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Methods Used to Survey Auckland's Soil Erosion:

Hill Country, Sand Country and Rural Land Use in 1999

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Methods Used to Survey Auckland's Soil Erosion: in Hill Country, Sand Country and Rural Land Use in 1999

D. L. Hicks

Contents

1 Technical appendix one

Statistical considerations when designing a point sample survey

1.1 Introduction

In August 1996 Helen Moodie (then ARC's Rural Soil Conservator) asked me whether separate surveys of rural land use and "soil health" could be avoided, by a sampling procedure that would enable both to be measured at the same time. In response, I prepared a proposal to record land use and sample soil carbon at 1000 points, randomly located across 17 soil groups depicted on the map *Susceptibility of Soils to Degradation* (Hicks et al 1996). This proposal was not implemented at the time, because of uncertainty about whether soil carbon would be adopted as a nationwide indicator of "soil health". The fairly high cost of collecting and analysing soil carbon samples at 1000 sites was probably also a deterrent. Error terms associated with a 1000 point sample, once split by soil group and land use, were also somewhat higher than desirable.

In September 1999 Tony Thompson (now ARC's Land Management Officer) requested advice about measurement of "soil intactness" on hill country and sand country in the Auckland region. Following discussion with other Councils and MfE in March 1999, ARC had decided to use area of recent erosion as its preferred indicator for "soil intactness". 1:10,000 colour enlargements, from aerial photo coverage taken earlier in 1999, provided an opportunity for up-to-date measurement. ARC also requested advice about deriving an estimate of current land use from the same photo coverage.

This appendix contains advice furnished to ARC between September and December 1999, about statistical considerations when designing a survey of eroded areas in hill country.

1.2 Point samples compared with area samples

A point sample network, similar to the 1996 proposal's, is still likely to be the best framework for estimating "soil intactness" in hill country and sand country. My reasons for advocating its use are:

- Substantial time savings through point sampling. The alternative - area sampling - would take considerably longer, as erosion would have to be measured by running a hand-held digitiser around any eroded areas in a large number of map grid squares (overlaid on the photos and used as sample plots).
- For any particular soil group, the proportion of eroded points can be used to estimate the area recently eroded, provided enough points are measured and provided they are random.

- While for the time being, only part of a point network would be used to meet ARC's current need - for soil groups H3 (hill country) and I3 (sand country) - the rest of it could be used for appropriate measurements of soil intactness on the other soil groups at a future date.
- Equally, the same point network could be used to sample "soil health", once ARC decides which indicators it is going to use.
- Data from a point network can be combined with spatial information e.g. changes in land use on sensitive land use capability units, should MfE's/Landcare's nationwide land use monitoring proposal ever get under way. Should it not, the point network can still provide ARC with land use estimates for its region.
- Random point sampling of hill country is currently used by two other regional councils (Manawatu-Wanganui and Gisborne) and may be adopted by a third (Wellington). A fourth (Taranaki) has used an area-sampling technique, which produced satisfactory results at considerable expense. No other regional councils are known to have implemented procedures for monitoring soil intactness in hill country.

The sample design which follows, while based on my 1996 proposal to ARC, is somewhat revised in view of:

- Considerably better aerial photo coverage now available for the Auckland region,
- Sampling procedure used for the Manawatu and Gisborne surveys,
- Sample size - accuracy relationships observed during the Manawatu surveys (the Gisborne survey is still under way).

1.3 Sample size

According to statistical sampling theory, Kolmogorov's formula

$n = (1.36/e)2$,

where n is sample size and e is maximum divergence between sample and population distributions, gives an estimate of the sample size required to attain a specified error margin. For instance, 1000 randomly located points would provide a sample size that estimates a distribution, for any particular soil parameter e.g. soil carbon, to within +-4.3% of the true distribution for all soils in the Auckland region, at the 95% confidence level.

In practice, such an estimate for an entire region is not very meaningful. Taking soil carbon as an example, the natural level in brown granular loams under indigenous vegetation is 3 to 7%. Under cropping (now widespread on these soils) the range generally declines. The natural level in yellow-brown earths is 3 to 6% and under pasture (now the dominant use) this range increases. Clearly there is no useful information to be gained about soil health, by mixing these two different distributions together in one point sample.

A change in a soil property is meaningful only if it is measured for a group of soils that typically have much the same range in that property when under a given use. This was the rationale behind grouping Auckland soils that have similar susceptibilities to degradation (Hicks et al 1996). Enough points have to be sampled, to be able to say for each of these groups, whether there is a measureable change in soil fertility, soil structure or soil erosion.

One way would be to randomly locate 1000 points in each group. However this would entail intensively sampling some groups, of minor significance for regional land use because they occupy a limited area of land. It would also result in a needlessly large sample for the region overall, once points from all soil groups are aggregated.

Another way would be to sample the entire region at points which correspond to regularly spaced map grid co-ordinates. While spatially non-random, this approach has the advantages of producing a sample that is:

- Randomly located with respect to soil properties and site characteristics,
- Stratified, with the strata proportional to each soil group's area.

With a point sample, the error term for a proportion:

+- 1.96 /(p*q)/n

is statistically appropriate (p = proportion of sample, q = 1-p, and n = sample size). However the error term for a mean:

+- 1.96 s//n

(where s = standard deviation and n = sample size) may be applied instead, if a numeric value is attached to each point e.g. "area under/not under a given use". When the infinitesimal areas are summed and averaged, this procedure equates proportion of points under a given use with average area under a given use.

Table 1 indicates the 95%-confidence-limit error margins that would be associated with land use estimates, if points are sampled at a density of one per square kilometre. 4412 points would be needed to cover rural land use in the region. Standard deviations of s=20% for area under a given land use and s=5% for area eroded were used when calculating error margins, as these are typical of values obtained during storm damage surveys in hill country (Hicks 1989-1998).

Note that three small soil groups - I3b, H1b and H2b - have been amalgamated with the closest equivalent groups (I3a, H1a and H2a respectively). This is consistent with what was done when selecting representative soils from each group, to be sampled as Auckland's contribution to the 500 Soils Project.

Table 1 Error margins for land use, estimated from a 4412-point sample split by soil group, Auckland region

Soil group	Area as % of rural land in region	No of points @ 1 per km2 of rural land	Margin of error (+-2 s.e. @ 95% conf.) (for average area under a given use) +-%
I1a	10	428	1.9
I1b	4	161	3.1
I2a	5	245	2.5
I2b	2	95	4.0
I3	3	125	3.5
L2	2	105	3.8
L3	6	263	2.4
H1	8	342	2.1
H2	6	558	1.7
H3a	18	797	1.4
H3b	7	302	2.2
H3c	4	174	3.0
S2	6	264	2.4
S3	13	552	1.7

Taking the smallest sub-sample, 95 points for I2b, we can be 95% confident that the average area under any land use will be within +- 4.0% of the true figure (for all points in the region where soil types fall within soil group I2b).

Estimates in Table 1 are fairly close to what actual survey data will produce, because the area of each soil group (and therefore the number of points) is already known.

Error margins for erosion under a given land use may be estimated by considering the likely number of use/non-use categories occurring in each soil group. I have assumed the categories will be:

m market gardens

o orchards and vineyards

g grain crops

f fodder crops

i intensive grazing (dairying or livestock fattening)

e extensive grazing (includes lifestyle blocks)

p plantation forest

b indigenous forest

s scrub

w wetland

d sand dunes

A sample of 4412 points should produce error margins that are close to the values in Table 2. Note that the actual number of points for each land use will be greater or less than the average number.

Table 2 Error margins for soil erosion, estimated for a 4412-point sample, split by soil group and land use, Auckland region

Soil group	Expected uses	Total uses	Average no of sites per use	Margin of error +- 2 s.e. @ 95% conf. (for average area eroded) +-%
I1a	m, o, g, f, i, e, b, s	8	54	1.3
I1b	o, f, i, e, b, s	6	27	1.9
I2a	m, o, g, f, i, e, b, s	8	31	1.8
I2b	o, f, i, e, b, s	6	16	2.5
I3	o, f, i, e, s, d	6	21	2.1
L2	e, s, w	3	35	1.7
L3	e, p, s, d	4	66	1.2
H1	o, f, i, e, p, b, s	7	49	1.4
H2	i, e, p, b, s	5	112	0.9
H3a	e, p, b, s	4	199	0.7
H3b	e, p, b, s	4	76	1.1
H3c	e, p, s, d	4	44	1.5
S2	e, s, w	3	88	1.0
S3	e, p, b, s	4	138	0.8

Thus for the I2b sub-sample split by land use, we could be 95% confident that the average area eroded under a particular land use is within +- 2.5% of the true figure.

Estimates in Table 2 may be somewhat greater or less than what an actual survey will produce, because the number of sites per land use on each soil group is currently unknown, so it has been necessary to use the average number.

1.4 Change between two dates

Because in successive surveys, the same point sample would be used to estimate land use and soil erosion, any changes between two dates are real, and no additional sampling error applies at the second date of survey (as would be the case if two different point samples were being compared).

1.5 Effect of a sample's standard deviation upon the error margin of an average value

In the formula for margin of error (sample mean cf. population mean):

e = +- 1.96*s//n

s is an estimate of the sample's standard deviation, if not known in advance,

n = number of observations,

1.96 = value of z distribution @ 95% confidence.

