9
Unimproved drystock pasture	6.8	1.0
Exotic forest	12.0	1.3
Natural forest	11.3	1.2
Exotic scrub	2.7	0.6
Natural scrub	19.7	1.6

Wetland vegetation	1.0	0.4
Earthworks	0.4	0.3

In short, there is 95% confidence that the sample percentage of land in each use is within +- 2.0% or better of the true region-wide figure for hill country.

Tables 1 to 4 give confidence limits for erosion, under each land use and on each soil group. As some of the sub-sample sizes are small, confidence limits are calculated using the test based on standard error of a mean. Margins of error are high for erosion data under land uses uncommon in hill country e.g. orchards and vineyards. They are generally better than +- 2.0% for land uses that are widespread.

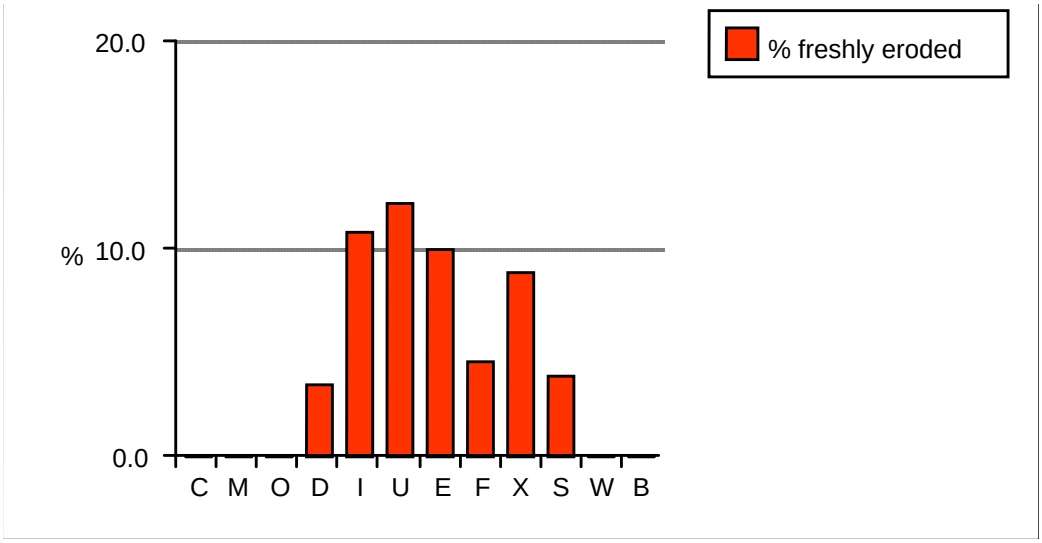
5.3 Fresh erosion

Table 1.

Fresh erosion under different land uses

Code	Land use	Points n	Bare %	Precision +-%	Error +-%
O	Orchards and vineyards	10	10	10	4.1
M	Outdoor vegetable production	5	20	20	41.3
C	Grain and fodder crops	17	35.3	5.8	10
D	Dairy pasture	235	3.4	0.4	0.7
I	Drystock pasture (improved)	883	10.9	0.1	0.4
U	Drystock pasture (unimproved)	171	12.3	0.6	1.5
E	Exotic forest	301	10	0.3	0.9
F	Natural forest	282	4.6	0.4	0.3
X	Exotic scrub	67	9	1.5	2.6
S	Natural scrub	491	3.9	0.2	0.4
W	Wetland	25	0	4	0
B	Earthworks	11	100	9.1	0

Figure 1.
Fresh erosion under different hill country land uses



Where hill country is intensively cultivated - grain and fodder crops, outdoor vegetable production, orchards or vineyards - a high percentage of sample points have bare soil. However caution should be exercised interpreting the figures:

- Very small proportions of the hill country are under these uses. Therefore, precision of bare ground measurement is low, and sample error is large.
- Under these uses, bare ground cannot be equated with fresh soil erosion. Rather, it indicates soil temporarily bared by cultivation, therefore at risk of erosion.

For both reasons, bare ground percentages for the three uses are not depicted as fresh erosion in Figure 1.

Where hill country is in pasture, forest or scrub, the percentage of sample points with bare soil can be regarded as a reliable measurement of fresh erosion, because:

- Under these uses, bare ground indicates disturbance of soil by sheetwash, wind erosion, gullying or mass movement.
- Precision of measurement is high, and sample error is small.

The percentages show distinct trends. Fresh erosion increases from dairy pasture, through improved pasture grazed by beef cattle or sheep, to unimproved drystock pasture. Under exotic scrub and forest plantations, the percentages of sample points freshly eroded are somewhat less than figures for drystock pasture. Under natural scrub and forest, the percentages freshly eroded are slightly higher than for dairy pasture. No fresh erosion was recorded on soil in wetlands.

The low percentage of fresh erosion on dairy pasture runs counter to a widespread perception that it is being 'hammered' by intensive grazing. Possible reasons are:

- Better ground cover due to more fertilisation of dairy pasture,

- A high proportion of drystock pasture on steep erosion-prone slopes.

Examination of aerial photographs suggests that the former accounts for much of the difference. Erosion form data (recorded for each point) indicate that the latter holds true for unimproved drystock pasture and to a lesser extent for improved.

Possible explanations for the fairly high percentages of sample points freshly eroded in exotic scrub and forest plantations are:

- Surface soil disturbance by forestry operations,
- Surface soil disturbance by scrub clearance,
- Mass movement erosion - landslides or earthflows - on unstable slopes.

Erosion form data indicate that the third factor is responsible for most of the recent erosion.

The same three explanations could account for fresh erosion observed in natural scrub and forest. Again, the erosion form data indicate that recent erosion here is overwhelmingly by mass movement. Percentages are somewhat lower than the figures for pasture, exotic forest or exotic scrub. Nevertheless, they contradict a widespread perception that natural vegetation cover 'prevents' erosion.

Where land is disturbed by earthworks, the high percentage of bare sample points should be treated with caution, for the same reasons as stated for cultivated ground. It indicates soil at risk of erosion - at many of these sites, sediment control measures may have been installed.

