Auckland Regional Council
TE RAUHĪTANGA TAIAO

Soil Erosion in Auckland's Sand Country

A Survey of Fresh and Recent Erosion in 1999

March 2009 TR 2009/025

Auckland Regional Council
Technical Report No.025 March 2009
ISSN 1179-0504 (Print)
ISSN 1179-0512 (Online)
ISBN 978-1-877528-32-3

Reviewed by:

Name: Amy Taylor

Position: Project Leader Land

Organisation: ARC

Date: 18 March 2009

Approved for ARC Publication by:

Name: Grant Barnes

Position: Group Manager Monitoring & Research

Organisation: ARC

Date: 18 March 2009

Recommended Citation:

Hicks, D. L. (2000b). Soil Erosion in Auckland's Sand Country: A Survey of Fresh and Recent Erosion in 1999. Prepared by Ecological Research Associates for Auckland Regional Council. Auckland Regional Council Document Type TR 2009/025.

Soil Erosion in Auckland's Sand Country. A Survey of Fresh and Recent Erosion in 1999

D. L. Hicks

Prepared for
Auckland Regional Council

By
Ecological Research Associates
Box 170, Orewa

Contents

1 Executive summary

1.1 Introduction

This contract report presents findings from a survey of erosion on sand 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 sand 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 sand country if 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 sand soils. This entailed approximately 500 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 a point fell on sand country, the following observations were recorded:

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

These 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 has 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 four appendices, so that ARC will be in a position to repeat/include the following survey attributes:

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

On Auckland's sand country, fresh erosion has been local within the year preceding survey (1998):

- Fresh erosion is least under wetland vegetation; here none has been recorded, and sedimentation at just one point.
- Under scrub and tree covers, fresh erosion ranges from 16.3% of sample points for natural scrub to 4.1% for exotic forest. Wind-blow of sand, associated with vegetation clearance or animal browsing, accounts for most of the erosion in scrub; though landslides on dissected terrain (H3c soils) are also a component. In exotic forest, the erosion is attributable to windblow in canopy gaps where plantings have failed close to the coast.
- On grazed sand country, fresh erosion is least under dairy pasture at 1.6% of sample points, higher in improved pasture grazed by beef cattle or sheep at 9.8%, and higher again in unimproved drystock pasture at 21.1%. Almost all the erosion on grazed sand country is topsoil loss to wind, where pasture is depleted; a small fraction is due to landslides or gullies on H3c soils.
- Fresh erosion and deposition is greatest on bare sand drifts, where 100% of sample points are affected.
- In the few places where sand country is intensively cultivated i.e. cropland, outdoor vegetable production or orchard, up to 20% of sample points are exposed to risk of topsoil erosion by windblow or sheetwash. Actual incidence is likely to be less, due to crop growth before wind or rain strikes.

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

- 38% of sample points in wetland is revegetating after sedimentation.
- 19% of sample points under natural scrub and exotic forest are revegetating after wind erosion or after soil disturbance during harvest.
- For pasture, the revegetating percentages range from 5% to 34% of sample points and are associated with vegetation recovery after heavy grazing, or pasture depletion by summer drought.
- There is little evidence of revegetation on bare sand drifts.

- At the few places where sand country is intensively cultivated, between 20% and 50% of sample points are revegetating after exposure to risk of topsoil erosion.

1.4 Findings: erosion on different soils

On the most erodible group of sand soils, L3, fresh or recent erosion by wind is still high. It occurs amongst:

- active sand dunes,
- coastal sand-binding grasses,
- natural scrub,
- drystock pasture,

but over most of L3, under closed-canopy pine plantation, it is slight.

On the I3 group (intermediate erodibility), fresh or recent erosion by wind is moderate.

It occurs on:

- cultivated ground, where present (limited area),
- drystock pasture, mainly where unimproved,

but over much of I3, under improved drystock pasture or dairy pasture, wind erosion is slight.

Fresh or recent erosion by wind is least on the H3c soil group, which has low susceptibility to wind erosion of topsoil. However, total erosion on H3c is greater than on I3 due to:

- landslides and gullies, in unimproved pasture or natural scrub,
- sheet erosion, in unimproved pasture,

on steep sides of valleys excavated through the weathered sand deposits.

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

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

L3	-	-	Exotic forest	-	-
I3	Dairy	-	-	-	-
H3c	-	-	-	-	-

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

L3	Dairy	Drystock	-	Natural scrub	Wetland
I3	-	Drystock	Exotic forest	Natural scrub	Wetland
H3c	Dairy pasture	Drystock	Exotic forest	Natural scrub	Wetland

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

L3	Coastal sand-binding grasses	Bare sand drifts	-
I3	-	-	Drystock
H3c	-	-	-

1.6 Conclusions

The survey's findings convey four messages:

- Erosion is a natural phenomenon in Auckland's sand country, even under natural vegetation cover. Apparently high rates of erosion under various land uses are not always greater than could be naturally expected.
- The incidence of erosion has been high on soil group L3 up until recent decades, because of its natural erodibility, and removal of vegetation cover by fire or grazing. Erosion has now largely been brought under control by extensive afforestation, but significant patches of active or revegetating sand drift remain.
- The incidence of current erosion, while high on soil group I3 under unimproved drystock pasture, is low to moderate under dairy pasture and improved drystock pasture. It does not preclude use of these soils for pastoral grazing, provided soil conservation techniques are implemented which minimise depletion of ground cover.
- Soil group H3c has low susceptibility to wind erosion of topsoil, but it is also susceptible to landslide and gully erosion in subsoil, and their current incidence is moderate. There is scope for land use change towards forestry or reversion, in order to minimise the erosion risk on this group.

2 Introduction

This contract report presents findings from a survey of erosion on sand 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 sand 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 ownership.

The survey identifies land uses which currently experience erosion on particular soils. Landowners who realise they are practising such a use, may wish to consider implementing soil conservation measures, which can reduce future incidence of soil loss and sediment entry into waterways. The survey findings may also prove helpful for informing purchasers of properties about land uses which may be safely practised, without risking undue erosion on 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 23 December 1999 was to quantify the current state of sand country erosion in selected susceptible west-coast areas of the Auckland region.

Following discussion with other Councils and MfE in March 1999, ARC's preferred indicator for 'soil intactness' in the sand country is area of recent erosion, in relation to vegetation cover and sand instability. 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 west coast sand 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 I3a, I3b, L3 and H3c (sand soils at risk of wind or/and water erosion, as depicted on the map Susceptibility of Auckland Soils to Degradation, Hicks Shepherd and Parfitt 1996). This entailed recording erosion, vegetation and sand instability at 520 points.

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 sand 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.

In response to ARC's interest in obtaining area measurements for individual areas of eroded sand, Technical Appendix Five outlines how it may be done. However it remains more economic to make measurements from the photographs as and when needed for environmental management on individual properties, than to derive a map depicting areas or percentages eroded on all sand country properties region-wide.

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 sand country, soils, land use and erosion.

3.2 Objective 2

To measure the current spatial extent and distribution 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 NZMS 260 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 sand 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 on sand country, together with summary tables and graphs. Its extent under different land uses is analysed in appendix A.

3.3 Objective 3

To measure the current spatial extent and distribution of different vegetation types

Some indication of vegetation types is given by the four land use classes - pasture, tree plantation, scrub, forest - likely to be recorded on sand country. More detailed differentiation of sand country vegetation may be needed, if ARC's purpose includes monitoring its effect on erosion.

To do this, I proposed recording the following vegetation types at each point:

- Grassland - improved pasture, semi-improved pasture, marram
- Plantation - pine, gum, wattle, other
- Scrub - coastal, manuka/kanuka, exotic
- Forest - pohutukawa, broadleaf-podocarp, kauri

These vegetation types are similar to what was recorded for Manawatu-Wanganui Regional Council's sand country state-of-environment survey, though with some adjustment for local Auckland scrub and forest types.

Vegetation types were recorded by adding extra codes to each land use class, for points which fell on sand country. Appendix B summarises extent and structure of sand country vegetation.

3.4 Objective 4

To determine the surface stability (susceptibility to wind and water erosion) of different sand country landforms, and their spatial prevalence/distribution

Some parts of the sand country are much more susceptible to erosion than others. This may need to be controlled for, in any analysis for state-of-environment reporting. To some extent, an indication is given by soil groups:

- L3: unweathered dune formations, with severe risk of wind erosion, and slight risk of water erosion
- I3a: weathered dune formations, with moderate risk of wind and water erosion
- I3b: podsolised dune formations, with slight risk of wind and water erosion (topsoil only)
- H3c: hill phases of I3a and I3b soils, with moderate to severe risk of water erosion and also mass movement erosion.