The standard deviations of erosion distributions in N. Z. hill country are quite variable (Hicks, various erosion surveys, late 1980s-early 1990s). +- 5% would be a conservative estimate i.e. actual standard deviations are generally less than this range. So using it, will produce an estimate of the maximum margin of error that's likely to attach to an "average % eroded" estimate for a particular soil group (Tables 1 and 2).

For instance, in a sample of 15 sites, 'e' will equal +- 2.5%. But if the actual value of 's' is less than the initial estimate, say 3%, then 'e' will be +- 1.5%.

1.6 Effect of sample size on precision of an average value

For a small stratum (sub-sample), the precision with which "% area eroded" can be determined is low. For example, in a sample of 15 sites, the precision is (1*100/15) i.e. +- 6.7%.

It would be desirable to have a measurement precision that is within the likely margin of error:

size	std. dev.	margin of error	precision
n = 15	s = 5%	1.96s//n = 2.5%	1*100/15 = 6.7%
n = 30	s = 5%	1.96s//n = 1.8%	1*100/15 = 3.3%
n = 60	s = 5%	1.96s//n = 1.3%	1*100/15 = 1.7%
n = 100	s = 5%	1.96s//n = 1.0%	1*100/15 = 1.0%

i.e. about 100 sites per stratum.

1.7 Stratified versus regular sampling

The required margin of error and precision could be obtained by stratified sampling i.e. 100 points on each soil group-land use combination. For a stratified sample of, say 5 soil groups x 4 land uses, this would necessitate 2000 points. However, it would not provide accurate estimates of land use.

A non-stratified sample can do both. If laid out on a regular sampling grid (as proposed in September), there is no problem with size of sub-samples in the hill country soil groups as n should generally be greater than 100. A problem emerges if the same sampling grid is used to locate points for measuring "soil intactness" on some of the lowland soil groups. On these, n for many sub-samples will be considerably less than 100.

The solution to this may be to modify the sampling design, so that:

- the 4412-point regular sampling grid gets used to estimate land use,
- where n for a soil group - land use sub-sample is greater than 100, 100 points are re-sampled for the eroded area estimate, and
- where n for a soil group - land use sub-sample is less than 100, extra points are sampled for the eroded area estimate, until n=100.

This would mean a sample of c. 6000 points for the eroded area estimates (60 soil group - land use combinations) if the survey eventually extends from hill country and sand country soils onto the other soil groups.

For the initial survey in hill country, no extra points are needed as the regular sampling grid will give c. 1900 which should be just enough for 20 soil group - land use combinations.

For sand country, where the regular sampling grid will give c. 300 points, an extra 300 would need to be sampled to obtain adequate precision. This could be done quite easily e.g. by off-setting a second point x metres from every point in the grid that falls on sand country.

1.8 Effect of small sub-sample sizes for uncommon land uses

A potential problem with bulking-up soil group - land use combinations to 100 points, is that land uses may be rare on some of the soil groups. Examples are dairy farming on hill soils, and exotic forestry on lowland volcanic ash soils. Points with these uses may be picked up by the regular sampling grid, but it will be hard to find 100 by extra sampling of off-set points.

The alternative may be to run with whatever number of points is picked up by the regular sampling grid, and for those sub-samples which are <<100 points, calculate non-parametric statistics. There is a range which may be used to compare small sub-samples of uneven size. Chi-square tests are the best-known. Difference-of-proportions tests, derived from the binomial formula, have proven particularly useful for comparing erosion data (erosion frequency distributions are typically binomial in form - see Omura and Hicks 1992).

A sensible approach to this problem is, rather than carry on collecting more and more data, to take the view that:

- if the initial sample indicates a land use is rare in the hill country landscape - for instance, natural forest on H1a - that is worth knowing for state-of-environment reporting,

- but it also tells us there is not enough of that particular land use, to have an influence on H1a, so summary statistics for erosion under natural forest on H1a will have little value for SER.
- great deal of useful information could be obtained by innovative two-way sample splits; for instance :
- What are the land uses on sample points where soil conservation work has been carried out cf. where it has not?
- At these points, how much soil erosion is there, compared with under the same land uses where no work has been carried out?

When using data for SER, simple analyses like these may have greater value than complex ones. Quite apart from avoiding the sub-sample size problem just discussed, they can reveal trends in data that are obscured if too many categories are used; and results are a lot easier to present to the general public. Sticking with one-way or two-way sample splits will be advisable, if ARC decides to carry out further work on the database once it has been supplied.

1.8.1 Footnote

This Appendix's estimates of sample size, margin of error and precision were made using statistical theory, as an aid to survey design. They may be compared with actual sample size, margin of error and precision, now that the survey has been carried out. Actual data are given in Technical Appendix Two (see section headed Validation of Results). In most instances, they are close to the estimates, giving cause for confidence in the procedures used.

1.9 Definitions of terms used when recording point sample data

The purpose of this Appendix is to give readers a clear picture of the terms used when recording data, and the reasons for choosing them.

1.9.1 Soils

Soil maps of the Auckland region depict 132 different types of soil. Many of them, similar in properties and suitability for use, have been differentiated because of differences in origin or appearance that are recognisable to a soil scientist but subtle to a farmer. When managing soils for agriculture - or other land uses - two approaches may be taken. One is to write detailed prescriptions for fertilisation, cultivation and conservation of each soil. This approach is appropriate for advising an individual farmer, when detailed soil data has been collected for his/her farm. The other is to write somewhat more generalised prescriptions, for soils that are similar. This approach is appropriate when advising a group of landowners, in the absence of information about their individual properties. For "over-views" of an entire district or region, it is also the only approach which is practical. The reality is that Landcare Research's National Soils Database (NSD) contains data for just 27 out of 132 Auckland soils. Advice to a district or regional council about soil management, for planning or environmental purposes must necessarily be based on extrapolating data from those soils to others which are similar.

An example of this was when Auckland soils with similar susceptibility to degradation were grouped by ranking NSD and other unpublished data (Hicks, Shepherd and Parfitt 1996). This was done to facilitate future survey of Auckland soils' condition for state-of-environment reports. 19 soil groups differentiated in the 1996 study have proven useful for several other purposes, such as reference maps for district planners (RDC and FDC), sampling soil quality (Sparling and Rijkse 2000), and ascertaining soils' suitability for disposal of liquid and solid effluent (Teale unpub., Parker in prep.). The 19 groups are:

Arable lowland soils :	
I1a	Susceptible to slight nutrient loss if intensively farmed
I1b	Susceptible to slight nutrient loss, structural breakdown or surface erosion if intensively farmed
I2a	Susceptible to moderate nutrient loss if intensively farmed
I2b	Susceptible to moderate nutrient loss, structural breakdown or surface erosion if intensively farmed
I3a	Susceptible to severe nutrient loss if intensively farmed
I3b	Susceptible to severe nutrient loss, structural breakdown or surface erosion if intensively farmed
Non-arable lowland soils	
L2	Susceptible to severe structural problems on account of waterlogging
L3	Susceptible to severe surface erosion on account of sandy texture
H3c	Susceptible to severe subsoil erosion on account of locally steep slope
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-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 ARC's contract report Susceptibility of Auckland Soils to Degradation (Hicks et al 1996).

1.9.2 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:

- 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 option has been used. Sample points were classified as hill country where DSIR soil maps indicate a soil type found on:

- hill country footslopes - groups H1a, H1b, H2a, H2b
- hill country faces - groups H3a1, H3a2, H3b1, H3b2
- locally steep slopes in lowlands - group H3c
- steeplands - groups S2, S3

This option proved satisfactory, except for points where a soil map indicates one of the above groups, 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 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 under the sub-heading Validation of results.

1.9.3 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:

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

For this survey, the second option was used. Sample points 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.

This 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.

1.9.4 Lowlands

"Lowlands" are defined by geomorphologists in terms of their landforms. The term embraces rolling downlands, alluvial terraces, river floodplains, and estuarine flats. In Auckland's region, such landforms occupy:

- the central part of Franklin district, between Waiuku and Papakura,
- valleys and basins in eastern (rural) parts of Papakura district and Manukau city,
- most of the urban area (Papakura, Manukau, Auckland, Waitakere, North Shore),
- small areas between the urban fringe of Waitakere city and the Waitakere range,
- valleys and estuarine shores throughout Rodney district.

Lowlands can be identified:

- 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 option has been used. Sample points were classified as lowland where DSIR soil maps indicate a soil type found on:

- downlands mantled by recent or weathered tephra (groups I1a and I2a)
- alluvial or estuarine terraces (groups I1b and I2b)
- floodplains or estuarine flats (group L2).

This option proved satisfactory, except for points where a soil map indicates one of the above groups, but the aerial photograph clearly shows a hill country or sand country landform - or vice versa. These anomalies occur where NZMS 260 map grid intersections. 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.

1.9.5 Land use

There are several options for recording land use. One is to use a hierarchical classification in which the first letter or number indicates broad land use; the second, exact type of use; and the third, vegetation cover associated with the use. The classification used for Land Information New Zealand's Land Cover Database is an example. Applying it to the Auckland region would entail recording a number of combinations, so large as to be unwieldy at the stage of data analysis. It is interesting to note that so far, agencies involved with the Land Cover Database have only attempted mapping its first layer. At this level, the categories are so broad that they have limited value for an analysis of land use.