5.4 Recent erosion

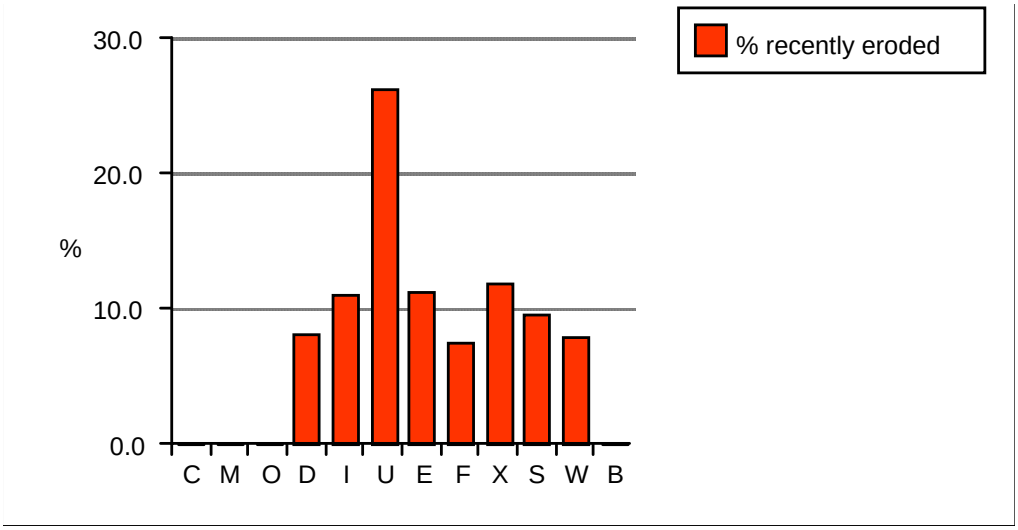
Table 2.

Recent erosion under different land uses

Code	Land use	Points n	Reveg. %	Precision +-%	Error +-%
O	Orchards and vineyards	10	20	10	8.3
M	Outdoor vegetable production	5	40	20	39.3
C	Grain and fodder crops	17	29.4	5.8	7.1
D	Dairy pasture	235	8.1	0.4	3.6
I	Drystock pasture (improved)	883	11.1	0.1	0.3
U	Drystock pasture (unimproved)	171	26.3	0.6	1.7
E	Exotic forest	301	11.3	0.3	1.3

F	Natural forest	282	7.4	0.4	0.9
X	Exotic scrub	67	11.9	1.5	4.8
S	Natural scrub	491	9.6	0.2	0.6
W	Wetland	25	8	4	13.6
B	Earthworks	11	0	9.1	0

Figure 2.
Recent erosion under different hill country land uses



At the few points where hill country is intensively cultivated, high percentages of sample points are revegetating after disturbance. However they cannot be equated with recent erosion, merely with exposure of soil to risk of erosion until the emerging crops form a complete ground cover. For this reason, revegetating ground in orchards, outdoor vegetable production and cropland is not depicted as recent erosion in Figure 2.

Under the more widespread hill country land uses the percentage of sample points with revegetating ground can be equated with recent erosion by sheetwash, wind, gullying or mass movement. Here, percentages show the same trends as for fresh erosion. Recent erosion increases with the transition from dairy pasture through improved to unimproved drystock pasture, and is particularly high for the latter.

Moderate percentages of sample points recently eroded, under exotic scrub and forest plantations, are similar to the figure for improved drystock pasture. Somewhat lower percentages eroded under natural scrub and forest, are close to the figure for dairy pasture. The only difference in trend is recent deposition of sediment on a moderate percentage of wetlands (no fresh deposition was recorded).

Explanations for these trends are the same as already presented for fresh erosion i.e.:

- Better fertilisation of dairy pasture,
- A greater proportion of drystock pasture, particularly unimproved, on mass movement-prone slopes.
- Mass movement in scrub and forest (whether natural or exotic).

Erosion form data (recorded for each point) show that very little of the revegetating ground in exotic forest is accounted for by poor regrowth after forest harvest. Most points falling on recently harvested areas are already completely vegetated, as a result of prompt oversowing and re-planting.

Where land has been recently disturbed by earthworks, no revegetating ground was recorded. All such ground appears to have quickly revegetated - perhaps as a deliberate sediment control measure - so was included in one or other of the preceding land use classes.

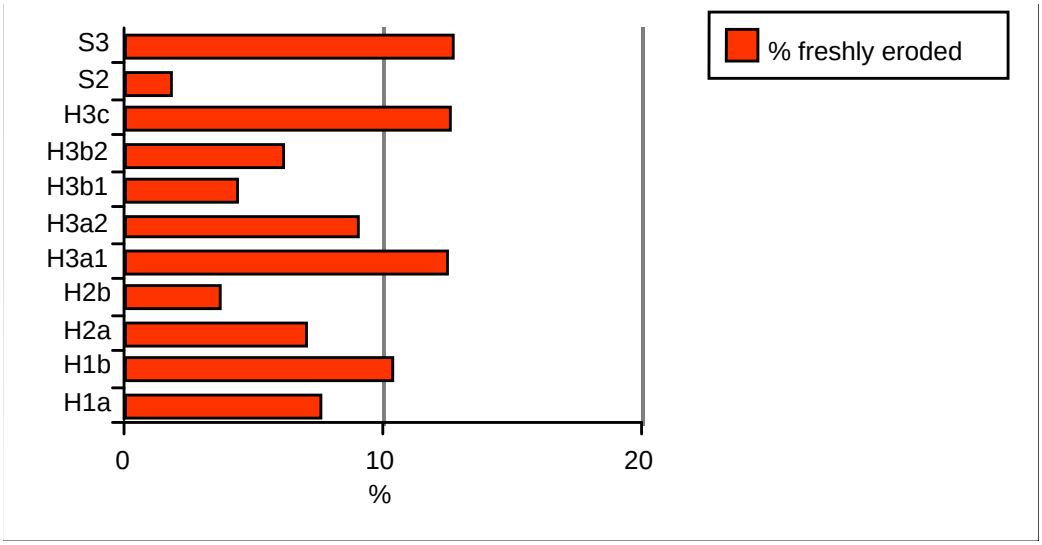
5.5 Fresh erosion by soil group

Table 3.