Within each soil group, erosion susceptibility varies depending on landform. The following landforms were also recorded at each point:

- Dune ridge
- Interdune hollow or flat
- Stream bank or gully
- Waterlaid sand terrace or wetland.

These landforms are similar to those recorded for Manawatu-Wanganui Regional Council's sand country state-of-environment survey, though somewhat adjusted for the Auckland landscape.

Landform codes were added to erosion status codes, for points which fell on sand country. Appendix C discusses the extent and stability of sand country landforms.

4 Definitions of sand 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 sand country:

4.1 Sand country

'Sand country' is defined by geomorphologists in terms of its landforms. It embraces mobile, bare sand dunes together with the bare sand flats between; hummocky dunes and flats stabilised by colonising vegetation; old, rounded dune landscapes with weathered soils; also old formations of windblown sand, geologically uplifted and dissected by streams and landslides, into a landscape of rolling ridges and steep-sided gullies with flat terraced floors. Significant parts of Auckland's region have such landforms:

- the Awhitu Peninsula,
- the South Kaipara Peninsula,
- western extremity of the Tapora Peninsula,
- areas landward of Mangawhai and Pakiri beaches,
- small areas landward of other east coast surf beaches, notably Tawharanui and Omaha.

Sand country can be identified in various ways:

- by field-mapping landforms,
- by stereoscopic viewing of aerial photographs,
- from maps depicting geology or soils.

For this survey, the second and third options were used. Sample points viewed on aerial photos were classified as sand country where DSIR soil maps indicate a soil type found on recently mobile sand, weathered dune landscapes, or old sand formations dissected by streams.

The option proved satisfactory, except for a small number of points where a soil map indicates one of the above, but the aerial photograph clearly shows a different landform - usually a floodplain, stream terrace or estuarine flat. 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 for state-of-environment reports. Sand country soils fall into 4 groups out of the 19.

Arable lowland soils:

I3a Susceptible to severe nutrient loss if intensively farmed

I3b Susceptible to severe nutrient loss, structural breakdown and surface erosion if intensively farmed

I3b is limited in extent (c. 2000 hectares), so it has been amalgamated with I3a.

Non-arable lowland soils:

L3 Susceptible to severe surface erosion on account of sandy texture

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

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

4.3 Land use

After some discussion of land use 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 or sheep)	I
Unimproved drystock pasture (beef cattle or sheep)	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.

To meet ARC's need for more detailed information about sand country vegetation, the following additional codes were used:

g	spinifex or pingao
m	marram
c	coastal scrub e.g. pohuehue, flax
k	kanuka or manuka scrub
s	broadleaved scrub
l	tree lupin
x	other exotic scrub e.g. shrubby acacia
p	coastal forest e.g. pohutukawa
f	inland forest e.g. taraire, rimu, kauri
b	exotic broadleaved woodlots e.g. gum or wattle
e	exotic conifer forest

Some of the additional codes e.g. marram, were widely recorded. Others e.g exotic broadleaved woodlots, were recorded at only a few points. Three - spinifex or pingao; broadleaved scrub; and tree lupin - were not recorded at all. All are differentiable on 1:10,000 colour aerial photographs, so failure to record these three, and the recording of others in small numbers, is believed to indicate their scarcity in the sand country. For the analysis of vegetation types (Appendix B), they were not numerous enough to be statistically separable, so were amalgamated with other codes that have similar vegetation structures.

4.4 Erosion

A point was recorded as freshly eroded, if the photo showed bare ground at or close to the point.

A point was recorded as recently eroded, if bare ground was visible at or near the point, but was already re-vegetating.

In sand country, 'sandblows', 'drifts' or 'dunes' are commonly-used terms for landforms where sand is being eroded from windward and deposited leeward by wind. The code 't' has been used elsewhere in the region to denote bare soil exposed where vegetation cover has been depleted by cultivation, over-grazing or plant die-back. In sand country, it denotes either:

- soil at risk of wind erosion, where vegetation is sparse but recovering,
- soil being eroded and deposited by wind, where vegetation is breached.

The 's' code, where used in sand country, denotes:

- sand deposited by water flowing across valley-bottom floodways or low terraces.

Other forms of erosion or deposition have also been recorded in the sand country, notably :

b bank erosion by streams flowing through low terraces,

l landslides on the flanks of gullies incised in weathered sand deposits,

d sand excavated or deposited by land contouring.

For comments on interpreting these types of erosion from aerial photographs, see Technical Appendix Two. It also includes discussion about the contentious - and important - 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.

To meet ARC's interest in surface stability of different sand country landforms, six additional landform codes were recorded:

d parabolic dune ridges and hollows

f linear fore-dunes and transverse dunes

g valley sides excavated through d or f terrain

t' elevated, slightly dissected terraces in valleys or alongside estuaries

t terraces at stream level in valleys or alongside estuaries

s sand-flats (water-laid sand in depressions on f terrain)

All categories were widespread, so proved useable for the analysis of surface stability in Appendix B.

5 Presentation of survey results

5.1 Analysis of sample

The sand country sample contains 520 points. Codes stored in the spreadsheet enable each category to be further subdivided according to soil group or type; land use or vegetation structure; and erosion status or form.

The purpose of this contract is simply to ascertain erosion's current extent under different land uses on sand 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).

More detailed analyses of vegetation's extent and structure, landforms' extent and stability, and erosion's extent under different land uses on each soil group, have also been prepared. They are contained in Appendices A to C.

5.2 Representativeness

Representativeness of data, for sand country throughout the region, has been ascertained by applying three statistical tests (see Technical Appendix One). As the sand country sample 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 sand country %	95% confidence limits +-%
Orchards and vineyards	1.0	0.8
Outdoor vegetable production	0.6	0.7
Grain and fodder crops	0.4	0.5
Dairy pasture	11.9	2.8
Improved drystock pasture	31.3	4.0
Unimproved drystock pasture	7.3	2.2
Exotic forest	28.5	3.9
Natural forest	0.6	0.7
Exotic scrub	0.8	0.8
Natural scrub	8.3	2.4

Wetland vegetation	2.5	1.3
Coastal sand-binding grasses	4.4	1.8
Sand drifts	2.5	1.3

In short, there is 95% confidence that the sample percentage of land in each use is within +- 4.0% or better of the true region-wide figure for sand 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, the test based on standard error of a mean has been used to calculate confidence limits. Margins of error are high for erosion data under land uses uncommon in sand country e.g. orchards and vineyards. They are generally better than +- 4.0% for land uses that are widespread.

5.3 Fresh erosion

Table 1.

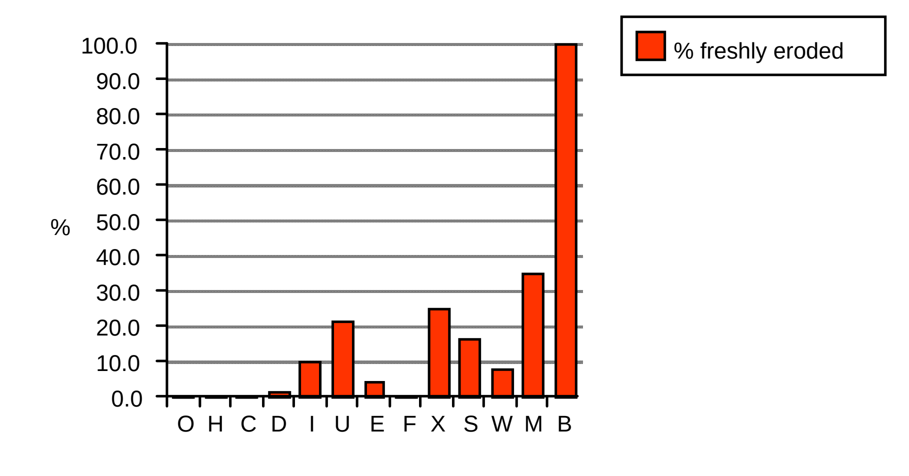
Fresh erosion under different land uses

Code	Land use	Points n	Bare %	Precision +-%	Error +-%
O	Orchards and vineyards	5	20	20	*
H	Outdoor vegetable production	3	0	33.3	*
C	Grain and fodder crops	2	0	50	*
D	Dairy pasture	62	1.6	1.6	0.3
I	Drystock pasture (improved)	163	9.8	0.6	1.3
U	Drystock pasture (unimproved)	38	21.1	2.6	2.3
E	Exotic forest	148	4.1	0.7	0.3
F	Natural forest	3	0	33.3	*
X	Exotic scrub	4	25	25	*
S	Natural scrub	43	16.3	2.3	3.1
W	Wetland	13	7.7	7.7	5.1
M	Coastal sand-binding grasses	23	34.8	4.3	6.7
B	Sand drifts	13	100	7.7	0

Representativeness of percentages depends on sub-sample size. For cropland, market gardens and orchards, precision is low and sample error is not calculable. For most pasture classes, also the natural scrub and exotic forest classes, precision and sample errors are good. Exotic scrub and natural forest are recorded at so few points, that precision is low and sample error not calculable for these land uses. Precision and sample error are moderate for coastal sand-binding grasses and wetlands. For sand drifts, precision of the percentage is moderate due to sample size, but sample error remains small because there is no variation; all points are eroded.