Another option is to map vegetation classes which can be matched with land use e.g. vegetation codes used for the former Ministry of Works and Development's New Zealand Land Resource Inventory maps. Most of its classes are more specific than the Land Cover Database categories, but three problems remain. It does not clearly differentiate between vegetable cropping (outdoor vegetable productions) and grain cropping. Nor does it differentiate between dairy pasture and drystock pasture. Its indigenous scrub and forest classes are somewhat more subdivided than is necessary for analysing land use (they correspond with scrub communities e.g. manuka shrubland or forest types e.g. lowland podocarp-hardwood).

A third option is to use a botanical classification which records dominant species in the tree canopy or ground cover. The classification used by DOC for its Protected Natural Area programme (PNA) - and adopted by ARC to describe its Significant Natural Areas (SNA) - is of great value for ecological studies. Similar categories could be developed for vegetation on farmed or afforested land. There are two practical difficulties in using such a classification to analyse land use. Dominant species cannot usually be ascertained from aerial photographs or by viewing from a distance; each site would have to be inspected at close quarters. Once dominant species lists are recorded for a large number of sites, they would have to be aggregated into a small number of classes to get them to correspond to land use categories. Doing this would take a great deal of time, and seems a round-about way to analyse land use.

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

Market gardens (outdoor vegetable production)	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 has proved practical when photo-interpreting land use. Comments about its ease of use are given in Technical Appendix Two.

1.9.6 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
- Bank 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.

Criteria for differentiating fresh from recent erosion varied somewhat, moving from hill country to sand country to lowlands. An account is given below, under these sub-headings.

1.9.6.1 Hill country

In surveys of erosion in the southern and eastern North Island (Hicks 1989-1998), using aerial photographs taken after the event, I have found that eroded ground remains bare for a period of up to 2 years. On the ARC's photos, appearance of scars from the July 1998 and January 1999 storms suggests that in Auckland's mild, humid climate, re-vegetation commences rapidly. What has been recorded in this survey as fresh erosion has occurred within the twelve months that precede date of photography.

In storm damage surveys elsewhere (Hicks ops. cit.), revegetating ground can be as young as 2 years or as old as 20, depending on nature of the exposed substrate and the local climate. In Auckland, deep weathering of exposed subsoil together with mild air temperatures and regular rainfall appear to ensure rapid revegetation. What has been recorded as recent erosion is at least 12 months old i.e. pre-dates the 1998 winter. Scars which opened up during the 1995 and 1996 storms still appear as re-vegetating ground, while scars known to have formed in the late 1980s are completely revegetated. Therefore, the upper age limit of what has been recorded in this survey as recent erosion, is somewhere in the range 5 to 10 years.

1.9.6.2 Sand country

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.

The time-frame for distinguishing between fresh and recent erosion (or deposition) in the sand country, is similar to that for hill country. It takes at least a year's de-stocking, for regrowth to colonise a sand drift to the stage where it can be recorded as "recently disturbed". On sheltered sites, between 2 and 5 years are needed, for colonising vegetation to form a complete ground cover. On exposed sites, complete revegetation may take 10 years or more.

1.9.6.3 Lowlands

On dairy farms and drystock farms, much erosion was topsoil loss associated with temporary depletion of pasture by heavy grazing, as opposed to "natural" erosion processes such as landslides. Likewise, in market gardens and orchards and on cropland, many sites were temporarily at risk from surface erosion due to cultivation at the time photos were taken. They contrasted with other sites under the same uses where risk was low due to good ground cover by growing crop, or by stubble after harvest.

In lowlands, the code "t" denotes bare soil exposed where vegetation cover has been depleted by cultivation, over-grazing or plant die-back. Similarly, the "s" code denotes bare soil where sediment has been deposited by water flowing across valley-bottom floodways or low terraces.

Other forms of erosion or deposition recorded in lowlands are:

- b bank erosion by streams flowing through low terraces,
- d soil excavated or deposited by land contouring.

Where the "t" or "s" codes are recorded in lowlands, it is impossible to tell from the aerial photographs whether surface erosion and deposition have actually occurred, or whether the bare ground is simply exposed to risk of erosion or deposition. This inability may not be the problem that it appears; for state-of-environment reporting, the fact that a high percentage of ground is exposed to risk under a particular use may be as useful an indicator, as whether fresh erosion/deposition has actually occurred.

Where "t" or "s" codes are recorded in lowlands, the time-frame for distinguishing between fresh and recent exposure to disturbance is considerably shorter than in hill country. Freshly cultivated cropland is recorded as such for a week or two at most; then as recently cultivated, once the crop emerges. When the crop forms a complete ground cover (usually within the month), a point is no longer recorded as having been recently cultivated. Pasture, freshly depleted by heavy grazing to a stage where bare soil is visible on aerial photographs, is recorded as such for about a month after stock come off. By then, regrowth is sufficient for a point to be recorded as recently depleted. It takes two to three months for sward to thicken to the point where bare soil is no longer visible.

1.9.6.4 Footnote

Further comments on interpreting erosion from aerial photographs are given in Technical Appendix Two under the sub-heading Photo-interpretation. It 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.

2 Technical appendix two

Procedure for carrying out a point sample survey of land use and erosion

2.1 Introduction

This appendix describes each step taken when carrying out ARC's year 2000 survey of land use and erosion in the Auckland region. It is intended, firstly to inform readers about how the survey was done; secondly to enable the survey to be repeated by the same method at a future date, in the event that high-tech alternatives are unavailable or too costly.

2.2 Aerial photographs

1:10,000 enlargements of ARC's aerial photographs, taken by Air Logistics in summer and autumn 1999, were used. A reference set is located in the Council's GIS Section.

The enlargements are from 1:50,000 negatives, and have not been rectified i.e. are not orthophotos. Nevertheless, points can be located on them to within +- 5mm (enlargement scale) or +- 50 metres of their true positions. Partly this is because much of Auckland's terrain has subdued relief, so relief displacement of points is small. That the photos are enlargements taken with a 6 inch lens from a plane flying at 25,000 feet, rather than 1:10,000 contacts taken with the same lens at 5,000 feet, greatly contributes to minimising relief displacement.

If the survey is repeated at a future date from fresh aerial photographs, it is most unlikely that their flight lines and photo centres will be in the same positions (despite the advent of GPS, cross-winds and turbulence make it rather difficult to fly an aircraft exactly over an imaginary line on the ground when the craft is several thousand feet up in the air). For this reason, alignment of sample points around photo centres, although easy to do, was avoided. Next time round, it will be easier to relocate points that are independent of the photograph's geometry. Instead, the NZMS260 one kilometre map grid was used to locate sample points. It has the advantage that points can be easily re-established on the 1999 photos or on new coverage, by referring to printed maps or GIS output (e.g. the map grid superimposed on a digitised satellite image). Using the map grid also avoids any need to mark point locations on ARC's reference set of 1999 photographs.

2.3 Map grid overlay

The map grid was located on each enlargement in two steps. A grid with lines at 100mm spacings was drawn on a sheet of transparent draughting film; line intersections corresponded to nominal positions of the map grid intersections at 1 :

10,000. First, this was overlaid on an enlargement and "jiggled" until grid intersections in the four corners were as close as possible to photo detail corresponding to map detail next to the same grid intersections on the NZMS 260 topo sheet.

Next, photo detail close to each overlay grid intersection was examined. Detail was recorded, not for the overlay grid intersection, but for the *off-set map grid intersection*, once it was located. All 40 points on the overlay were generally within +- 5mm of photo detail corresponding to map grid intersections on the topo sheet. Occasionally, displacements were up to 10 mm over steep hill country e.g. Dome Hills, Puhoi, Kaipara Hills, Waitakeres, Hunuas. It is essential to realise, if attempting to re-locate sample points on the 1999 photos, that they are off-set from the overlay grid. Use it as an approximate guide, and re-locate exactly *by cross-referencing photo detail with map detail in vicinity of the same intersection* on the corresponding topo sheet.

2.4 Photo-interpretation

Once each map grid point was located:

- Presence/absence of active erosion,
- Presence/absence of recent erosion,
- Land use,

were visually interpreted from the photograph. Points were interpreted sequentially, moving from top left on each enlargement to top right, then working through the next row until bottom right was reached. Each point was assigned an identifying number e.g. R10 1.1 1 to 35, R10 1.2 1 to 40, R10 1.3 1 to 35, R10 1.4 1 to 40. This number sequence enables any point in the sample to be quickly re-located on its correct photo enlargement. Had NZMS map grid co-ordinates been used e.g. R10 500190, it would not be immediately apparent which enlargement (out of 32 per topo sheet) to look for.

2.5 How big is a point?

Debate about "how big should a point be?" is in the same category as "how many angels can dance on the head of a pin?" It is more important to adopt a practical procedure, so as to avoid the anomalies that can be encountered if rigid measurement of exact points, or fixed areas around points, is attempted.

In this survey, land use was recorded for an area approximately 5 mm in radius around each point. The reason is that if it were recorded at the exact point, what would be recorded would often be mis-leading. A good example is when a point happens to be on a pine tree in the middle of a grassed paddock. The point should be recorded not as pine forest, but as pasture with scattered trees. Similarly, if a point lies on grass in a paddock that's a mix of pasture with scattered trees, it should be recorded as that, not as clean pasture.

Likewise, if erosion were only recorded when bare ground lies exactly under each point, the consequence would be under-recording of its extent. Erosion was recorded, if bare ground was present anywhere within a c. 5 mm radius of each point. Recording a point as eroded does not mean that 100% of the surrounding area is eroded; it denotes erosion is occurring on soil under the land use that's being practised in the point's immediate vicinity.