Fresh erosion on different soil groups

Soil group	Points n	Bare ground %	Precision +-%	Error +-%
H1a	53	7.6	1.9	4.7
H1b	242	10.3	0.4	0.7
H2a	214	7	0.5	1.1
H2b	303	3.7	0.3	2.1
H3a1	144	12.5	0.7	1.5
H3a2	586	9	0.2	2.3
H3b1	139	4.3	0.7	0.7
H3b2	98	6.1	1	1.2
H3c	135	12.6	0.7	2.2
S2	164	1.8	0.6	1.1
S3	418	12.7	0.2	0.8

Figure 3.
Fresh erosion on hill country soil groups



Bare ground in Table 3 and Figure 3 equates with fresh erosion (landslides, earthflows, gullies, streambanks). The few points where this is not the case (cultivated ground or earthworks) are so thinly distributed across the soil groups, that their inclusion has minimal effect on each percentage.

The percentage of sample points with freshly eroded soil increases moving from H1a to H1b then declines moving through the footslope soil groups from H1b to H2b. There are two possible explanations:

- 'Low-erosion' land uses, such as natural scrub and forest, increase moving from H1a (least-weathered; most fertile) to H2b (most-weathered; least fertile) - can be verified by analysis of land use on different soil groups.
- The more-weathered soils, being clayey, have greater resistance to surface erosion processes - true to some extent, but clayey footslope soils also have less resistance to subsurface erosion by earthflows.

Freshly eroded soil also declines moving through the equivalent hill soil groups from H3a1 to H3b1, but increases slightly for H3b2. The possible explanations are :

- An increase in the proportion of 'low-erosion' land uses, except on H3b2. Again, this can be verified by analysis of land use.
- Greater resistance to surface erosion processes - true to some extent, but likely to be counter-acted by their lower resistance to sub-surface erosion (on the hill soils, most erosion is due to sub-surface processes).

Fresh erosion is widespread on the hill phases of lowland soils (H3c). This is consistent with the nature of their parent materials - slightly weathered volcanic ashes, estuarine sediments and coastal sands. All three materials are weak, so prone to surface erosion and gullying or mass movement of subsoil, where dissected into steep slopes.

Fresh erosion is low on stony soils (S2). Again, this is consistent with the nature of parent materials - rocky lava flows or stony breccias that are strong enough to resist erosion processes.

Fresh erosion is high on steepland soils (S3), though no higher than on the worst-eroded hill soils (H3a1) or the hill phases of lowland soils (H3c). S3 parent materials - sandstone, greywacke, basalt, andesite - differ greatly in rock strength, but all are slightly weathered on steepland sites, and in this respect resemble the H3a1 and H3c groups. The over-riding factor on H3a1, H3c and S3 alike is steepness of slope - in excess of 35 degrees - which pre-disposes the less-weathered soils to stripping by landslides or debris avalanches (slopes are generally less than 35 degrees and often less than 25 on the more-weathered soils).

Accuracy of fresh erosion percentages is good for all groups except H1a, for which precision is reduced and sample error increased by relatively small sub-sample size.

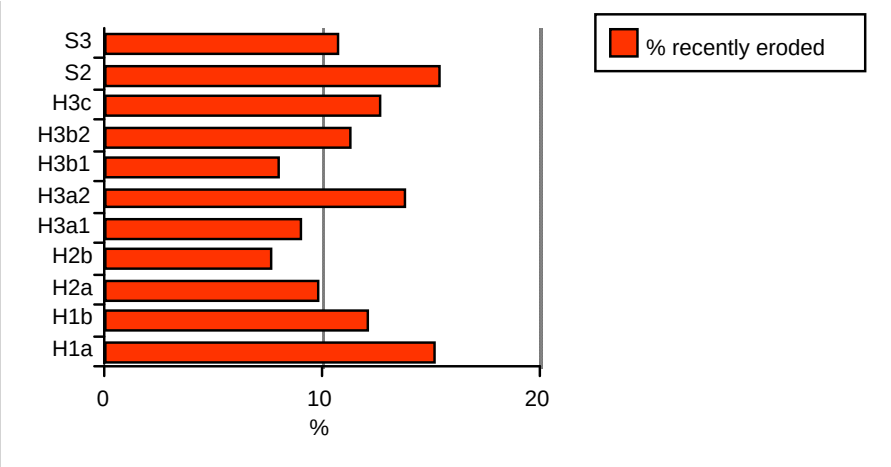
5.6 Recent erosion by soil group

Table 4.

Recent erosion on different soil groups

Soil group	Points n	Reveg. ground %	Precision +-%	Error +-%
H1a	53	15.1	1.9	5.8
H1b	242	12	0.4	1.1
H2a	214	9.8	0.5	2
H2b	303	7.6	0.3	1.4
H3a1	144	9	0.7	4.7
H3a2	586	13.7	0.2	0.9
H3b1	139	7.9	0.7	1.1
H3b2	98	11.2	1	2.2
H3c	135	12.6	0.7	4.9
S2	164	15.3	0.6	3.6
S3	418	10.7	0.2	3

Figure 4.
Recent erosion on hill country soil groups



Revegetating ground in Table 4 and Figure 4 equates with recent erosion. The few points where this is not the case (cultivated ground) are so thinly distributed across the soil groups, that their inclusion has minimal effect on each percentage.

On footslope soil groups, a similar trend is evident to that for fresh erosion i.e. the percentage of sample points with recently eroded soil declines moving from the less-weathered to the more-weathered soils. The same explanations as given for fresh erosion, apply equally to incidence of erosion in previous years.