Figure 1.

Fresh erosion under different sand country land uses



Little of the sand country is intensively cultivated, as cropland, market garden or orchard. Bare ground has only been recorded under orchards, at two points where soil appears to have been cultivated in between the tree rows. Here it cannot be equated with fresh erosion, rather with exposure of soil to erosion risk (see Appendix B) so does not appear in Figure 1.

Under other uses, the percentage of sample points with bare soil can be regarded as reliable measurements of fresh erosion, generally by wind-blow; also by sheetwash, gullies or landslides on some sand country landforms (see Appendix C).

Where sand country is grazed, fresh erosion increases from 1.6% of sample points in dairy pasture, through 9.8% in improved pasture grazed by beef cattle or sheep, to unimproved drystock pasture at 21%.

Under exotic forest plantations, the percentage of sample points with fresh erosion at 4% is intermediate between the figures for dairy and improved drystock pasture.

Few points were recorded in natural forest. Precision is too low and sample error too high, for the 0% freshly eroded to be regarded as a reliable estimate.

Likewise for exotic scrub, precision is too low and sample error too high, for the 25% freshly eroded to be reliable.

Under natural scrub, the percentage of sample points with fresh erosion at 16% is surprisingly high. Most of the erosion is wind-blow where scrub has been depleted by grazing or attempts at clearance; with a lesser proportion of landslides on the sides of gullies or amongst coastal scrub on cliffs.

Fresh sedimentation was recorded at 1 out of the 13 points (8%) which fell in wetlands. Fresh erosion or deposition by wind-blow was present at 8 out of 23 points (35%) on coastal sand-binding grasses; at all 12 points (100%) where sand dunes were so extensive that no land use could be recorded; and at just 1 point where ground was bared by earthworks.

5.4 Recent erosion

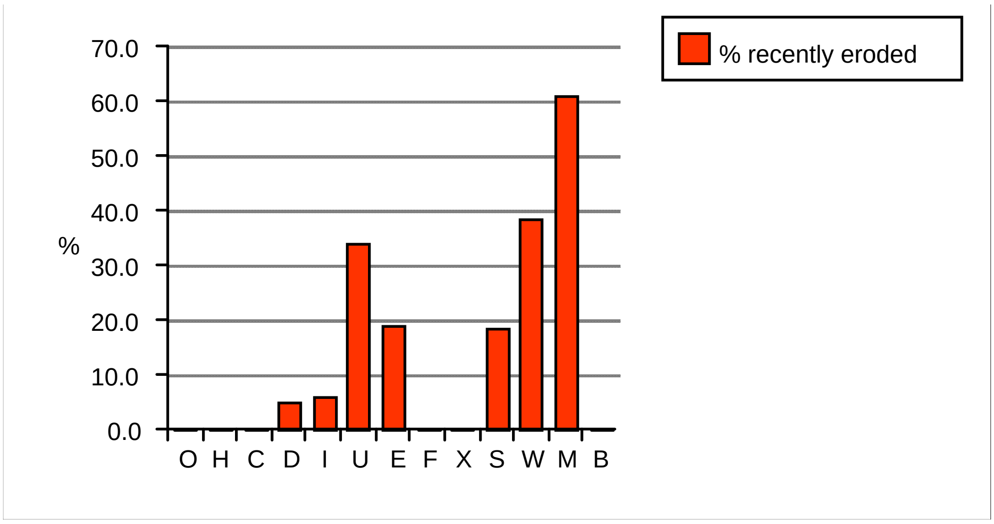
Table 2.

Recent erosion under different land uses

Code	Land use	Points n	Reveg. %	Precision +-%	Error +-%
O	Orchards and vineyards	5	20.0	20.0	*
H	Outdoor vegetable production	3	33.0	33.3	*
C	Grain and fodder crops	2	50.0	50.0	*
D	Dairy pasture	62	4.8	1.6	2.1
I	Drystock pasture (improved)	163	6.1	0.6	0.8
U	Drystock pasture (unimproved)	38	34.2	2.6	1.3
E	Exotic forest	148	18.9	0.7	3.5
F	Natural forest	3	0.0	33.3	*
X	Exotic scrub	4	0.0	25.0	*
S	Natural scrub	43	18.6	2.3	3.4
W	Wetland	13	38.5	7.7	13.6
M	Coastal sand-binding grasses	23	60.9	4.3	11.7
B	Sand drifts	13	100.0	7.7	0.0

Again, representativeness of percentages depends on sub-sample size. For cropland, market gardens and orchards, precision is low and sample error is not calculable. For most pasture classes, also the natural scrub and exotic forest classes, precision and sample errors are good. Exotic scrub and natural forest are recorded at so few points, that precision is low and sample error not calculable for these land uses. Precision and sample errors are moderate for coastal sand-binding grasses. For wetlands, sample error becomes high, because of variations in sedimentation amongst a small number of points. In the case of sand drifts, sample error remains moderate despite the small number of points, because there is no variation; none are revegetating.

Figure 2.
Recent erosion under different sand country land uses



Sample results show very high percentages of revegetating ground at the few points where sand country is intensively cultivated. However they cannot be equated with recent erosion, merely with recent exposure of soil to erosion risk (see Appendix B); so do not appear in Figure 2.

Under other uses, the percentage of sample points with revegetating ground can be regarded as reliable measurements of soil or sand that has been recently eroded by wind-blow; also by sheetwash, gullies or landslides on some sand country landforms (see Appendix C).

Increasing percentages of sample points are recently eroded, with the transition from dairy pasture (4.8%) through improved (6.1%) to unimproved drystock pasture (34%).

A fairly high percentage of sample points, 19%, is recently eroded under exotic forest plantations. Much of this is accounted for by re-vegetating canopy gaps where plantings have failed close to the coast. Some points also show disturbance of soil where mature pines have been harvested.

No significance can be attached to the absence of recent erosion from natural forest, in view of small sub-sample size, and its effects on precision and sample error.

Absence of recent erosion from exotic scrub cannot be viewed as significant, for the same reasons.

The percentage of sample points recently eroded under natural scrub is also 19%. This is mainly recovery from wind erosion after grazing or attempts at clearance; with a proportion accounted for by revegetating landslide scars on coastal cliffs or inland gullies.

The only differences in trend compared with fresh erosion are:

- Recent sedimentation on a high percentage of wetland soil (5 out of 13 points, 38%),
- Very high recent erosion or deposition of sand by wind-blow, in amongst coastal sand-binding grasses (14 points out of 23, 61%),
- No recent erosion recorded on bare sand dunes or re-contoured ground, because all 13 points (100%) are freshly eroded.

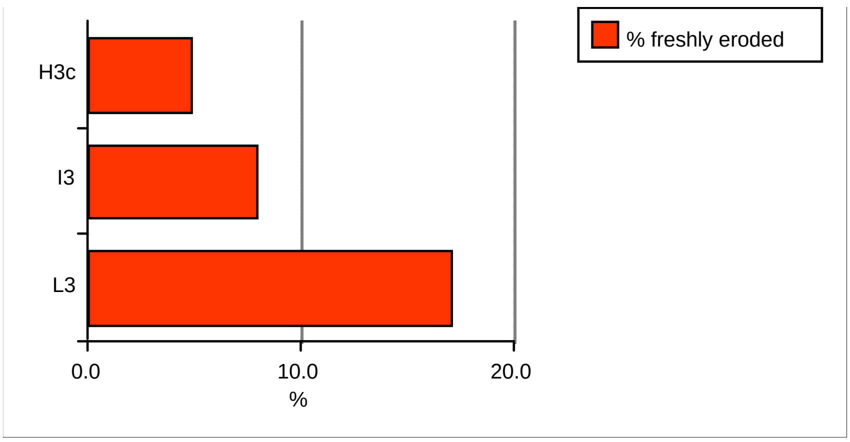
5.5 Fresh erosion by soil group

Table 3.