The reason for the 5 mm "rule of thumb" is that on the photo enlargements, land use is usually uniform for about this distance either side of a point. Over greater distances, land use boundaries are likely to be crossed.

At some points, land use boundaries were encountered within 5 mm radius. In this situation, whichever land use occupied the greater area was recorded. Erosion was recorded, only if present in the area under that use.

2.6 Erosion

A point was recorded as:

- freshly disturbed (e): if the photo showed bare ground at or close to the point,
- recently disturbed (r): if bare ground was visible at or near the point, but was already re-vegetating,
- unstable (u): if relief indicated former disturbance by erosion or deposition, but the point and its vicinity had completely revegetated,
- stable (s): if relief did not indicate any former disturbance.

Technical Appendix 1B contains relevant definitions and criteria.

One modification was necessary as photo-interpretation progressed. The original plan was to record simply whether a point was eroded or not, as this is the essential information ARC needs to know for state-of-environment reporting. In the course of photo-interpretation, it became apparent that much erosion was topsoil loss associated with temporary depletion of pasture by heavy grazing, as opposed to "natural" erosion processes such as landslides. Likewise, in market gardens and orchards and on cropland, many sites were temporarily at risk from surface erosion due to cultivation at the time photos were taken. They contrasted with other sites under the same uses where risk was low due to good ground cover by growing crop, or by stubble after harvest).

Annotations were added to survey check-sheets, to indicate whether the bare ground is subject to subsoil erosion due to natural processes:

- Landslide
- Earthflow
- Gully

- Bank collapse

or at risk of surface erosion/deposition where vegetation is depleted by :

- Sedimentation
- Cultivation, over-grazing, plant die-back
- Earthworks, tracking.

The hill country and sand country reports (Hicks 2000a and b) discuss circumstances where bare ground should be interpreted as one or the other.

On sand country what was recorded was fresh or recent disturbance, rather than erosion of soil. The reason is that on slightly weathered sand soils (L3 group), erosion on the windward side of sand blows is accompanied by deposition on their landward side. Even on weathered soils of the I3 group, disturbance by wind entails deposition of sand in proximity to the area from which it was eroded. It is only on older leached soils of the I3 group, and the hill phases of sand country soils (H3c group), that disturbance is predominantly erosion, by sheetwash, gullies or landslides.

The distinction between fresh and recent disturbance on sand country was as outlined i.e. bare soil or sand cf. re-vegetating soil or sand.

Where disturbance was recorded as surficial (t code), one difference between sand country points and others, is it generally entails visible erosion and deposition of sand. This contrasts with other landscapes in the Auckland region, where the t code denotes temporary exposure of soil - by heavy grazing of pasture, cultivation in cropland, or ground cover removal in market gardens or orchards - but not necessarily its erosion or deposition.

2.7 Land use

Land use was recorded as:

- Market garden where in vegetable crops (including onion and potato)
- Cropland where in grain crops (maize) and greenfeed crops (chou, kale, turnips)
- Orchards and vineyards
- Dairy pasture where races and dairy sheds are visible
- Improved drystock pasture (beef cattle or sheep) where not, provided pasture is clean and vigorous
- Unimproved drystock pasture (beef cattle or sheep) where pasture has weed infestation and lacks vigour.
- Exotic scrub - mainly gorse, also brush wattle, shrubby acacias and tobacco tree

- Exotic forest - mainly pine, also includes small stands of cypress, fir, gum and blackwood
- Natural scrub - encompasses manuka, kanuka, tree fern and broadleaved shrubs such as karamu
- Natural forest - encompasses kauri, podocarps such as totara, and broadleaved trees such as taraire
- Wetland vegetation - flax, raupo, sedges, rushes
- Coastal vegetation - spinifex and marram (coastal scrub, forest and swamp are included in preceding categories)

Technical Appendix One outlines reasons for the choice of these categories. Three modifications were necessary as photo-interpretation progressed:

- 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. I concluded that "lifestyle block" describes property size, not land use; and that 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. These 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.

The composition of two classes is somewhat different on sand country:

- M Coastal vegetation: dominated by the exotic sand-binding grass marram; indigenous sand-binding grasses e.g. spinifex, together with associated coastal shrubs e.g. pohuehue, were a minor component.
- X Exotic scrub: dominated by the sand-tolerant box thorn and brush wattle; tree lupin scarce and stunted; exotic scrub species common elsewhere in the region e.g. gorse were rare.

2.8 Vegetation types on sand country

To enable a more detailed analysis of vegetation types, dominant species were initially recorded for points on sand country as follows:

- Pasture - ryegrass-clover; kikuyu; cocksfoot and other
- Exotic forest - pine, cypress, gum, wattle, other
- Exotic scrub - lupin, boxthorn, brush wattle, gorse
- Coastal grasses - marram, spinifex and other
- Natural scrub - coastal, manuka-kanuka, broadleaved, fern
- Natural forest - coastal, broadleaf, podocarp, kauri

However it quickly became apparent that most of these species were scarce. In practice, species composition was overwhelmingly:

- in pasture - kikuyu mixed with cocksfoot and other
- in exotic forest - pine
- in exotic scrub - boxthorn or brush wattle
- in coastal grasses - marram
- in natural scrub - manuka or kanuka
- in natural forest - mixed podocarp-broadleaf

Points where other types occurred were so few, that it would not have made any sense to carry out an analysis of differences in dominant species' extent and distribution. Instead, they were added to the predominant vegetation type for each class. An alternative analysis was carried out, based on differences in vegetation's structure within each class (Appendix B of Hicks 2000b).

2.9 Landforms on sand country

To enable analysis of erosion's extent on different landforms, the following landforms were recorded in sand country:

- d: parabolic dunes
- t transverse dunes
- f foredunes
- g valley sides cut by streams through parabolic dune terrain
- t' elevated terraces
- t stream-level terraces
- s sand flats

There was little difficulty in interpreting these landforms from the aerial photographs, except where dune form was masked by closed-canopy pine forest. Here, crossreference with the soil map was needed to ascertain whether the dune form was transverse (restricted to younger Pinaki soils in the L3 group) or parabolic (older Pinaki soils in the L3 group, Red Hill soils in the I3 group).

2.10 Time taken

All map grid intersections on rural land in the Auckland region were photo-interpreted. They number 4,158 (excluding a further 75 on two missing photo enlargements). Doing this, from 166 photo enlargements, took 10 days.

2.11 Data recording

Data were recorded manually on a check-sheet next to the enlargement. It was quicker to do this, then enter the data into a computer subsequently, than to constantly turn back and forth between the enlargement (which needs a complete desk-top) and a computer on another desk. Data were stored in an Excel-format spreadsheet to facilitate access and re-analysis by ARC staff in future years.

Codes used to record data on the checksheets were slightly altered when entering them into spreadsheets. Annotated comments about erosion type etc. on the checksheets were also converted into codes at this stage. The codes as finally stored are:

Land use

H	outdoor vegetable production (market garden horticulture)
C	cropland (grain or greenfeed)
O	orchards and vineyards
D	dairy pasture
I	improved drystock pasture
U	unimproved drystock pasture
X	exotic scrub
S	natural scrub
E	exotic forest
F	natural forest
W	wetland vegetation
M	coastal vegetation (sand-binding grasses)
B	bare ground (extensive disturbance by natural process or human activity)

Lower-case letters after a land use code indicate that a second land use is present, intermingled with the first e.g. Us denotes improved drystock pasture with clumps of scrub.

In scrub and forest, a dash after a main vegetation code indicates canopy gaps.

In cultivated land (H, C, O) and grassland (D, U, I) where a second land use is recorded, a dash after the second land use denotes it is scattered as opposed to clumped.

Erosion

S	stable slope, ridge or spur
U	unstable slope, currently vegetated
R	recently disturbed slope, currently revegetating
E	freshly disturbed slope, currently bare
S'	stable footslope or terrace
U'	unstable footslope, terrace or floodway, currently vegetated
R'	recently disturbed footslope, terrace or floodway, currently revegetating
E'	freshly disturbed footslope, terrace or floodway, currently revegetating

Nature of disturbance was recorded as:

Subsoil	
l	landslide
e	earthflow
g	gully
b	streambank
Topsoil	
t	surface, where vegetation depleted or cultivated
d	surface, where vegetation removed by earthworks
s	surface, where vegetation buried by sedimentation

Landform codes were added in a separate column, only where enough information about landforms was not already conveyed by the preceding. The additional codes used were:

s	point adjacent to watercourse
l	point adjacent to lake or pond
e	point adjacent to estuary
c	point adjacent to open coast
f	foredune
d	parabolic dune
g	slope on dissected, weathered dune terrain
t	terrace or floodway on dissected, weathered dune terrain

Data for all points in the region were stored in a master spreadsheet, which will be accessed in connection with other surveys (region-wide land use, erosion on sand country, erosion risk on lowlands).

Soil codes were added to an extra column in the spreadsheet, and converted to soil groups (see next sub-heading for details). Points on hill country were identified by sorting those which had been assigned a hill country or steepland soil group - H1a, H1b, H2a, H2b, H3a1, H3a2, H3b1, H3b2, H3c, S2 or S3. These were copied into separate spreadsheets, one for each soil group, to be used for data analysis.

In the event that this survey is repeated, I recommend that data be stored in a separate master spreadsheet. Relevant sections of data from the new spreadsheet and the 1999 spreadsheet may then be copied into "working spreadsheets" for comparison. To operate directly on the master spreadsheet files by copying from one to the other, would risk corruption of data - hard to detect, and difficult to rectify.