On hill soil groups, there is no trend. Possible explanations for its disappearance are:

- 'High-erosion' land uses may have been more extensive on H3a2, H3b1 and H3b2 between 2 and 10 years ago - likely, as scrub reversion and afforestation between now and then could be expected to have reduced incidence of fresh erosion in 1998 and 1999.
- Points recorded as 'recently eroded' are an amalgam of several erosion events between 1990 and 1997. It is harder to discern trends in erosion susceptibility from the record of several events superimposed, than from the record of three events (the 1998 winter and January 1999 rainstorms, together with pasture depletion in the 1998-1999 summer, account for what was recorded as 'freshly eroded').

On hill phases of lowland soils (H3c), recent erosion is high, consistent with these soils' erodibility due to weak parent material.

On stony soils (S2), a high percentage of sample points has been recorded as recently eroded; surprising in view of their resistant parent materials. This is almost certainly an artefact of equating revegetating ground with recent erosion. For most hill country, equating the two is valid - the vegetation is recolonising landslide scars; or thickening-up again where over-grazing has depleted it and exposed topsoil to surface erosion. On stony or rocky steeplands, a high percentage of what appears to be revegetating ground may be natural rock outcrop.

On steepland soils (S3), the percentage of sample points with recently eroded soil is high, but similar to the percentages recorded for the worst-eroded hill soils. Two explanations are likely, as to why it is no higher:

- Most of the steepland soils are under 'low-erosion' uses such as natural forest or scrub. Hence accumulated erosion should be less compared with hill soils, which have had a greater proportion of their area under 'high-erosion' uses - notably drystock pasture - up till recent years.
- On steeplands, most points recorded as recently eroded, are landslide scars revegetating into scrub. Closure of the scrub canopy may lead to scars being recorded as revegetated, earlier than would be the case on hill country (where browsing keeps recolonising vegetation sparse for longer).

The former explanation seems more likely, given that studies elsewhere in North Island steeplands indicate slow recolonisation of landslide scars by scrub in bush country; but the second cannot be excluded.

Accuracy of recent erosion percentages is good for all groups except H1a, where small sub-sample size again affects precision and sample error.

6 Conclusions

Erosion is present throughout Auckland's hill country, on all soil groups and under all land uses. This is to be expected, given that most soils' resistance to erosion has been weakened by weathering; that many of them are on steep slopes; and that they are subject to irregular heavy rainfall.

6.1 Erosion under different land uses

Fresh erosion is least under wetland vegetation; here, none has been recorded.

Fresh erosion ranges from 3.9% - 4.6% of sample points for natural scrub and forest, to 9.0 - 10.0% for exotic scrub and forest. Topsoil erosion associated with vegetation clearance or tracking accounts for just a small proportion of the higher figures for exotic scrub and forest; most of the difference is attributable to landslides in standing vegetation.

On grazed hill country, fresh erosion is least under dairy pasture at 3.4% of sample points, higher in improved pasture grazed by beef cattle or sheep at 10.9%, and higher again in unimproved drystock pasture at 12.3%. About a third of the erosion in grazed hill country is topsoil loss where pasture is depleted; the balance is due to landslides or earthflows.

In the few places where hill country is intensively cultivated i.e. cropland, outdoor vegetable production or orchard, more than 10% of sample points are at risk of fresh topsoil erosion by sheetwash or windblow; though its actual incidence is likely to be less, due to crop growth before rain or wind strikes.

In the few places where hill country is disturbed by earthworks i.e. farm tracking, forestry tracking, house sites, road construction, 100% of sample points are at risk of fresh topsoil erosion; though its actual incidence is likely to be reduced, by sediment control measures before rain or wind strikes.

Large areas of soil are currently revegetating after erosion in recent years (1990-1997). About 8% of wetland sample points are revegetating after sedimentation. From 7.4 to 11.9% of sample points under scrub and forest have revegetating landslide or earthflow scars. For pasture, the percentages range from 8.1% up to 26.3%. For the few places where hill country soil is intensively cultivated, over 20% of sample points are revegetating after exposure to risk of topsoil erosion.

6.2 Erosion on different soils

Fresh erosion ranges from 1.8% to 12.7% of sample points on different soil groups.

On foothills it generally declines, moving from slightly weathered, through strongly weathered, to leached or podsolised soils. As the proportion of clay increases,

susceptibility to surface erosion processes - sheet-wash, wind-blow, rilling or gullying - becomes less.

On hill faces, fresh erosion declines in a similar fashion, moving from slightly-weathered to leached soils. The slightly-weathered soils occur on steep faces, more susceptible to landslides (soil slips); the strongly-weathered, leached and podsolised soils on successively lower-angle slopes. As clay content increases, so does susceptibility to earthflows (slumps); hence a slight increase in erosion on podsolised hill soils (H3b2).

Fresh erosion is least on stony steepland soils, affecting 1.8% of sample points. It is greatest on shallow steepland soils, where it affects 12.7%; and similarly great where locally steep slopes occur on lowland soils (H3c, 12.6%). The differences are largely explicable in terms of soils' parent material and slope - hard and unweathered beneath S2 soils; slightly weathered on steep slopes, beneath S3 soils; weathered but unconsolidated on steep slopes, beneath H3c soils.

Recent erosion ranges from 7.6% to 15.3% of sample points on different soil groups. On footslopes the same trend (for erosion to decrease as soil weathering increases) is found, reflecting annual exposure of footslopes to surface erosion by winter rains throughout the region. On hill faces the trend disappears, over-ridden by variable accumulation of revegetating mass movement scars, as storms have struck different parts of the region between 1990 and 1997. Recent erosion appears greatest on stony steepland soils, affecting 15.3% of sample points, but the figure may be inflated by interpreting naturally sparse vegetation as recently eroded. Recent erosion on shallow steepland soils is genuinely high at 10.7%, clearly identifiable as revegetating landslide scars. Recent erosion is slightly greater where locally steep slopes occur on lowland soils (H3c at 12.6%); again clearly identifiable as revegetating landslide or gully scars.