Fresh erosion on different soil groups

	Points n	Bare ground %	Precision +-%	Sample error +-%
L3	259	17	0.4	3.6
I3	178	7.9	0.6	4.1
H3c	83	4.8	1.2	1

Figure 3.
Fresh erosion on sand country soil groups



Sample points with freshly eroded soil decline moving from soil group L3 to I3 to H3c (Figure 3). This is to be expected in view of differences in soil properties amongst the groups:

L3 Un-weathered or slightly weathered sand, with minimal topsoil formation and low organic matter,

I3 Weathered sand; well-developed topsoil with a significant silt component and some organic matter present,

H3c Weathered sand; subsoil generally has a clay fraction; underlying regolith is consolidated (indurated).

Points to note, which may also affect the figures, are:

- The figure for L3 would be very much higher, but for afforestation since the 1930s. Most of L3 is now under this 'low-erosion' use (see Appendix A). Residual erosion is concentrated on un-afforested ground i.e. bare sand drifts or coastal sand-binding grasses or unimproved pasture.
- The H3c soils, being clayey, have greater resistance to surface erosion by wind. However, their situation on the flanks of gullies, excavated by streams through the old consolidated sand deposits, renders them susceptible to sub-surface erosion by gullies and landslides.

Precision of all percentages is good. Sample error is moderate for groups L3 and I3, and low for H3c (a consequence of small variance within the sub-sample).

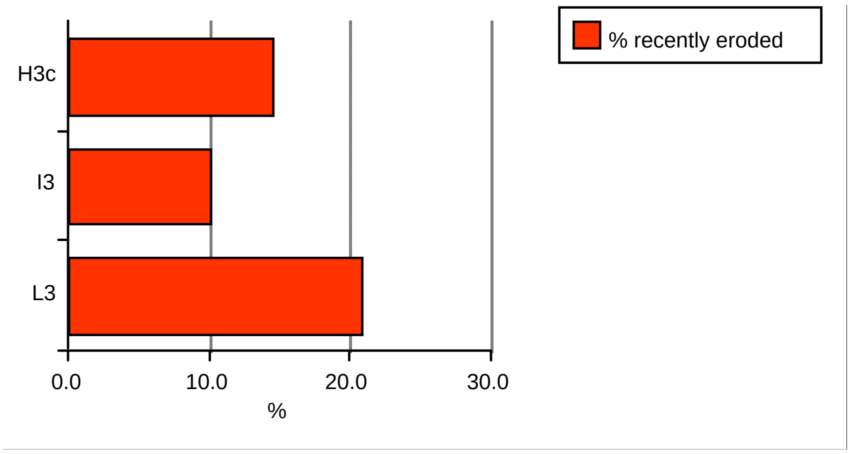
5.6 Recent erosion by soil group

Table 4.

Recent erosion on different soil groups

	Points n	Reveg. %	Precision +-%	Sample error +-%
L3	259	20.8	0.4	2.7
I3	178	10.1	0.6	2.6
H3c	83	14.5	1.2	4.6

Figure 4.
Recent erosion on sand country soil groups



Sample points with recent erosion decline moving from L3 to I3 but increases on H3c (Figure 4). A decline from L3 to I3 is to be expected in view of soil properties:

L3 Un-weathered or slightly weathered sand, with minimal topsoil formation and low organic matter,

I3 Weathered sand; well-developed topsoil with a significant silt component and some organic matter present,

but the increase from I3 to H3c is not:

H3c Weathered sand; subsoil generally has a clay fraction; underlying regolith is consolidated (indurated).

Points to note, which may explain these trends, are:

- Most L3 soils have undergone a transition from 'high-erosion' uses e.g. bare sand, coastal sand-binding grasses or extensively-grazed drystock pasture, to a 'low-erosion' use i.e. exotic forestry (see Appendix A). Recent erosion is concentrated on ground which remains in 'high-erosion' uses, though it is also present at a percentage of points in harvested pine forest.

- I3 soils have not undergone a similar transition, as they are better able to support 'high-erosion' uses such as pastoral grazing. The incidence of recent erosion on I3 soils, while moderate, need not cause undue concern as it is comparable with equivalent figures for pasture on soil groups elsewhere in the region.

- High incidence of recent erosion on H3c soils is accounted for by revegetating landslide scars on gully sides. These are mainly on gully sides in pasture, though some have also been recorded in scrub, bush and exotic woodlots.

Precision of percentages is good. Sample error is moderate for L3 and I3, but poor for H3c (a consequence of large variance within the sub-sample).

6 Conclusions

6.1 Erosion under different land uses

Fresh erosion is least under wetland vegetation; here none has been recorded, and sedimentation at just one point.

Under scrub and tree covers, fresh erosion ranges from 16.3% of sample points in natural scrub to 4.1% in exotic forest. Wind-blow of sand, associated with vegetation clearance or animal browsing, accounts for most of the erosion in scrub; though landslides on dissected terrain (H3c soils) are also a component. In exotic forest, the erosion is attributable to wind-blow in canopy gaps where plantings have failed close to the coast.

On grazed sand country, fresh erosion is least under dairy pasture at 1.6% of sample points, higher in improved pasture grazed by beef cattle or sheep at 9.8%, and higher again in unimproved drystock pasture at 21.1%. Almost all the erosion on grazed sand country is topsoil loss to wind, where pasture is depleted; a small fraction is due to landslides or gullies on H3c soils.

Fresh erosion and deposition of sand is greatest on bare sand drifts, where 100% of sample points are affected.

In the few places where sand country is intensively cultivated i.e. cropland, outdoor vegetable production or orchard, up to 20% of sample points are exposed to risk of topsoil erosion by windblow or sheetwash. Actual incidence is likely to be less, due to crop growth before wind or rain strikes.

Moderate to high areas of soil are currently revegetating after erosion in recent years (1990-1997). 38% of wetland sample points are revegetating after sedimentation. 19% of points under natural scrub and exotic forest are revegetating after wind erosion or after soil disturbance during harvest. For pasture, the percentages range from 5% to 34% of points; and are associated with vegetation recovery after heavy grazing, or pasture depletion by summer drought. There is little evidence of revegetation on bare sand drifts. At the few places where sand country is intensively cultivated, between 20 and 50% of sample points are revegetating after exposure to risk of topsoil erosion.

6.2 Erosion on different soils

On the most erodible group of sand soils, L3, fresh erosion by wind is still high, at 17% of sample points. It occurs amongst:

- active sand dunes,
- coastal sand-binding grasses,

- natural scrub,
- drystock pasture,

but over most of L3, under closed-canopy pine plantation, it is slight.

On the I3 group (intermediate erodibility), fresh erosion by wind is moderate, at 7.9% of sample points. It occurs on:

- cultivated ground, where present (limited area),
- drystock pasture, mainly where unimproved,

but over much of I3, under improved drystock pasture or dairy pasture, wind erosion is slight.

Fresh erosion is least on the H3c soil group, which has low susceptibility to wind erosion of topsoil. Erosion here at 4.8% of sample points is due to:

- landslides and gullies, in unimproved pasture or natural scrub,
- sheet erosion, in unimproved pasture,

on steep sides of valleys excavated through the weathered sand deposits.

Recent erosion by wind is present at 20.8% of sample points on L3 soils, but falls to 10.1% on I3 (more weathered). Recent erosion by wind is minimal on H3c soils, but here 14.5% of sample points are recently eroded by landslides on gully sides (excavated by streams through consolidated regolith underlying these older soils).