2.12 Time taken

Data entry from checksheets into the master spreadsheet took 3.5 days. Checking the contents took 1 day extra.

2.13 Interpretation of soil maps

Soil types were ascertained by overlaying the NZMS 260 grid on DSIR Soil Bureau maps, and added to the master spreadsheet. The same soil type codes were used, as are stored in ARC's regional subset of the NZLRI. Soil types were assigned to groups depicted in the report and map Susceptibility of Auckland Soils to Degradation (Hicks et al 1996). This operation enabled a sub-set of data for the hill country soil groups to be extracted and analysed.

Codes used for soil groups are:

Arable lowland soils	
I1a	Susceptible to slight nutrient loss if intensively farmed
I1b	Susceptible to slight nutrient loss and structural breakdown if intensively farmed
I2a	Susceptible to moderate nutrient loss if intensively farmed
I2b	Susceptible to moderate nutrient loss and structural breakdown if intensively farmed
I3a	Susceptible to severe nutrient loss if intensively farmed
I3b	Susceptible to severe nutrient loss, structural breakdown and surface erosion if intensively farmed
Non-arable lowland soils	
L2	Susceptible to severe structural breakdown on account of waterlogging
L3	Susceptible to severe surface erosion on account of sandy texture
H3c	Susceptible to severe subsoil erosion on account of locally steep slope
Grazeable footslope soils	
H1a	Susceptible to slight nutrient loss if intensively grazed

H1b	Susceptible to slight nutrient loss, structural breakdown and surface erosion if intensively grazed
H2a	Susceptible to moderate nutrient loss, structural breakdown and surface erosion if intensively grazed
H2b	Susceptible to severe nutrient loss, structural breakdown and 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-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

Technical Appendix One gives reasons for using these soil groups. Detailed accounts of each group, including the constituent soils, are given in ARC's contract report Susceptibility of Auckland Soils to Degradation (Hicks et al 1996).

This operation will not need to be repeated for a future survey, unless larger-scale soil maps i.e. 1:50,000 or better become available for part or the entire Auckland region meanwhile. In the unlikely event this happens, soil type codes from NZMS 260 grid intersections on the new maps could be entered into the new survey's master spreadsheet.

2.14 Soil groups in sand country

The sand country soil groups had to be further sub-divided, to enable analysis of erosion on different sand country landforms (Appendix C of Hicks 2000b). The subdivisions are:

	Soil groups
Older I3:	rli, tt, tek, 24d, 80
Younger I3:	rl, ho, 24a
Older H3c:	rlih, 24dh, 80h
Younger H3c:	rlh, hoh, 24ah
Older L3:	pn, pnh
Younger L3:	pn & pnh where mapped on foredunes or transverse dunes; sd, sdh, sa

2.15 Time taken

Overlaying grids onto the soil maps, and entering soil type codes from them into the master spreadsheet, took 4.5 days. Initial sort by soil type code, addition of soil group codes, and creation of soil group spreadsheets took 1 day extra.

2.16 Data analysis

Each soil group's "working spreadsheet" was printed. For each combination of codes relevant to the present contract e.g. all E and E' on Us, points were manually counted and entered into the relevant cell on a summary spreadsheet.

Both operations were done manually, because that is quicker than repeating "sort" and "count" operations in a spreadsheet program such as Claris Works. They could be done quicker by setting up pivot tables in a spreadsheet program like Excel 97, and I suggest this is the way to go for data analysis in a future re-survey.

Numbers, percentages, proportions and ratios were entered into a second set of spreadsheets which had been set up for testing sample representativeness and significance. The tests, and reasons for their choice, are described in Appendix 1. They were constructed step-by-step in Claris Works. Programs like Excel 97 may possibly have built-in statistical test functions; if so, their use would speed up data analysis in a future re-survey.

Results from all three operations were entered into a third set of spreadsheets, used to print the tables and graphs in each report (Hicks 2000a, b, c). While the Claris Works presentations are adequate, quality of table and graph presentation could be improved in a future re-survey, by using a better graphics software package.

2.17 Time taken

Manual counting of points was quicker to do than it sounds - about half an hour for each "working spreadsheet". Percentages, proportions and ratios were calculated by hand from the summary spreadsheets - about an hour's work for each. Together, these operations took 2 days for the hill country, 1 day for the sand country, and 2 days for the lowlands.

Setting spreadsheets up for statistical testing, entering the data, and checking the results took an extra 2 days for the hill country, 3 extra for the sand country (includes data analysis for two appendices), and 2 extra for the lowlands.

2.18 Documentation

The main reports contain in each case:

- A summary of the ARC's brief, and how it has been met,

- An outline of the land use classes, soil groups and erosion states recorded,
- Presentation of survey results as tables and graphs, with brief accompanying text,
- Conclusions - what the survey shows about land use, hill country erosion, and sand country erosion, on Auckland's rural land,
- Appendices - lengthier and more detailed interpretations of survey data.

The intention is to provide a readable account of why the survey has been done, and what it has found. Any discussion about what might need to be done about land use on particular soil types, or erosion under particular land uses, has been avoided. That is not part of the project brief. Doubtless it will be the subject of discussion amongst ARC's staff once they have had a chance to read the reports.

The ARC's brief also requested that information be supplied about survey method, and ways the data could be used in future. These details are confined to technical appendices which are bound together in this volume. Apart from this Appendix which describes survey method, three other Appendices give:

- Statistical considerations in design of the point sample survey, and definitions of terms used when recording point sample data,
- How to extract MfE's preferred environmental indicator for hill country from the survey data,
- Ways to compare 1999 survey data with data which may be gathered by new technology e.g. satellite remote sensing in a future re-survey.

The intention here is to avoid mixing technical advice with the main subject matter of the reports.

2.19 Time taken

Writing the draft report for hill country took 3.5 days in March; revision to final status (including preparation of an appendix) an extra 4 days in July. The draft report for sand country (including two appendices) took 3.5 days in May, and an extra 2 days in July. The draft land use report took 3 days in June, and its revision is expected to take a further 2 days in August. Preparing the technical appendices took 3.5 days in April, and their revision a further 2 days in August.

2.20 Validating results

2.20.1 Sample representativeness

Margins of sampling error have been calculated from the number of sample points falling into each soil group and the standard deviation of individual measurements (percentage under a given land use, percentage eroded etc.) within that group.

For land use region-wide, the margin of error (+- 2 s.e. @ 95% confidence) is very low:

	+-1.96s//n
All soil groups combined:	+-0.3%

For land use on different soil groups, the margins of error (+- 2 s.e. @ 95% confidence) are:

Soil group	*+-1.96s//n*
I1	+-1.1%
I2	+-1.3%
I3	+-2.1%
L2	+-2.4%
L3	+-1.7%
H1	+-1.9%
H2	+-1.1%
H3a	+-0.8%
H3b	+-1.3%
H3c	+-2.2%
S2	+-2.2%
S3	+-1.1%

In plain language this means that there is 95% confidence that, for instance, the sample percentage of H1 under any particular use is within +- 1.9% of the true figure for all H1 soils in the Auckland region.

For fresh erosion on different soil groups in hill country, the margins of error (+- 2 s.e. @ 95% confidence) are, in hill country:

Soil group	+1.96s//n
H1a	+4.7%
H1b	+0.7%
H2a	+1.1%
H2b	+2.1%
H3a1	+1.5%

H3a2	+2.3%
H3b1	+0.7%
H3b2	+1.2%
H3c	+2.2%
S2	+1.1%
S3	+0.8%

and in sand country:

Soil group	+1.96s//n
L3	+3.6%
I3	+4.1%
H3c′	+1.0%

There is 95% confidence that, for instance, the sample percentage of H1a freshly eroded is within +- 4.7% of the true figure for all H1a soils in the Auckland region.

For recent erosion on different soil groups, the margins of error (+- 2 s.e. @ 95% confidence) are, in hill country:

Soil group	+1.96s//n
H1a	+5.8%
H1b	+1.1%
H2a	+2.0%
H2b	+1.4%
H3a1	+4.7%
H3a2	+0.9%
H3b1	+1.1%
H3b2	+2.2%
H3c	+4.9%
S2	+3.6%
S3	+3.0%

and in sand country:

Soil group	+1.96s//n
L3	+2.7%
I3	+2.6%
H3c′	+4.6%

There is 95% confidence that, for instance, the sample percentage of H1a recently eroded is within +- 5.8% of the true figure for all H1a soils in the Auckland region.

2.20.2 Precision of measurements

Precision of measurements has been calculated from the number of sample points which under-pin each percentage. Where erosion on a soil type is calculated as a percentage of, say 100 points, the precision of calculation is +- 1%. Where it is calculated as a percentage of say 10 points, the precision is +-10%.