6.3 Soil groups where erosion is unusually high or low

There are several soil groups where Appendix A indicates that erosion is statistically less than expected under certain land uses. These are:

H1a	-
H1b	Natural cover (forest, scrub, wetland)
H2a	-
H2b	-
H3a1	Natural cover
H3a2	Natural cover
H3b1	Natural cover
H3b2	-

H3c	-
S2	-
S3	Natural cover

For many other land uses, erosion is statistically no greater or less than can be expected, given the natural level of erosion on a soil group:

H1a	Natural cover	Pasture	-	-	-
H1b	-	-	-	Cultivated land	-
H2a	Natural cover	Pasture	Exotic forest	-	-
H2b	Natural cover	Pasture	Exotic forest	-	-
H3a1	-	-	-	-	-
H3a2	-	-	-	Cultivated land	-
H3b1	-	-	Exotic forest	-	-
H3b2	Natural cover	Pasture	Exotic forest	-	-
H3c	Natural cover	Pasture	Exotic forest	-	-
S2	Natural cover	Pasture	Exotic forest	-	Earthworks
S3	-	-	Exotic forest	-	Earthworks

On some soil groups, a few land uses clearly have greater levels of erosion than could be statistically expected:

H1a	-	-	-	Cultivated land	-
H1b	-	Pasture	-	-	-
H2a	-	-	-	Cultivated land	Earthworks
H2b	-	-	-	Cultivated land	Earthworks
H3a1	-	Pasture	Exotic forest	Cultivated land	Earthworks
H3a2	-	Pasture	Exotic forest	-	-
H3b1	-	Pasture	-	-	Earthworks
H3b2	-	-	-	-	Earthworks
H3c	-	-	-	Cultivated land	-
S2	-	-	-	-	-

S3	-	Pasture	-	-	-	

The survey's findings convey three messages:

- That erosion is a natural phenomenon in Auckland's hill country, even under natural vegetation cover,
- That the incidence of erosion is higher where certain land uses are being practiced on certain hill country soils,
- But that most of the hill country land uses are not causing significantly higher erosion than can be expected, and some of them have levels of erosion that are close to natural vegetation cover.

7 Acknowledgements

The assistance of Tony Thompson, Kate Martin and Tony Batistich, in arranging access to ARC's aerial photographs and providing facilities for their interpretation, is gratefully acknowledged.

8 References

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Hicks, D. L. (2000d). Methods Used to Survey Auckland's Soil Erosion in Hill Country, Sand Country and Rural Land Use. Prepared by Ecological Research Associates for Auckland Regional Council. Auckland Regional Council Document Type TR 2009/024.

Hicks, D.L., 1994 Monitoring the Sustainability of Soil Resources. Contract report to Auckland Regional Council.

9 Appendix A – erosion's extent under different land uses in hill country

9.1 Fresh Erosion under Different Land Uses on each Soil Group

One of the purposes of the survey is to ascertain whether erosion is currently a problem under particular land uses on the different soil groups. One way to do this is a three-way-split of the sample (Tables 1a-c).

Table 1a.

Percentage of sample points with bare ground/fresh erosion under different land uses, on footslope soils

	H1a %	H1b %	H2a %	H2b %
Orchards and vineyards	*	*	17	0
Outdoor vegetable production	*	*	*	0
Grain and fodder crops	50	0	25	67
Dairy pasture	0	7	3	1
Drystock pasture (improved)	3	14	10	4
Drystock pasture (unimproved)	25	6	0	5
Exotic forest	*	*	0	0
Natural forest	0	*	0	0
Exotic scrub	0	0	0	0
Natural scrub	*	0	0	0
Wetland	*	*	0	0
Earthworks	*	*	100	100

** denotes land use not recorded on soil group*

Table 1b.

Percentage of sample points with bare ground/fresh erosion under different land uses, on hill soils

	H3a1 %	H3a2 %	H3b1 %	H3b2 %
Orchards and vineyards	0	0	*	*
Outdoor vegetable production	*	100	*	*
Grain and fodder crops	25	*	*	*
Dairy pasture	17	0	0	0
Drystock pasture (improved)	13	13	7	7
Drystock pasture (unimproved)	13	12	10	11
Exotic forest	19	11	0	4
Natural forest	0	2	0	0
Exotic scrub	0	7	*	17
Natural scrub	4	4	0	0
Wetland	0	0	*	0
Earthworks	100	*	100	100

** denotes land use not recorded on soil group*

Table 1c.

Percentage of sample points with bare ground/fresh erosion under different land uses, on steepland soils and steep phases of lowland soils

	H3c %	S2 %	S3 %
Orchards and vineyards	0	*	*
Outdoor vegetable production	0	*	*
Grain and fodder crops	33	*	*
Dairy pasture	8	*	0
Drystock pasture (improved)	12	4	24
Drystock pasture (unimproved)	27	20	15
Exotic forest	0	0	18
Natural forest	0	0	9
Exotic scrub	33	0	15
Natural scrub	14	0	8
Wetland	0	0	0
Earthworks	*	100	100

* *denotes land use not recorded on soil group*

Reliable comparisons can be made amongst some but not all percentages in Tables 1a to c, because many sub-samples are small. The tables are presented here for completeness, and will not be further analysed.

Instead, an analysis of difference-in-proportions is presented in sections 9.3 and 9.4. The difference-in-proportions test (see Technical Appendix One) enables reliable conclusions to be drawn from small sub-samples.

9.2 Recent erosion under different land uses on each soil group

The same comments apply to these tables, as for Table 1a to 1c.

Table 2a.

Percentage of sample points with revegetating ground/recent erosion under different land uses, on footslope soils

	H1a %	H1b %	H2a %	H2b %
Orchards and vineyards	*	*	33	0
Outdoor vegetable production	*	*	*	33
Grain and fodder crops	50	0	25	33
Dairy pasture	17	9	3	5
Drystock pasture (improved)	6	15	9	8
Drystock pasture (unimproved)	50	11	15	20
Exotic forest	*	*	11	0
Natural forest	0	*	25	0
Exotic scrub	0	25	0	25
Natural scrub	*	0	8	0
Wetland	*	*	50	18
Earthworks	*	*	0	0

* *denotes land use not recorded on soil group*

Table 2b.