6.3 Soil groups where erosion is unusually high or low

There are just two soil groups where Appendix C indicates erosion is statistically less than expected under certain land uses. These are:

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

L3	-	-	Exotic forest	-	-
I3	Dairy pasture	-	-	-	-
H3c	-	-	-	-	-

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

L3	Dairy	Drystock	-	Natural scrub	Wetland
I3	-	Drystock	Exotic forest	Natural scrub	Wetland
H3c	Dairy	Drystock	Exotic forest	Natural scrub	Wetland

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

L3	Coastal sand-binding grasses	Bare sand drifts	-
I3	-	-	Drystock
H3c	-	-	-

6.4 Closing remarks

The survey's findings convey four messages:

- Erosion is a natural phenomenon in Auckland's sand country, even under natural vegetation cover. Apparently high rates of erosion under various land uses are not always greater than could be naturally expected.
- The incidence of erosion has been high on soil group L3 up until recent decades, because of its natural erodibility, and removal of vegetation cover by fire or grazing. Erosion has now largely been brought under control by extensive afforestation, but significant patches of active or revegetating sand drift remain.
- The incidence of current erosion, while high on soil group I3 under unimproved drystock pasture, is low to moderate under dairy pasture and improved drystock pasture. It does not preclude use of these soils for pastoral grazing, provided soil conservation techniques are implemented which minimise depletion of ground cover.
- Soil group H3c has low susceptibility to wind erosion of topsoil, but it is also susceptible to landslide and gully erosion in subsoil, and their current incidence is moderate. There is scope for land use change towards forestry or reversion, in order to minimise the erosion risk on this group.

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

Hicks, D., Shepherd, G. and Parfitt, R. 1996 Susceptibility of Auckland soils to degradation. Unpub. Contract Report to Auckland Regional Council.

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.

9 Appendix A – Erosion's extent under different land uses on each soil group

9.1 Fresh erosion under different land uses, by 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 (Table 1).

Table 1.

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

	L3 %	I3 %	H3c %
Orchards and vineyards	*	20	*
Outdoor vegetable production	*	0	*
Grain and fodder crops	*	0	*
Dairy pasture	0	2	0
Drystock pasture (improved)	23	9	2
Drystock pasture (unimproved)	28	20	10
Exotic forest	4	0	0
Natural forest	0	*	0
Exotic scrub	50	0	0
Natural scrub	25	0	12
Wetland	0	20	0
Coastal sand-binding grasses	35	0	0
Sand drifts	100	100	0

* *denotes land use not found on soil group*

Reliable comparisons can be made amongst some but not all percentages; many sub-samples are small because the land use in question e.g. outdoor vegetable production is simply not a feature of the sand country landscape. Table 1 is presented here for completeness, and will not be further analysed.

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

9.2 Recent erosion under different land uses, by soil group

The same comments apply to table 2, as for Table 1.

Table 2.

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

	L3 %	I3 %	H3c %
Orchards and vineyards	*	20	*
Outdoor vegetable production	*	33	*
Grain and fodder crops	*	50	*
Dairy pasture	18	0	17
Drystock pasture (improved)	0	5	12
Drystock pasture (unimproved)	33	40	30
Exotic forest	18	25	67
Natural forest	0	*	0
Exotic scrub	0	0	0
Natural scrub	25	33	6
Wetland	60	40	0
Coastal sand-binding grasses	61	*	*
Sand drifts	0	0	0

* *denotes land use not found on soil group*

Again, see section 9.3 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 c).

For instance in Table 3a, 0.02 of the soil disturbance on L3 occurs under dairy pasture and 0.04 of L3's area is under dairy pasture. It is 0.48 times what one would expect (after removal of rounding to two decimal places), if soil disturbance were unaffected by land use. This ratio is correct for the points sampled. However if the number of points under dairy pasture is small, or if the number of points on L3 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 +0.99 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 less where L3 soil is used for dairy farming. The low ratio may simply be an artefact of small sub-sample size.

The ratios and tests in Tables 3a to c highlight a few situations where cumulative 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:

L3	Exotic forest	Less soil disturbance than expected
	Coastal sand-binding grasses	Greater soil disturbance than expected
	Bare sand drifts	Greater soil disturbance than expected
I3	Dairy pasture	Less soil disturbance than expected
	Unimproved drystock pasture	Greater soil disturbance than expected
H3c	No significant differences	

Table 3a Proportion of soil group L3 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	0.04	0.02	0.48	0.99	
Drystock pasture (improved)	0.12	0.07	0.62	1.23	
Drystock pasture (unimproved)	0.07	0.11	1.62	-1.32	
Exotic forest	0.53	0.31	0.58	3.77	Significant difference
Natural forest	0.00	0.00	0.00	0.62	
Exotic scrub	0.01	0.01	1.32	-0.23	
Natural scrub	0.08	0.10	1.32	-0.75	
Wetland	0.02	0.03	1.59	-0.64	
Coastal sand-binding grasses	0.09	0.22	2.53	-3.45	Significant difference
Sand drifts	0.05	0.12	2.64	-2.56	Significant difference

Table 3b Proportion of soil group I3 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	0.01	0.03	2.78	-0.88	
Outdoor vegetable production	0.02	0.03	1.85	-0.55	
Orchards and vineyards	0.03	0.06	2.23	-1.00	
Dairy pasture	0.25	0.03	0.12	2.79	Significant difference
Drystock pasture (improved)	0.52	0.41	0.79	1.15	
Drystock pasture (unimproved)	0.06	0.19	3.34	-2.58	Significant difference
Exotic forest	0.04	0.06	1.39	-0.43	
Natural forest	0.00	0.00			
Exotic scrub	0.01	0.00	0.00	0.43	
Natural scrub	0.03	0.06	1.85	-0.78	
Wetland	0.03	0.09	3.34	-1.79	
Coastal sand-binding grasses	0.00	0.00			
Sand drifts	0.01	0.03	5.56	-1.37	

Table 3c Proportion of soil group H3c eroded under each use, as a ratio of proportion of group in each land 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	0.07	0.06	0.86	0.14	
Drystock pasture (improved)	0.49	0.38	0.76	0.87	
Drystock pasture (unimproved)	0.12	0.25	2.08	-1.36	
Exotic forest	0.04	0.13	3.46	-1.49	
Natural forest	0.02	0.00	0.00	0.63	
Exotic scrub	0.01	0.00	0.00	0.44	
Natural scrub	0.20	0.19	0.92	0.16	
Wetland	0.04	0.00	0.00	0.77	
Coastal sand-binding grasses	0.00	0.00			
Sand drifts	0.00	0.00			

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

Tables 4a to f 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,
- Coastal sand-binding grasses, compared with natural vegetation cover,
- Sand drifts, compared with natural vegetation cover.

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

Soil disturbance is:

- Significantly greater under natural cover compared with other vegetation, on soil group I3. While somewhat greater on soil group L3, the difference is not statistically significant.

- Significantly less under pasture compared with natural cover, on soil group I3. Likewise while less on soil group L3, the difference is not statistically significant.
- Significantly less under exotic forest compared with natural cover, on soil groups L3 and H3c; also less but not significantly so, on I3.
- Not significantly different on cultivated land compared with natural cover, on soil group I3 (the only one cultivated).
- Significantly greater compared with natural cover, where sand drifts are disturbed by windblow or re-contouring, on soil group L3 (the only one with sand drifts).

These differences are undoubtedly surprising, as they contradict the conventional wisdom that natural vegetation cover "prevents" soil erosion. Natural vegetation on sand country in the Auckland region is mainly scrub, with small areas of wetland, and very little indigenous forest. There are two possible explanations for the high amounts of soil disturbance recorded

- Canopy disruption by sand drift is a natural phenomenon in scrub on sand country soils,
- Scrub on sand country soils has been extensively disrupted by cutting, fire and animal browsing.

Both explanations are likely to be correct.