At the level of one-way splits (land use for all soil groups; erosion for all soil groups), precision of measurement is extremely high:

	i*100/n
All soil groups combined:	+- 0.1%

At the level of two-way splits, it is still high. For land use on different soil groups, it is:

Soil group	i*100/n
I1	+-0.2%
I2	+-0.3%
I3	+-0.6%
L2	+-1.0%
L3	+-0.4%
H1	+-0.3%
H2	+-0.2%
H3a	+-0.1%
H3b	+-0.4%
H3c	+-0.7%
S2	+-0.6%
S3	+-0.2%

For fresh and recent erosion on different soil groups in hill country, it is:

Soil group	i*100/n
H1a	+-1.9%
H1b	+-0.4%
H2a	+-0.5%
H2b	+-0.3%
H3a1	+-0.7%

H3a2	+-0.2%
H3b1	+-0.7%
H3b2	+-1.0%
H3c	+-0.7%
S2	+-0.6%
S3	+-0.2%

and in sand country it is:

Soil group	i*100/n
L3	+0.4%
I3	+0.6%
H3c'	+1.2%

2.20.3 Measurement errors

The first source of measurement error is mis-interpretation of the aerial photographs. As yet this has not been checked but it could be, by field-checking a proportion of the points sampled. What can be said meanwhile, is that aerial photo-interpretation has been carried out from the best set of photographs I have ever worked with. Previous field checks of my accuracy recording similar land use and erosion classes, from small-scale black and white photography, indicate errors of between 4% and 8%. I expect that any mis-interpretation of the 1:10,000 colour photographs will be considerably less.

The second source of measurement error is difference between soil type at a point on the photograph, and soil type as depicted at the corresponding point on the soil map. Published soil maps of Auckland range in scale from 1:20,000 to 1:100,000. Patterns on the small-scale maps are somewhat generalised, so it is possible that soil type at a point on a 1:10,000 photo enlargement differs from what is shown at the same point on a soil map. Comparing soil types recorded off grid points on the maps with my recollections of terrain's appearance at the same grid points overlaid on the photos, I can say that this is not a problem except where points lie close to line boundaries on the maps. In instances where the boundary is clearly in the wrong position with respect to the point, I have been able to adjust for mis-match by recording a soil type from its other side. An example is where the map point falls on a hill soil, but detail recorded for the photo point indicates an alluvial terrace. However, I cannot exclude the possibility that a few mis-matches remain in the data-base's soil type column. Their presence could only be identified by augering each sample point in the field.

2.20.4 Significance of comparisons

For erosion by land use by soil group i.e. a three-way split of the data, many sub-samples are so small that it is meaningless to calculate percentages eroded. Standard error for some sub-samples would be far larger than the estimate. This can be seen by looking at size of sub-samples for hill country:

	H	C	O	D	I	U	X	E	S	F	W	B
H1a		2		6	35	8	1			1		
H1b		1		58	143	18	4		18			
H2a		4	6	40	99	13	2	18	24	4	2	2
H2b	3	3	1	81	130	20	4	30	16	3	11	2
H3a1		4	1	13	53	15	4	21	23	14	1	2
H3a2	1		1	13	210	41	27	108	125	55	5	
H3b1				8	41	10		22	46	10		2
H3b2				10	30	9	6	23	14	4	1	1
H3c	1	3	1	12	68	11	3	5	22	6	3	
S2					23	5	3	2	79	50	1	1
S3				1	51	20	13	72	124	135	1	1

The difficulty can be resolved to some extent, by amalgamating soil groups and land uses that are similar:

	H&C&O	D&I&U	E	X&S&W	F	B
H1	3	268	0	23	1	0
H2	17	383	48	59	7	4
H3a	7	338	129	185	69	2
H3b	0	108	45	67	14	3
H3c	5	81	5	28	6	
S	0	100	74	221	185	2

These categories are informative, but some sub-sample sizes are still too small to calculate reliable percentages. Also, they do not permit useful comparisons such as, erosion under dairy pasture with improved drystock pasture. Instead, such comparisons may be made between small sub-samples by applying difference-in-proportions tests.

A difference in proportion of soil eroded under two land uses on the same soil group - or between two soil groups under the same land use - may be real, or simply an artefact of the land areas occupied by different uses. For instance, say 5% of the erosion on H1a occurs under dairy pasture and 1% occurs under exotic forest. If dairy pasture occupies 5% of H1a and exotic forest 1%, the difference is as expected given the proportions of H1a under each use. If on the other hand, 10% of the erosion on

H1a is under dairy pasture, then erosion under dairy pasture is twice as high as expected.

The difference in proportion may also be an artefact of sub-sample size, if either or both of the sub-samples are small. A standard non-parametric test for significance of the difference may be applied, to find out.

Test results for three-way sample splits - erosion by land use by soil group - are given in the appendices of Hicks 2000a and Hicks 2000b, so will not receive further discussion here. The remainder of this section will outline the tests used, so that they can be repeated in a future re-survey.

2.20.5 Statistical tests for significance of differences between categories

The trial's data collection format has been designed for calculating enumeration statistics i.e. numbers and proportions of observations falling into various classes. A large number of statistical tests are available for use with enumeration statistics. Of these, the following are recommended on the grounds that they are:

- Applicable to a variety of distributions, non-normal as well as normal,
- Convenient for pairwise comparison between sub-samples,
- Easy to calculate,
- Standard tests used by professional statisticians.

They will cover most situations where Council staff may wish to establish confidence limits for, or test significance of summary statistics used in, statements about landform type, soil disturbance, vegetation cover, or vegetation condition.

2.20.6 Confidence limits for the proportion of the population in a given class region-wide

Example: Out of 118 sites in pasture with conservation tree plantings on a particular soil group, 30 have plantings that are clumped or spaced (i.e. in good condition and sufficient in extent).

p' = .26 (proportion of the sample)

N = 118 (sample size)

a = .05 for 95% confidence

Read $z_{0.5a}$ and $z_{1\text{-}0.5a}$ from z distribution table

Lower limit = $p' + z_{0.5a}$ / $(p'(1\text{-}p')/N$ = .26 - .08

Upper limit = $p' + z_{1\text{-}0.5a}$ / $(p'(1\text{-}p')/N$ = .26 + .08

There is 95% confidence that the proportion lies between .18 and .34 for the population as a whole i.e. all sites in pasture with soil conservation plantings region-wide.

2.20.7 Test proportions in the same class for two samples

Are proportions in the same class for tow samples significantly different at same date?

Example: Unstable, revegetated surfaces are recorded on 26 out of 30 sites in pasture with space-planted trees, on another soil group. The equivalent proportion for sites in pasture with scattered remnant scrub is 19 out of 40.

p1 = .87 (26/30)

p2 = .48 (19/40)

The null hypothesis is $H : p_1 = p_2$

$$p_0 = \frac{N_1 p_1 + N_2 p_2}{N_1 + N_2} = .65$$

$$z = \frac{p_1 - p_2}{\sqrt{p_0(1-p_0)(1/N_1 + 1/N_2)}} = 3.39$$

Read $z_{0.5a}$ *and* $z_{1-0.5a}$ *from z distribution table*

Reject hypothesis if $z < z_{0.5a}$ $3.39 < -1.95$

or $z > z_{1-0.5a}$ $3.39 > +1.95$

The null hypothesis is rejected. There is 95% confidence that the two proportions are significantly different i.e. unstable surfaces in pasture have been less disturbed where trees have been space-planted cf. where remnant scrub has been left.

2.20.8 Test that proportion of a sample falling into a particular class

Test that proportion of a sample falling into a particular class has changed significantly between two dates.

Example: Surfaces have been freshly/recently eroded on 19 out of the 27 sites in pasture where remnant scrub is present. Assume that when the sites are re-surveyed in 5 years, the new proportion is 22 out of 27:

Construct a contingency table

First date

In	*Out*			
Second date				
In		f_1=16	f_2=6	22
Out		f_3=3	f_4=2	5
		19	8	27

$p_2 - p_3 = f_2/N - f_3/N \quad = .11$

$se = \sqrt{f_2 + f_3 - (f_2 - f_3)^2/N} \quad = .11$

The null hypothesis is H : $p_2 = p_3$

$z = p_2 - p_3/se \quad = 1.00$

Read $z_{0.5a}$ *and* $z_{1-0.5a}$ *from z distribution table*

Reject hypothesis if $\quad z < z_{0.5a} \quad 1.00 < -1.95$

or $\quad z > z_{1-0.5a} \quad 1.00 > +1.95$

The null hypothesis is not rejected. There is not 95% confidence that the changes are significant i.e. the apparent increase in erosion may be an artefact of the small sub-sample size.

2.20.9 A cautionary note about the use of statistical tests

In many instances Council staff will not need to use them. Where sub-sample sizes are large, and differences in proportions substantial, the conclusion is obvious. Statistical tests should be applied as a check only if there is an element of doubt. Some good rules of thumb are:

- Test a large difference in proportions if one or both sub-samples are small,
- Test two large sub-samples if there is a small difference in proportions.

2.21 Re-formatting survey data to extract different information

The point sample database may prove useful for other purposes besides its initial ones, which are reliable estimates of land use and erosion on different soil groups.

One example is MfE's preferred indicator for hill country erosion - the area of moderate erosion-risk land in pasture without soil conservation measures. Technical Appendix three discusses how this may be extracted from the data.

Another example is extent of erosion where vegetation's condition varies within a land use e.g. closed-canopy scrub compared with open-canopy scrub, or clumped scrub in pasture compared with scattered scrub. Appendix B of Hicks 2000b illustrates how these figures can be obtained. Appendix C illustrates how erosion's extent can be estimated for different landforms, as an alternative to analysis by soil groups.

A third example is the proportion of secondary vegetation remaining under different land uses e.g. patches of indigenous forest within intensively cultivated land. Appendix A of Hicks 2000c illustrates how this information can be made available.