Percentage of sample points with revegetating ground/recent erosion under different land uses, on hill soils

	H3a1 %	H3a2 %	H3b1 %	H3b2 %
Orchards and vineyards	0	0	*	*
Outdoor vegetable production	0	0	*	*
Grain and fodder crops	25	*	*	*
Dairy pasture	17	31	13	0
Drystock pasture (improved)	8	15	12	13
Drystock pasture (unimproved)	13	34	20	33
Exotic forest	19	14	5	13
Natural forest	0	11	0	0
Exotic scrub	0	11	0	17
Natural scrub	0	5	4	0
Wetland	100	0	0	0
Earthworks	0	0	0	0

* *denotes land use not recorded on soil group*

Table 2c.

Percentage of sample points with revegetating ground/recent erosion under different land uses, on steepland soils and steep phases of lowland soils

	H3c %	S2 %	S3 %
Orchards and vineyards	0	*	*
Outdoor vegetable production	100	*	*
Grain and fodder crops	33	*	*
Dairy pasture	8	*	100
Drystock pasture (improved)	10	0	8
Drystock pasture (unimproved)	36	40	30
Exotic forest	40	0	10
Natural forest	0	8	17
Exotic scrub	0	67	0
Natural scrub	5	22	14
Wetland	0	0	0
Earthworks	*	0	0

* *denotes land use not recorded on soil group*

Again, sections 9.3 and 9.4 for an alternative approach, which identifies land uses where erosion is significantly higher than expected on particular soil groups.

9.3 Proportion of soil group eroded under each land use

Where a sub-sample's size is too small and its error margin too high, to draw a conclusion about the percentage of sub-sample eroded from number of points, an alternative is to re-express it as a proportion of the larger sample, and test for difference-of-proportions. If for a soil group, the percentages of each land use freshly or recently eroded (Tables 1 and 2) are converted to proportions of soil disturbed under each use, they may be compared with the proportions of the soil group under each use (Tables 3a to 3k).

For instance in Table 3a, 0.17 of the soil disturbance on H1a occurs under cropland, but only 0.04 of H1a's area is under cropland. It is 4.42 times greater (after removal of rounding to two decimal places) than one would expect, if soil disturbance were un-

affected by land use. This ratio is correct for the points sampled. However if the number of points under cropland is small, or if the number of points on H1a is small, the ratio could be greatly altered by adding or deleting a few points. Applying a difference-of-proportions test, the z statistic is -1.68 which is within the range +-1.96 (95% confidence limits). There is no significant difference in proportions, so it would be unwise to conclude that soil disturbance is unduly great where H1a soil is cropped. The high ratio may simply be an artefact of small sub-sample size.

The ratios and tests in Tables 3a to k highlight a number of situations where soil disturbance is greater or less than expected under a particular land use on a certain soil group, and where the differences are statistically significant:

H1a	Drystock pasture (improved)	Less erosion than expected
	Drystock pasture (unimproved)	Greater erosion than expected
H1b	Drystock pasture (improved)	Greater erosion than expected
	Natural scrub	Less erosion than expected
H2a	Dairy pasture	Less erosion than expected
	Bare ground	Greater erosion than expected
H2b	Cropland	Greater erosion than expected
	Bare ground	Greater erosion than expected
H3a1	None	
H3a2	Drystock pasture (unimproved)	Greater erosion than expected
	Natural scrub	Less erosion than expected
H3b1	Earthworks	Greater erosion than expected
H3b2	None	
H3c	Drystock pasture (unimproved)	Greater erosion than expected

S2 None

S3 None

9.4 Proportion of each soil group eroded under modified compared with natural vegetation

Tables 4a to e give additional ratios and difference-of-proportions tests for:

- Natural vegetation cover grouped, compared with all other vegetation
- Pasture grouped, compared with natural vegetation cover
- Exotic forest, compared with natural vegetation cover
- Cultivated land grouped compared with natural vegetation cover
- Earthworks, compared with natural vegetation cover.

These groups' larger sub-sample sizes enable some conclusions to be drawn from the difference-of-proportions test results, that are not possible from equivalent tests based on the smaller sub-sample sizes in Tables 3a to k.

Soil disturbance is:

- Significantly less under natural cover compared with other vegetation, on soil groups H1b, H3a1, H3a2, H3b1 and S3.
- Significantly greater under pasture compared with natural cover, on soil groups H1b, H3a1, H3a2, H3b1, and S3.
- Significantly greater under exotic forest compared with natural cover, on soil groups H3a1 and H3a2.
- Significantly greater on cultivated land compared with natural cover, on soil groups H1a, H2a, H2b, H3a1, and H3c.
- Significantly greater on earthworks compared with natural cover, on soil groups H2a, H2b, H3a1, H3b1 and H3b2.

These differences do not correspond with the conventional wisdom that natural vegetation cover 'prevents' erosion. They indicate that erosion is slight but still present where natural vegetation cover remains on hill soils and shallow steepland soils.

The differences also confirm a widespread perception that there is more erosion, where hill soils and shallow steepland soils are used for grazing. However they also indicate that on footslope soils used for grazing or exotic forestry, soil disturbance - whether erosion or deposition - is not significantly higher than beneath natural cover.

Soil disturbance persists on hill and steepland soils after conversion to exotic forest. As mentioned in the main report, disturbance is largely:

- Natural landslide and gully erosion in standing forest,

and to a lesser extent:

- Topsoil erosion during timber harvest.

Only on weathered hill soils (H3a1 and H3a2), does timber harvest raises erosion higher than the levels observed in natural cover.

High levels of soil disturbance, at the few sites where hill country is cultivated or subject to earthworks, are scarcely surprising. However as noted in the main report, these indicate exposure to risk of topsoil erosion, and its actual incidence is likely to be less due to:

- Crop growth before rain or wind strikes (cultivated ground),
- Sediment control measures (earthworks).