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

Soil group	Proportion N eroded	Proportion other eroded	Ratio	Z statistic	Significance @ 95% conf.
L3	0.50	0.36	1.38	1.41	
I3	0.42	0.16	2.56	2.21	Significant difference
H3c	0.13	0.21	0.61	-0.86	

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

Soil group	Proportion P eroded	Proportion N eroded	Ratio	Z statistic	Significance @ 95% conf.
L3	0.34	0.50	0.68	-1.44	
I3	0.14	0.42	0.33	-2.57	Significant difference
H3c	0.19	0.13	1.48	0.67	

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

Soil group	Proportion E eroded	Proportion N eroded	Ratio	Z statistic	Significance @ 95% conf.
L3	0.22	0.50	0.44	-3.06	Significant difference
I3	0.25	0.42	0.60	-0.77	
H3c	0.67	0.13	5.11	2.22	Significant difference

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

Soil group	Proportion C eroded	Proportion N eroded	Ratio	Z statistic	Significance @ 95% conf.
L3	*	0.50			
I3	0.40	0.42	0.96	-0.08	
H3c	*	0.13			
* : Denotes land use not found on soil group					

Table 4e Difference in proportion eroded - coastal sand-binding grasses compared with natural vegetation cover

Soil group	Proportion M eroded	Proportion N eroded	Ratio	Z statistic	Significance @ 95% conf.
L3	0.96	0.50	1.91	3.56	Significant difference
I3	*	0.42			
H3c	*	0.13			
* : Denotes land use not found on soil group					

Table 4f Difference in proportion eroded - bare sand drifts compared with natural vegetation cover

Soil group	Proportion B eroded	Proportion N eroded	Ratio	Z statistic	Significance @ 95% conf.
L3	1.00	0.50	2.00	3.04	Significant difference
I3	1.00	0.42	2.40	1.12	
H3c	*	0.13			
* : Denotes land use not found on soil group					

10 Appendix B – Extent and structure of vegetation in sand country

To meet ARC's need for more detailed information about sand country vegetation, the following additional codes were used:

g	spinifex or pingao
m	marram
c	coastal scrub e.g. pohuehue, flax
k	kanuka or manuka scrub
s	broadleaved scrub
l	tree lupin
x	other exotic scrub e.g. shrubby acacia
p	coastal forest e.g. pohutukawa
f	inland forest e.g. taraire, rimu, kauri
b	exotic broadleaved woodlots e.g. gum or wattle
e	exotic conifer forest

Some of the additional codes e.g. marram, were widely recorded. Others e.g. exotic broadleaved woodlots, were recorded at only a few points. Three - spinifex or pingao; broadleaved scrub; and tree lupin - were not recorded at all. All are differentiable on 1:10,000 colour aerial photographs, so failure to record these three, and the recording of others in small numbers, is believed to indicate their scarcity in the sand country. For the analysis of vegetation types (Appendix B), they were not numerous enough to be statistically separable, so were amalgamated with other codes that have similar vegetation structures.

Natural vegetation occupies 11% of the sand country (Table 1). 7.7% is closed-canopy, apparently undisturbed and with foliage in good condition. If weed invasion or possum browsing occur in these stands, then it is at levels which do not defoliate plants or open gaps in the canopy. A further 3.7% has canopy gaps due to recent or current disturbance e.g. partial clearance, fire, weed invasion or browsing by stock.

Table 1.

Natural vegetation types

Intact :	
Closed canopy forest	0.4% by area
Closed canopy scrub	5.7%
Mixed forest & scrub	0.6%
Wetland	1.0%
	7.7% total +-2.3% (95% confidence limit)
Disturbed :	
Scrub with canopy gaps	2.2% (gaps are occupied by pasture, pines, exotic shrubs)
Wetland with gaps	1.5% (gaps are occupied by pasture or exotic shrubs)
	3.7% total +-1.6% (95% confidence limit)

There are few places on the South Kaipara Head, Awhitu Peninsula or Mangawhai-Pakiri dunes where natural vegetation was recorded at two or more adjacent points. This confirms that natural plant communities are nowhere extensive; they are distributed throughout all three tracts of sand country as small pockets less than 100 hectares in area - generally much less - interspersed with exotic plant cover.

In keeping with this trend, remnant natural vegetation interspersed with other plant communities, was frequently recorded (Table 2). A further 13% of the sand country has some degree of natural cover. Scrub still predominates, though forest trees are also widespread.

Table 2.

Remnant natural vegetation

Natural forest trees, clumped or scattered :	
In dairy pasture	0.4% by area
In improved drystock pasture	3.3%
In unimproved drystock pasture	0.4%
In exotic forest plantations	0.0%
In exotic scrub	0.0%
In coastal grasses (marram)	0.0%
	4.1% total +-1.7% (95% confidence limit)
Natural scrub, clumped or scattered :	
In dairy pasture	0.6%
In improved drystock pasture	6.3%
In unimproved pasture	1.5%
In exotic forest plantations	0.8%
In exotic scrub	0.0%
In coastal grasses (marram)	0.0%
	9.2% total +-2.5% (95% confidence limit)

Exactly what type of forest, scrub or wetland vegetation remains appears to be partly controlled by site conditions, and partly by past clearance. Pohutukawa forest remains close to the coast at Awhitu, the southern end of South Kaipara Head near Muriwai, and the southern end of Pakiri; except for a few dense groves near Muriwai, it survives as clumps or scattered trees interspersed with pasture. Broadleaf-podocarp forest remains common at sheltered locations on the Awhitu sand country, both as small dense stands, and as scattered trees in pasture. Occasional kauri in some stands indicate that it may have been a larger component of forest cover prior to land clearance; there were no points where kauri were sufficiently dominant to class the forest as kauri, rather than mixed. Broadleaf-podocarp and kauri forest - whether intact stands or scattered trees - appear absent from the South Kaipara Head. Scattered podocarps in pasture were recorded at a handful of points on drained inter-dune swamps at Mangawhai and Omaha.

Coastal scrub was recorded at points which fell on cliffs at Awhitu and the south end of Muriwai. Its exact composition could not be ascertained from the aerial photos, but is known from previous site visits to be dominated by pohuehue and flax. Elsewhere on the dune terrain of Awhitu and the South Kaipara, scrub was either manuka or kanuka. Again, which could not be determined from the photos, but previous site visits indicate manuka dominates sites which are either windswept or swampy or have leached soils (Horea or Tangitiki); while kanuka dominates the more fertile Red Hill soils, and also sheltered dry sites on the Pinaki. Broadleaved scrub was recorded at just a few points, on the sides of valleys excavated by streams through the dune terrain. Such sites are typically sheltered and moist, with soils that are hill phases of the Red Hill, Horea or Tangitiki.

The most extensive exotic plant community is open grassland, without shrub or tree cover (Table 3). A surprising feature is the high percentage of good pasture (dairy or improved drystock). Out of 31% in pasture, only 3.4% could be classed as unimproved. Lush, fertilised pasture, with a low percentage of weeds, was clearly discernible on the aerial photographs cf. pasture that was rank, un-fertilised, and/or weed-infested. Its species composition could not be ascertained, but is known from site visits to be dominated by kikuyu, with cocksfoot, ryegrass, lotus and clover as sub-dominant species.

Table 3.

Grassland

Dairy pasture	10.0% by area
Improved drystock pasture	17.9%
Unimproved pasture	3.4%
	31.3% total +-4.0% (95% confidence limit)

Grassland with exotic trees or shrubs is not particularly widespread (Table 4) i.e. farm shelter is not a common feature in pasture on the sand country. The exotic trees are about evenly split between shelter belts (pine, cypress, gum, willow) in proximity to sample points, and wildling pines. The main exotic shrub in pasture appears to be boxthorn, though gorse was also recorded at a few points.

Table 4.

Grassland with exotic trees or shrubs

Exotic trees clumped or scattered in:	
Dairy pasture	1.0% by area
Improved drystock pasture	3.8%
Unimproved pasture	0.2%
	5.0% total +-1.9% (95% confidence limit)
Exotic shrubs clumped or scattered in:	
Dairy pasture	0.0%
Improved drystock pasture	0.0%
Unimproved pasture	1.1%
	1.1% total +-0.9% (95% confidence limit)

These are additional to areas in open grassland (Table 3), as are the grassland-natural tree and shrub mixes (Table 2). When all three are added, the total area in grassland is 50% of the sand country, of which 12% is dairy pasture, 31% improved drystock pasture, and 7% unimproved pasture.

Pasture, together with pasture-tree or pasture-shrub mixes, occupies extensive tracts of land from the centre of the Awhitu Peninsula to its western coastline; and from the centre of the South Kaipara Head to its eastern (harbour) coastline. At Awhitu, much of the unstable Pinaki sand soil close to the coast remains in pasture cf. South Kaipara where just the landward margin of the Pinaki dunes hasn't been afforested. Most of the pasture at South Kaipara is on Red Hill soils, with a proportion on older Houhora and Tangitiki soils to the east. In the Mangawhai-Pakiri dunefield, there is very little pasture, except on the landward margin of the Whananaki and Marsden soils.

Exotic vegetation types formerly planted for sand stabilisation - principally lupin and marram - are now a surprisingly rare component of the landscape (Table 5). Points recorded as 'coastal grass' are dominated by marram, clearly visible on the aerial photographs. Sub-dominant species (identified during site visits but not discernible on the photos) are exotic grasses, wiwi rush, pohuehue, and occasional stunted tree lupins.