2.22 Comparison of 1999 survey results with a survey in the future

It is likely that new technological advances e.g. orthophotos or high-resolution satellite images will be available when ARC wishes to update its land use and erosion data, in several years' time. This raises the question, whether changes can be detected by comparing the new data with point sample estimates from the 1999 survey. The comparison is feasible, and Technical Appendix four discusses how to make it.

3 Technical appendix three

How to derive the Ministry for Environment's preferred indicators for hill country erosion monitoring

3.1 Introduction

Objective 3 of the contract brief is 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.

For the 1999 survey, erosion and land use have been recorded 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".

3.2 LUC units with moderate or greater erosion risk

Erosion risk for North Auckland LUC units has been defined in the bulletin Land Use Capability Classification for Northland (Harmsworth 1995), and for South Auckland LUC units in an as yet unpublished bulletin Land Use Capability Classification for South Auckland-Waikato (Jessen unpub.).

In North Auckland, all Class VIe, VIIe and VIIIe land use capability units (excluding units on sand country) could be regarded as hill country at moderate risk from one or more types of erosion; likewise in South Auckland.

3.3 Vegetation covers regarded as soil conservation measures

There are no standard definitions of these. Consensus amongst practising soil conservators in regional councils would be:

- Pair-planted poplars or willows in pasture
- Space-planted poplars or willows in pasture
- Close-planted poplars or willows
- Pine, cypress, eucalypt or wattle woodlots

In some regions, indigenous tree or scrub cover is regarded as a soil conservation measure where retained or restored. These would be:

- Manuka or kanuka scrub
- Broadleaved scrub
- Kauri, hardwood, podocarp or beech forest
- Mixes of the above

There is increasing recognition that other indigenous vegetation covers also have value for soil conservation:

- Tussock grassland
- Alpine scrub
- Coastal vegetation
- Wetland vegetation

There is no consensus about the role of exotic scrub. Some species are widely planted for soil conservation e.g. shrubby acacias, brush wattle, tree lupin, tree lucerne. Others regarded as weeds e.g. gorse, buddleia, sweet briar, have some value as ground cover and as a nurse crop for natural regeneration.

Bearing in mind the above consensus (or lack of it in some cases), the following vegetation codes in the 1999 survey could be regarded as soil conservation measures:

Dc	Dairy pasture with spaced conservation trees
De	Dairy pasture with spaced conifers
Ds	Dairy pasture with natural scrub clumps
Dn	Dairy pasture with natural tree clumps

Ic	Improved drystock pasture with spaced conservation trees
Ie	Improved drystock pasture with spaced conifers
Is	Improved drystock pasture with natural scrub clumps
In	Improved drystock pasture with natural tree clumps
Uc	Unimproved drystock pasture with spaced conservation trees
Ue	Unimproved drystock pasture with spaced conifers
Us	Unimproved drystock pasture with natural scrub clumps
Un	Unimproved drystock pasture with natural tree clumps
C	Close-planted soil conservation trees (poplars, willows, gums, wattles)
E	Coniferous plantations or woodlots (pines, firs, cypresses, redwoods)
S	Natural scrub (undifferentiated)
N	Natural forest (undifferentiated)
M	Coastal vegetation (marram, spinifex, mingimingi, flax etc.)
W	Wetland vegetation (flax, raupo, sedges, rushes)

X (exotic scrub), together with Dx, Ix and Ux, should probably be excluded, as species in the Auckland area are generally gorse, tobacco tree, brush wattle and shrubby acacias.

Where tree or scrub cover in pasture is sparse e.g. Pc', it should not be regarded as an effective conservation measure, as its density (or spacing if planted) is insufficient for roots to stabilise soil.

Likewise, where tree or scrub cover has gaps occupied by different vegetation e.g. Fs, Sx, it should not be regarded as a conservation measure, because its ability to stabilise soil has been impaired by disturbance (windthrow, landslides, animal browsing, plant diseases).

Open pasture (D, U, I) can be regarded as a conservation measure on stable sites, as here it is capable of protecting soil from surface erosion. On its own, it should not be regarded as a conservation measure on unstable sites, where its root structure is insufficient to protect against subsoil erosion.

Cropland, orchard and market garden (C, O, H) can be regarded as conservation measures on stable sites, provided plant density is sufficient to protect soil from surface erosion. This includes harvested sites, provided stubble is left in situ or mulched. Where cover has been removed by cultivation or up-rooting, prior to planting a fresh crop, sites have to be regarded as being at risk from surface erosion. Orchards can be regarded as conservation measures where planted on unstable sites, as tree root density is generally sufficient to anchor subsoil. However this is not the case for cropland or market garden.

3.4 Why it is inadvisable to proceed with MfE's preferred indicator

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.

The chief weakness of MfE's preferred indicator is its in-built expectation that erosion is related to land use capability. Land use capability survey is exactly that - a technique for assessing land's capability for sustained primary production (Soil Conservation and Rivers Control Council 1973). The amount of erosion on a piece of land, to which a land use capability unit has been assigned in the course of survey, may be very great or extremely small or somewhere in between, depending on how that piece of land is managed.

Because erosion has long been recorded as part of New Zealand's land use capability surveys, an expectation has formed in its practitioners' minds that each land use capability unit has its own characteristic level of erosion, which should be measureable.

There is a long history of surveys of "erosion control effectiveness", "catchment condition", "storm damage" etc., stratified according to land use capability. In each case, people have spent a lot of time and money on data collection, only to find out on sitting down to analyse the collected data that statistical analysis either can't be carried out; or if it can, doesn't reveal any clear trends or significant differences.

The reasons for this are:

- Analysis by LUC unit entails dividing the data into a large number of strata, each of which contains only a few observations. Their representativeness is uncertain.
- LUC units are composites of a rock type, a soil type, and a slope class. If a difference in erosion is detected between two LUC units, it's quite unclear whether the difference is due to rock type, or soil type, or slope class, or all three acting in combination; or another factor external to all three e.g. a difference in the mix of land uses on each unit.
- The "measurements" of erosion have usually been 1 to 5 arithmetic rankings of erosion's severity, 1 to 1000 logarithmic rankings of sediment supply etc. These do not lend themselves to quantification, establishment of error limits, or testing for statistical significance.

Over the same period of time, other surveys of vegetation's effectiveness for erosion control have been carried out, which avoid stratifying observations by LUC unit. They fall into four categories:

- Stratification by rock type e.g. Pain 1968, Eyles 1971, Selby 1967, 1976
- Stratification by slope angle on one or more rock types e.g. Crozier et al 1980, Trustrum and de Rose 1988, De Rose et al 1993, 1994
- Stratification by land use on a single rock type e.g. Pain and Stephens 1986, Black 1988
- Collection of a sufficiently large random sample to represent the "mix" of rock types, soil types, slope classes etc. in the area being surveyed e.g. Philips 1982, Philips and Marden 1990, Marden et al 1991, Marden and Rowan 1993, Bergin et al 1995, Hicks 1989 - 1998.

These surveys have generally measured density of erosion scars, area of soil eroded, or volume eroded. They have produced data with measured error margins. They have statistically tested comparisons. And they have usually produced clear findings about the influence of rock type etc. on erosion.

MfE has chosen to promote a method which has clearly failed to deliver the goods on previous occasions, and to ignore alternative methods which have. The choice is, to say the least, puzzling. Its preferred indicator does not even measure hill country erosion; just the extent of land which lacks erosion control measures under a single land use, pastoral farming. Erosion and erosion control, on land under other uses, do not rate a mention.

3.5 Can MfE's proposed method be improved upon?

The answer is clearly yes - it not only can be, but must be. Otherwise, regional councils will end up collecting a lot of expensive but un-useable data. The three essential changes are:

- Use LUC units as a template to define "all hill country land at risk of erosion" - but avoid analysing data according to individual LUC unit.
- If a stratification of data is desired, stratify by physically recognisable characteristics i.e. geology, soil type (grouped, not individual), slope angle. Alternatively, analyse a bulked sample that's sufficiently large to represent the "mix" of geology etc. in a region.
- Make measurements for which error limits can be defined, and which are statistically testable.

The Auckland point sample has been designed in a way which meets the second and third criteria. The first criterion (a LUC template) can be added if desired, simply by ARCINFO layer overlay on the Regional Council's GIS. The result of so doing would be just four measurements:

- Area of all hill country LUC units without vegetation regarded as soil conservation measures,
- Area of current erosion, on all hill country LUC units without vegetation regarded as soil conservation measures,
- Area of all hill country LUC units with vegetation regarded as soil conservation measures,
- Area of current erosion, on all hill country LUC units with vegetation regarded as soil conservation measures.

These appear to be simple measurements which will enable extent of erosion in hill country to be used as an environmental indicator, in line with MfE's preference.

4 Technical appendix four

How to compare the 1999 point sample with data collected by alternative methods in future years

4.1 Introduction

Objective 4 of ARC's brief was 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.

4.2 Up-date of observations made in the Hicks (1994) scoping paper

Pages 36 to 41 of Hicks 1994 compare feasibility, time and cost of various methods available for surveying land use and soil condition, as of 1994.

4.2.1 Field survey

Ground-based survey, using a mixture of car and foot inspection, was estimated to take 500 to 1000 days; clearly beyond the resources of ARC staff, but could be done by commissioning temporary labour e.g. university students during their summer vacation. A disadvantage of this approach was identified as variable quality of the mapping. This option was discussed with former land management officers Helen Moodie and Simon Cathcart in 1995 and 1996, but rejected. A variant of the option, mapping land use and erosion only on areas of soil susceptible to degradation, was also rejected at the time but has been partly implemented in summer 1999-2000 with the mapping of market gardens and cropland on soil groups I1 and I2 in Franklin District by Trent Sunich, working under the supervision of current land management officer Tony Thompson.