Table 3a Proportion of soil group h1a eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.04	0.17	4.42	-1.68	
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.00	0.00			
Dairy pasture	0.11	0.08	0.74	0.30	
Drystock pasture (improved)	0.66	0.25	0.38	2.60	Significant difference
Drystock pasture (unimproved)	0.15	0.50	3.31	-2.66	Significant difference
Exotic forest	0.00	0.00			
Natural forest	0.02	0.00	0.00	0.48	
Exotic scrub	0.02	0.00	0.00	0.48	
Natural scrub	0.00	0.00			
Wetland	0.00	0.00			
Earthworks	0.00	0.00			

Table 3b Proportion of soil group h1b eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.00	0.00	0.00	0.47	
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.00	0.00			
Dairy pasture	0.24	0.17	0.70	1.16	
Drystock pasture (improved)	0.59	0.76	1.28	-2.31	Significant difference
Drystock pasture (unimproved)	0.07	0.06	0.75	0.49	
Exotic forest	0.00	0.00			
Natural forest	0.00	0.00			
Exotic scrub	0.02	0.02	1.12	-0.10	
Natural scrub	0.07	0.00	0.00	2.07	Significant difference
Wetland	0.00	0.00			
Earthworks	0.00	0.00			

Table 3c Proportion of soil group h2a eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.02	0.06	2.97	-1.34	
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.03	0.08	2.97	-1.65	
Dairy pasture	0.19	0.06	0.30	1.95	Significant difference
Drystock pasture (improved)	0.46	0.53	1.14	-0.72	
Drystock pasture (unimproved)	0.06	0.06	0.91	0.12	
Exotic forest	0.08	0.06	0.66	0.58	
Natural forest	0.02	0.03	1.49	-0.36	
Exotic scrub	0.01	0.00	0.00	0.58	
Natural scrub	0.11	0.06	0.50	1.03	
Wetland	0.01	0.03	2.97	-0.94	
Earthworks	0.01	0.06	5.94	-2.04	Significant difference

Table 3d Proportion of soil group h2b eroded under each use, as a ratio of proportion of group in each use

	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.01	0.09	8.94	-3.28	Significant difference
Outdoor vegetable production	0.01	0.03	2.98	-1.00	
Orchards and vineyards	0.00	0.00	0.00	0.33	
Dairy pasture	0.27	0.15	0.55	1.52	
Drystock pasture (improved)	0.43	0.44	1.03	-0.15	
Drystock pasture (unimproved)	0.07	0.15	2.24	-1.72	
Exotic forest	0.10	0.00	0.00	1.92	
Natural forest	0.01	0.00	0.00	0.58	
Exotic scrub	0.01	0.03	2.24	-0.74	
Natural scrub	0.05	0.00	0.00	1.37	
Wetland	0.04	0.06	1.63	-0.65	
Earthworks	0.01	0.06	8.94	-2.67	Significant difference

Table 3e Proportion of soil group h3a1 eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.03	0.06	2.32	-1.02	
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.01	0.00	0.00	0.47	
Dairy pasture	0.04	0.06	1.55	-0.55	
Drystock pasture (improved)	0.37	0.35	0.96	0.14	
Drystock pasture (unimproved)	0.10	0.13	1.24	-0.40	
Exotic forest	0.15	0.26	1.77	-1.52	
Natural forest	0.10	0.00	0.00	1.81	
Exotic scrub	0.03	0.00	0.00	0.94	
Natural scrub	0.16	0.03	0.20	1.87	
Wetland	0.01	0.03	4.65	-1.20	
Earthworks	0.01	0.06	4.65	-1.71	

Table 3f Proportion of soil group h3a2 eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.00	0.00			
Outdoor vegetable production	0.00	0.01			
Orchards and vineyards	0.00	0.00			
Dairy pasture	0.02	0.03	1.36	-0.54	
Drystock pasture (improved)	0.36	0.44	1.24	-1.83	
Drystock pasture (unimproved)	0.07	0.14	2.04	-2.74	Significant difference
Exotic forest	0.18	0.20	1.10	-0.50	
Natural forest	0.09	0.05	0.56	1.53	
Exotic scrub	0.05	0.04	0.82	0.43	
Natural scrub	0.21	0.08	0.39	3.47	Significant difference
Wetland	0.01	0.00	0.00	1.07	
Earthworks	0.00	0.00			

Table 3g Proportion of soil group h3b1 eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.00	0.00			
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.00	0.00			
Dairy pasture	0.06	0.06	1.02	-0.02	
Drystock pasture (improved)	0.29	0.47	1.60	-1.47	
Drystock pasture (unimproved)	0.07	0.18	2.45	-1.47	
Exotic forest	0.16	0.06	0.37	1.09	
Natural forest	0.07	0.00	0.00	1.14	
Exotic scrub	0.00	0.00			
Natural scrub	0.33	0.12	0.36	1.80	
Wetland	0.00	0.00			
Earthworks	0.01	0.12	8.18	-2.54	Significant difference

Table 3h Proportion of soil group h3b2 eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.00	0.00			
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.00	0.00			
Dairy pasture	0.10	0.00	0.00	1.38	
Drystock pasture (improved)	0.31	0.35	1.15	-0.38	
Drystock pasture (unimproved)	0.09	0.24	2.56	-1.72	
Exotic forest	0.23	0.24	1.00	-0.01	
Natural forest	0.04	0.00	0.00	0.85	
Exotic scrub	0.06	0.12	1.92	-0.84	
Natural scrub	0.14	0.00	0.00	1.66	
Wetland	0.01	0.00	0.00	0.42	
Earthworks	0.01	0.06	5.76	-1.42	