Table 5.

Exotic sand stabilisation plantings

Coastal grass (dense marram)	1.7% by area	
Coastal grass (broken marram)	2.7%	(bare sand in gaps)
Coastal grass (scattered marram)	2.1%	(present in pasture, pines or scrub)
	6.5% total	+-2.1% (95% confidence limit)
Dense exotic scrub	0.2%	
Broken exotic scrub	0.6%	(pasture, pines or scrub in gaps)
Scattered exotic scrub	1.3%	(present in pasture, pines, or scrub)
	2.1% total	+-1.2% (95% confidence limit)

Marram is now restricted either to coastal foredunes where pine-planting has not been attempted (South Kaipara Head and Pakiri)) or canopy gaps in pines where it has been planted to stabilise windblows (South Kaipara Head and Mangawhai), or similar windblows in pasture (South Kaipara Head and Awhitu).

Dense or broken exotic scrub is mainly brush wattle, though shrubby acacia and gorse may be present at one or two points. These stands are where sand country abuts the Kaipara estuaries. Of the scattered exotic scrub, most is boxthorn in pasture on Pinaki soils of the Awhitu Peninsula; with the balance on Pinaki soils towards the base of the South Kaipara Head (between Woodhill and Waimauku). None appeared to be tree lupin, which has virtually disappeared from pasture in the sand country, though it persists as scattered, stunted plants in un-grazed areas.

No points were recorded as being under the natural sand-binding grasses, spinifex, sand tussock or pingao. They are known to be locally present on foredunes behind the estuarine beaches at Awhitu and South Kaipara Head, also on foredunes behind the east coast beaches at Pakiri, Te Arai and Mangawhai; but nowhere dense enough to form recognisable ground cover.

Exotic tree plantations occupy 28% of the sand country (Table 6). They are almost entirely pine, though a handful of points fell on farm woodlots containing other species (cypress, gum, wattle); too small a number to differentiate.

Table 6.

Exotic forest

Young pines	6.9% by area	(not yet closed-canopy)
Maturing pines	2.5%	(canopy gaps occupied by pasture, scrub or marram)
Maturing pines	15.9%	(closed-canopy)
Harvested pines	3.1%	(not yet re-planted)
	28.4% total	+-3.9% (95% confidence limit)

The pine plantations are mainly in Woodhill Forest on unstable Pinaki soil, and Mangawhai Forest on unstable Marsden soil. Maioro Forest at the Awhitu Peninsula's base, while on sand country, is outside the Auckland region. A proportion of points are accounted for by private woodlots on farmland; these are scattered throughout the Awhitu and South Kaipara; also on small parts of the Mangawhai-Te Arai- Pakiri dunefield within farmland west of the forest boundary. Most of the private woodlots are on weathered, stable Red Hill soil, though some are on landward margins of the Pinaki or Marsden dune terrain.

Small patches of the sand country landscape are under intensive use:

Table 7.

Vegetation types associated with intensive agriculture

Grain or fodder crops	0.6%	(includes pasture renewal)
Market gardens	0.6%	
Orchards	1.0%	
	2.2% total	+-1.3% (95% confidence limit)

These are currently insignificant vegetation covers on the sand country, but their successful establishment on the best sand country soil - Red Hill loam - indicates that they could become more widespread.

A final component of the sand country landscape is areas devoid of vegetation:

Table 8.

Devegetated land

Sand blows	2.1% by area	
Disturbed ground	0.2%	(earthworks, tracks, quarries)
	2.3% total	+-1.3% (95% confidence limit)

That such a small percentage remains devegetated compared with the extensive sand drifts which characterised this landscape up till the 1940s, illustrates the extent and success of efforts by the people who reclaimed them with marram and lupin, subsequently establishing pasture and pine plantations.

Summary

Auckland's sand country is covered by a patchwork of vegetation; more diverse than the popular perception that it's one or other of three extremes: treeless pasture, monotonous pine plantation, or windblown sand.

The reality is that pasture, while occupying over half the sand country, contains much remnant natural scrub and forest cover. Most of the stands are open or scattered; clearly grazed by stock, so likely to be in poor condition as regards their structure and botanical composition. However, for landowners who wish to restore a degree of indigenous vegetation cover to their properties, these stands still offer a chance to do so without planting 'from scratch'.

Pine plantations, while occupying three-tenths of the landscape, are far from monotonous. They are at all stages of growth and harvest. The pine stands actually enclose a large proportion of what little 'intact' natural forest, scrub and wetland cover remains. This is undoubtedly a consequence of the NZ Forest Service, which planted Woodhill and Mangawhai, protecting these areas at the time of planting. Protection is continued by Carter Holt Harvey which currently owns cutting rights to both forests.

Patches of 'intact' natural cover are also interspersed with grassland on farms of the South Kaipara Head and Awhitu Peninsula. While individually small, they are widespread at both localities. Many now appear to be protected by local landowners. They are likely to have value as bird habitat and sources of seed for dispersal into scattered remnants elsewhere on the farmland.

This survey confirms what is already known about disappearance of sand-binding lupin from unstable coastal margins of the sand country. What little remains, is too sparse and stunted to show up on the aerial photographs. Surprisingly, sand-binding marram is less extensive here than anticipated. The reason appears to be that most of the country where it was formerly planted has been converted to pine forest or improved pasture in recent years.

Some good news is that exotic weeds like gorse and shrubby acacia, known to be locally present, are certainly not widespread or extensive. So there is good chance of getting them under control before they spread. One exotic weed, widespread but not detected by the survey, is pampas grass. Residual pampas is present beneath the pine canopy in maturing stands at Woodhill. Where pines have been harvested or re-planted, fresh growth of pampas occurs amongst the grasses and weeds. However regrowth was not dense enough to be visible on the aerial photographs, possibly as a consequence of pre-plant spraying to protect pine seedlings.

Brush wattle and boxthorn account for most of the 2% in exotic shrub cover. While these species are on ARC's list of weeds, and certainly invade disturbed sites on sand country, their extent need not be a cause for concern. Brush wattle in particular has an open canopy which admits light, and lets native species re-establish at ground level.

A final bit of good news is the limited extent of sand blows at 2.1%. While there are places which have local concentrations, particularly at Awhitu, fortunately they are not widespread either there or at South Kaipara Head or between Pakiri and Mangawhai. The problem areas, where they exist, are large enough to be a worry but still at a stage where they can be tackled.

11 Appendix C – Extent and stability of landforms in sand country

Differences in erosion amongst the three sand country soil groups are explicable in terms of soil properties (see main report). Briefly:

- Erosion of topsoil by wind or water, and erosion of subsoil by gullying or mass movement, are least on the weathered soils of group I3. These are dunefields of Pleistocene age which have stabilised and were formerly forested.
- Erosion of subsoil by gullying or mass movement is significant only on group H3c. They are hill phases of the same soils, on the flanks of 'gullies' (actually steep-sided, flat-bottomed valleys) where streams have dissected the Pleistocene dunefields.
- Erosion of topsoil by wind - and water - is greatest on the unweathered soils of group L3, which are dunesands of Holocene age, which had stabilised under scrub and coastal grasses, plus active dunes landward of the coastal beaches.

Within each soil group, erosion is known to be concentrated on particular landforms, but field observations to date have been anecdotal. To find out exactly how much soil is disturbed on different landforms, where this survey's sample points fell on sand country, they were classified as:

d parabolic dune ridges and hollows

f linear foredunes and transverse dunes

g valley sides excavated through d or f terrain

t' elevated, slightly dissected terraces in valleys or alongside estuaries

t terraces at stream level in valleys or alongside estuaries

s sandflats (waterlaid sand in depressions on f terrain).

Table 1 gives the extent of each landform:

Table 1.

Extent of different landforms

Landform	points (n)	area (%)	conf. limits (+-%)
Dissected terraces (older I3)	36	6.8	2.2
Stream-level terraces (within I3 & H3c)	21	4.0	1.7
Sand flats (younger L3)	15	2.8	1.4
Valley sides (older I3 and H3c)	36	6.8	2.2
Valley sides (younger I3 and H3c)	40	7.6	2.3
Valley sides (older L3)	8	1.5	1.0
Dissected parabolic dunes (older I3)	55	10.4	2.6
Weathered parabolic dunes (younger I3)	74	14.0	3.0
Slightly weathered parabolic (older L3)	59	11.2	2.7
Transverse dunes (younger L3)	89	16.9	3.2
Fore dunes (younger L3)	95	18.0	3.3

Waterlaid landforms occupy 14% of Auckland's sand country; the greater part being elevated, dissected terraces with older (leached) I3 soils.