Table 3i Proportion of soil group h3c eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.02	0.06	2.65	-1.13	
Outdoor vegetable production	0.01	0.03	3.97	-1.06	
Orchards and vineyards	0.01	0.00	0.00	0.50	
Dairy pasture	0.09	0.06	0.66	0.57	
Drystock pasture (improved)	0.50	0.44	0.88	0.65	
Drystock pasture (unimproved)	0.08	0.21	2.53	-2.10	Significant difference
Exotic forest	0.04	0.06	1.59	-0.57	
Natural forest	0.04	0.00	0.00	1.25	
Exotic scrub	0.02	0.03	1.32	-0.25	
Natural scrub	0.16	0.12	0.72	0.65	
Wetland	0.02	0.00	0.00	0.88	
Earthworks	0.00	0.00			

Table 3j Proportion of soil group S2 eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.00	0.00			
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.00	0.00			
Dairy pasture	0.00	0.00			
Drystock pasture (improved)	0.14	0.04	0.25	1.55	
Drystock pasture (unimproved)	0.03	0.11	3.51	-1.88	
Exotic forest	0.01	0.00	0.00	0.59	
Natural forest	0.30	0.14	0.47	1.76	
Exotic scrub	0.02	0.07	3.90	-1.63	
Natural scrub	0.48	0.61	1.26	-1.23	
Wetland	0.01	0.00	0.00	0.41	
Earthworks	0.01	0.04	5.86	-1.43	

Table 3k Proportion of soil group S2 eroded under each use, as a ratio of proportion of group in each use

Land use	P in use	P eroded in use	Ratio	Z statistic	Significance @ 95% conf.
Grain and fodder crops	0.00	0.00			
Outdoor vegetable production	0.00	0.00			
Orchards and vineyards	0.00	0.00			
Dairy pasture	0.00	0.01	4.27	-1.12	
Drystock pasture (improved)	0.12	0.16	1.34	-1.09	
Drystock pasture (unimproved)	0.05	0.09	1.92	-1.70	
Exotic forest	0.17	0.20	1.18	-0.74	
Natural forest	0.32	0.22	0.70	1.91	
Exotic scrub	0.03	0.02	0.66	0.57	
Natural scrub	0.30	0.28	0.93	0.41	
Wetland	0.00	0.00	0.00	0.48	
Earthworks	0.00	0.01	4.27	-1.12	

Table 4a Difference in proportion eroded natural vegetation compared with other vegetation

Soil group	Prop. N eroded	Prop. other eroded	Ratio	Z statistic	Significance @ 95% conf.
H1a	0.00	0.24	0.00	-0.78	
H1b	0.05	0.24	0.19	-2.12	Significant difference
H2a	0.13	0.18	0.71	-0.73	
H2b	0.09	0.11	0.77	-0.47	
H3a1	0.05	0.28	0.17	-3.25	Significant difference
H3a2	0.10	0.29	0.35	-5.63	Significant difference
H3b1	0.04	0.18	0.20	-2.67	Significant difference
H3b2	0.08	0.21	0.39	-1.49	
H3c	0.15	0.29	0.51	-1.71	
S2	0.17	0.16	1.07	0.20	
S3	0.19	0.32	0.58	-3.72	Significant difference

Table 4b Difference in proportion eroded pasture compared with natural vegetation cover

Soil group	Prop. P eroded	Prop. N eroded	Ratio	Z statistic	Significance @ 95% conf.
H1a	0.20	0.00		0.71	
H1b	0.24	0.05	5.32	2.11	Significant difference
H2a	0.22	0.13	1.74	1.18	
H2b	0.11	0.09	1.23	0.35	
H3a1	0.23	0.05	4.82	2.55	Significant difference
H3a2	0.31	0.10	2.99	5.43	Significant difference
H3b1	0.20	0.04	5.69	2.75	Significant difference
H3b2	0.20	0.08	2.55	1.37	
H3c	0.26	0.15	1.79	1.38	
S2	0.14	0.17	0.83	-0.39	
S3	0.36	0.19	1.93	3.16	Significant difference

Table 4c Difference in proportion eroded exotic forest compared with natural vegetation cover

Soil group	Prop. E eroded	Prop. N eroded	Ratio	Z statistic	Significance @ 95% conf.
H1a	*	0.00			
H1b	*	0.05			
H2a	0.11	0.13	0.89	-0.15	
H2b	0.00	0.09	0.00	-1.67	
H3a1	0.38	0.05	8.00	3.41	Significant difference
H3a2	0.25	0.10	2.41	3.43	Significant difference
H3b1	0.05	0.04	1.27	0.20	
H3b2	0.00	0.08	0.00	-1.39	
H3c	0.40	0.15	2.72	1.38	
S2	0.00	0.17	0.00	-0.65	
S3	0.28	0.19	1.49	1.70	

* denotes land use not found on soil group

Table 4d Difference in proportion eroded cultivated land compared with natural vegetation cover

Soil group	Prop. C eroded	Prop. N eroded	Ratio	Z statistic	Significance @ 95% conf.
H1a	1.00	0.00		2.00	Significant difference
H1b	0.00	0.05	0.00	-0.22	
H2a	0.50	0.13	4.00	2.52	Significant difference
H2b	0.57	0.09	6.48	3.09	Significant difference
H3a1	0.40	0.05	8.40	2.67	Significant difference
H3a2	0.50	0.10	4.82	1.80	
H3b1	*	0.04			
H3b2	*	0.08			
H3c	0.60	0.15	4.08	2.34	Significant difference
S2	*	0.17			
S3	*	0.19			

* denotes land use not found on soil group

Table 4e Difference in proportion eroded earthworks compared with natural vegetation cover

	Prop. B eroded	Prop. N eroded	Ratio	Z statistic	Significance @ 95% conf.
H1a	*	0.00			
H1b	*	0.05			
H2a	1.00	0.13	8.00	3.15	Significant difference
H2b	1.00	0.09	11.33	3.62	Significant difference
H3a1	1.00	0.05	21.00	4.58	Significant difference
H3a2	*	0.10			
H3b1	1.00	0.04	28.00	5.29	Significant difference
H3b2	1.00	0.08	12.50	2.82	Significant difference
H3c	*	0.15			
S2	0.50	0.17	2.89	1.20	
S3	0.50	0.19	2.68	1.13	

* denotes land use not found on soil group