Valley sides, excavated by streams through vegetated parabolic dune terrain, account for 16%. They are about evenly divided between older I3 or H3c soils; and younger, weathered I3 or H3c soils. Very few are cut through the older L3 soils.

Parabolic dune terrain is the largest component of the sand country's landscape, at 36%. It is more-or-less evenly occupied by dissected dunes (older I3 soils); undissected but stable dunes (younger I3 soils), and undissected unstable dunes (older L3 soils).

Transverse dunes and foredunes account for 17% and 18% of the sand country's landscape respectively. They are associated with the younger L3 soils, now forming on recently stabilised raw sand.

Tables 2 to 5 give the percentages of each landform that are stable, unstable but vegetated, revegetating and eroded. However, because most landforms are a small part of the 521-point sample, number of points in each sub-sample is small. Confidence limits around the percentages (Table 6) are unacceptably large cf. the more satisfactory limits that were obtained for percentages stable etc. on the three sand country soil groups (see main report).

Any percentages cited in the ensuing discussion of Tables 2 to 5, therefore, merely indicate trends in soil disturbance on the different landforms. Sub-sample sizes are too small for them to be regarded as representing the true figures region-wide. Figures for soil groups I3, H3c and L3, cited in the main report, are a more reliable indication of erosion's current extent in the sand country.

Table 2.

Soil disturbance on water-deposited landforms

Landform	Points (n)	Eroded (%)	Reveg. (%)	Unstable (%)	Stable (%)
Dissected terraces	36	11	6	8	75
Stream terraces	21	10	10	52	28
Sand flats	15	27	20	53	0

On dissected terraces, a moderate percentage of soil is disturbed i.e. eroded or revegetating. One third is ground where grazing or cultivation have exposed topsoil to surface erosion. The balance are points where subsoil has been eroded by gullies or terrace edge collapses, generally along tidal estuaries.

The number of points on stream-level terraces is small, but indicates a moderate percentage of soil is disturbed by streambank erosion or deposition.

Sandflats are restricted to the recently active dune terrain on L3 soils. Here, they take the place of terraces. While the number of points is small, a high percentage are clearly subject to fresh or recent disturbance. This takes the form of alternating deposition - when the sandflats are moist - and deflation - when they are dry.

Table 3.

Soil disturbance on valley sides

Landform	Points (n)	Eroded (%)	Reveg. (%)	Unstable (%)	Stable (%)
Older I3 terrain	36	11	14	75	0
Younger I3 terrain	40	8	22	70	0
Older L3 terrain	8	25	13	62	0

Soil disturbance is moderate on valley sides cut through old dissected dunes (leached soils in the I3 or H3c groups); somewhat higher where valleys are cut through undissected dunes (weathered soils in the I3 or H3c groups); and greatest where valleys are cut through young parabolic dunes (slightly weathered soils in the L3 group). However the number of points on valley sides in L3 terrain is small, so the figures here should be treated with caution.

In all three cases, disturbance is largely subsoil erosion by landslides or gullies, though surface erosion is also present at a few points in heavily-grazed pasture; particularly on L3 terrain where valley sides are usually mantled by a veneer of Pinaki sand soil which has cascaded down an older surface cut in underlying weathered sand.

Table 4.

Soil disturbance on parabolic dune terrain

Landform	Points (n)	Eroded (%)	Reveg. (%)	Unstable (%)	Stable (%)
Older I3 terrain	55	9	14	22	55
Younger I3 terrain	74	5	7	28	59
Older L3 terrain	59	10	10	80	0

The moderate percentage disturbed on older I3 terrain is surprising. It is almost entirely topsoil erosion where soil has been exposed by heavy grazing or cultivation. Given that the soils here - Red Hill sandy clay loam, Horea clay, Tangitiki silty sand - have low susceptibility to wind erosion, disturbance is more likely to be sheetwash.

A lesser percentage of soil is disturbed on younger I3 terrain (Red Hill loam and Houhora silty sand). About half of disturbed points show evidence of surface erosion or deposition of topsoil, by wind or sheetwash in depleted pasture. The balance are either gullies where stream heads are starting to dissect the dunes, or sites where dunes have been collapsed by landslides on the coastal cliffs beneath.

On older L3 terrain (slightly weathered Pinaki soils), a fifth of soil is disturbed. In almost all cases, disturbance is erosion or deposition of sandy topsoil by wind, in depleted pasture.

Table 5.

Erosion on transverse dunes and foredunes

Landform	Points (n)	Eroded (%)	Reveg. (%)	Unstable (%)	Stable (%)
Transverse dunes	89	17	16	67	0
Fore dunes	95	20	31	49	0

Transverse dunes and foredunes are restricted to the younger L3 terrain; areas where dunes are still active or have just been stabilised by revegetation since the 1920s. On transverse dunes, a third of sample points are disturbed. On foredunes, the percentage is even higher, just over half. On both terrains, disturbance is erosion or deposition - of sand rather than topsoil - by wind.

Summary

Within each soil group, different types of erosion are concentrated on different landforms - though the picture is fogged by the published soil maps' recording of I3 soils on some steep valley sides, and H3c soils on some parabolic dune terrain. After adjusting for this discrepancy, a clear pattern emerges:

- Dissected terraces (older soils in the I3 group) - moderate percentage of soil disturbed, mainly by gullies or bank collapses along estuaries.
- Stream-level terraces (Parore soils rarely differentiated by the soil maps) - moderate percentage of soil disturbed by streambank erosion or deposition during floods.
- Sandflat terrain (younger L3 soils) - just under half of soil disturbed; by alternating deposition of sand by wind when wet, and erosion of it when dry.
- Valley sides excavated through parabolic dunes - increasing percentage of soil disturbed by landslide or gully erosion, moving from older I3 through younger I3 to older L3 terrain.
- Dissected parabolic dunes (older I3 soils) - moderate percentage of soil disturbed, mainly surface erosion by sheetwash; though it's possible that at a number of points, soil is merely exposed rather than actively eroding.
- Weathered parabolic dune terrain (younger I3 soils) - low percentage of soil disturbed; about half is surface erosion by wind or sheetwash; the balance gullies or landslides where the dunes are being undermined.
- Slightly weathered parabolic dune terrain (older L3 soils) - moderate percentage of soil disturbed; mainly surface erosion and deposition of sandy topsoil by wind.
- Unweathered transverse dune and foredune terrain (younger L3 soils) - a third and half of soil disturbed respectively; entirely erosion or deposition of raw sand by wind.

Table 6 summarises the pattern, and also gives 95% confidence limits:

Table 6.

Fresh and recent soil disturbance on different landforms

	Area	95% conf. limits
Dissected terraces (older I3)	17%	+- 12
Stream-level terraces (within I3 & H3c)	20%	+- 17
Sand flats (younger L3)	47%	+- 25
Valley sides (older I3 and H3c)	25%	+- 14
Valley sides (younger I3 and H3c)	30%	+- 14
Valley sides (older L3)	38%	+- 34
Dissected parabolic dunes (older I3)	25%	+- 11
Weathered parabolic dunes (younger I3)	12%	+- 7
Slightly weathered parabolic (older L3)	20%	+- 10
Transverse dunes (younger L3)	33%	+- 10
Fore dunes (younger L3)	51%	+- 10

The confidence limits are rather too large for these percentages to be regarded as representing the true figures for soil disturbance on each landform region-wide. However, they suffice to demonstrate a strong correspondence between erosion susceptibility and age of the landforms which underlie soils in each group.

As might be expected, the most extensive disturbance by wind erosion occurs on the youngest landforms - transverse dunes, foredunes and sand flats which have only been stabilised by vegetation within recent decades.

In comparison, parabolic dunes are less affected by wind erosion, and more affected by other forms of erosion, as their age increases.

Steep valley sides, cut by streams through the parabolic dune terrain, are susceptible to landslides and gullies. However their incidence declines with increasing dune age - in the older terrains, valley sides have lower slope angles and more weathered soils.

On water-laid landforms in the sand country, disturbance similarly declines with increasing age. Its nature also changes, from wind erosion on sand flats, through streambank erosion and deposition on stream-level terraces, to gullies and edge collapses in the weathered soils of dissected terraces.