4.2.2 Aerial photographs

Interpretation of existing aerial photographs was estimated to take 79 to 158 days, but to have the disadvantage that existing coverage had been taken at non-uniform scales and different dates between 1979 and 1993. A variant of this option was identified as new aerial photographic coverage at a scale of either 1:25,000 or 1:50,000. Helen Moodie and Simon Cathcart identified a high level of interest amongst staff in other ARC sections, which needed new photographic coverage for their own purposes e.g. planning, heritage protection, arks and reserves management. In 1998, ARC decided to commission new coverage at a scale of 1:50,000, with enlargements printed at 1:10,000; cost to be shared amongst the various sections' budgets. Coverage was taken by Air Logistics between January and July 1999. This enabled the SER survey of land use and erosion to proceed. Following discussion between Tony Thompson and the author late in 1999,it was decided to undertake the survey as a point sample, instead of producing maps which depict land use and erosion. The rationale for this was that a point sample could produce data of known accuracy (see Technical Appendix 1), at a fraction of the time and cost entailed in producing region-wide maps.

4.2.3 Airborne scanner

Another option outlined in the 1994 paper was airborne scanner coverage. At the time, another regional council had decided to obtain such coverage for SER in 1995, using an aircraft and instrument flown in from Australia, to be followed by computer classification of the images. This "high-tech" approach was given widespread newspaper publicity. The 1994 paper pointed out that there could be a delay of up to 12 months before suitable cloud-free images could be acquired for the entire region; that the instrument concerned had a resolution of approximately 3 metres (inferior to aerial photographs); that computing costs entailed in digital classification would be large; and that visual interpretation of the scanner images while slower, would be more accurate. The option would however have the advantage, that scanner images could be rectified into a format resembling an orthophotograph, for entry of boundaries into GIS storage. ARC staff did not show much interest in this option; wisely as it turns out, because the other regional council experienced all the problems forecast. It never obtained a satisfactory map of regional land use or erosion from its scanner coverage.

4.2.4 Satellites

Yet another option was computer classification of land use and erosion from satellite images. The best available at the time were those taken by the French remote sensing satellite SPOT, with a resolution of 10 m (black-and-white) and 20 m (colour). The American LANDSAT came a close second, with resolution of 30 m. These resolutions were viewed as sufficient to discriminate broad land uses e.g. cropland, pasture, scrub, forest plantation, indigenous bush; but not detailed patterns of land use. Visual interpretation of satellite images was recommended as likely to produce better results than digital classification, without the latter's costs and time delays.

Existing satellite images dated back to 1986 - 1991, so commissioning new satellite coverage was identified as a variant to the option. The scoping paper recommended an interim map of land use from 1987-1988 satellite images which could be acquired for minimal cost; if this proved satisfactory, then new coverage to be commissioned in 1995-1996, and a new map to be prepared showing:

- Changes in land use 1987-88 to 1995-96
- Land where uses likely to cause soil degradation coincide with susceptible soils (by digital overlay with soil maps).

New SPOT coverage of the Auckland region fortuitously became available in 1995 - 1996, at no cost to ARC. The Council's Natural Heritage Section commissioned Landcare Research to produce a map of vegetation cover, similar to those which Landcare had already produced for the Gisborne, Marlborough, Canterbury and Otago regions. Vegetation categories depicted on these maps were considerably more detailed than land use classes proposed by the 1994 scoping paper, and the production method was digital classification. The equivalent Auckland map was duly produced, and proved to have the disadvantages forecast i.e. the desired level of detail could not be attained, and errors in digital classification were unacceptably high.

4.2.5 Land information databases

Other options, not covered in any detail by the 1994 scoping paper but discussed with Helen Moodie and Simon Cathcart in 1995 - 1996, were to:

- Merge cadastral parcel-based land use data, held by the Rodney and Franklin District Councils, with DOSLI's Digital Cadastral Data Base (DCDB) for the Auckland region,
- Acquire a regional sub-set of MAF's AgriBase (AB).

These options were not pursued at the time, because of the high annual lease costs for DCDB and AB. The Council's GIS Section subsequently acquired DCDB in 1998.

4.3 New technologies, not envisaged in 1994, which may be available by 2010

Has remote sensing technology delivered the goods between 1994 and 2000? The answer has to be "no". Out of potential problems with new technology identified in the scoping paper:

- Time delays in acquiring data,
- Limited resolution,

have not been problematical. However:

- Accuracy of digital classification,
- Cost of digital classification,

have. I can do no more than repeat two messages here:

- The chief uses of digital image processing are to produce a hard-copy image from remotely sensed data, and rectify it to fit a map grid.
- Digital classifications of land use etc. from remotely sensed data - whether satellite or airborne - have been carried out experimentally since 1973. They have not yet produced a map with category discrimination or accuracy, as good as what can be achieved by a photo-interpreter visually classifying a hard copy of the same image.

Is the situation likely to change between 2000 and 2010? The main change that we will see is availability of high-resolution images from commercial remote sensing satellites. After several abortive launches and instrument failures between 1995 and 1999 e.g. SPOT 4, JERS 1 and a Russian equivalent, 1-metre-resolution panchromatic coverage is finally available from the IKONOS 1 satellite launched in October 1999. Test images of U.S. sites have been widely disseminated on the Internet, and appear sufficiently detailed to undertake land use classification. The commercial owner is offering 11 by 11 km coverage at a cost of approximately US$3000.

It is quite likely that a repeat SER survey of land use or erosion, in about 10 years time, will be undertaken from this type of satellite image. Its present limitations - the "grainy" appearance of 1-metre-resolution cf. aerial photographs, and panchromatic sensing instead of colour - are likely to be overcome between now and then.

If not, then in 10 years ARC is likely to be using a similar product taken from high-flying aircraft - colour photographs which have been scanned and rectified to fit a map projection, so that they can be registered with various layers (cadastral boundaries, soil maps etc.) in a GIS.

What I do not foresee, is successful automated classification of land use from the satellite or aircraft images. If 27 years of attempts at digital classification have only produced maps of dubious accuracy, the options are either to persist with the attempt; or to recognise that visual classification is a superior method. In this regard, it is interesting to note that military agencies, which have had access to high-resolution images and high-speed computers since the 1960s, use digital classification only for change detection. For identification of what the change is, that portion of the image is passed to a suitably trained photo-interpreter.

4.4 Ways to compare point data collected at different dates

A final issue to be addressed, is how ARC's point sample, visually observed from aerial photographs taken in 1999, can be compared with data collected by other means e.g. area measurements - possibly from other media like satellite images - in a future re-survey.

4.4.1 If a point sample is taken for future re-survey

Re-survey of the same points is simplest, and also best in terms of minimising sample error. A single error term applies at both dates; whereas two would need to be applied if a different point sample is taken (see Technical Appendix One).

It would have been easy, this time round, to sample points evenly spaced around each photo enlargement's centre; or points on a nominal map grid aligned with each enlargement's edge. These strategies were avoided, as relief displacement of the points would have resulted in their forming an irregular pattern on future photography, taken at a different scale along different flight lines. This would have made them tedious to re-locate. Instead, NZMS 260 map grid intersections were used to sample points for the 1999 survey, because they can be easily re-located by overlay of the map grid onto rectified satellite or aircraft images. Detail photo-interpreted in the 1999 survey will be within +- 50 m of these points (see Technical Appendix Two).

4.4.2 If an area measurement is taken for future re-survey

It is conceivable that in 10 years' time, there may be valid reasons for doing the survey differently e.g. as sample area measurements; or even as measurements of land use and erosion region-wide. There is no problem comparing estimates of land use or erosion from sample areas, with estimates of land use or erosion from sample points, so long as the error terms for both samples are known. Similarly, if the 1999 estimates are compared with region-wide data, the significance of changes can still be tested by working out whether the increase/decrease for a region-wide parameter - such as area of H1b soil eroded - exceeds the 1999 sample error.

4.4.3 Depth measurements

One difficulty I foresee is if depth of soil eroded - or volume of soil eroded - is measured at sample points in a future re-survey. Such data cannot be compared with estimates of eroded area. Depth or volume measurement has not been attempted in the 1999 survey, firstly because it entails field measurement which is time-consuming. Secondly, there is considerable uncertainty about the interpretation of soil depths or volumes. New technology may overcome the first obstacle within ten years. It is unlikely to overcome the second.

4.4.4 Land use categories

The only other difficulty I foresee is if a future re-survey uses land use categories that differ from the 1999 survey. The 1999 categories have been selected, not just because it's feasible to interpret them from aerial photographs, but because they suffice for the purpose of state-of-environment reporting (see Technical Appendix Two). There is no reason why more detailed categories should not be used for a re-survey - say, different types of indigenous scrub cover; or exact crops grown in market gardens - provided there's another valid reason for surveying land use to this level of detail in the year 2010 (or when-ever). What will be necessary for a new SER report in 2010 is to ensure that whatever categories are selected, they can be amalgamated into the same land use classes used for the 1999 survey, so that a comparison of change between the two dates remains possible.

4.4.5 Frequency of re-survey

SER survey at 5 year intervals is proposed in a number of consultants' reports commissioned by MfE. The reason is generally obscure and if stated, weak e.g. because fresh aerial photographic coverage is often obtained at intervals of roughly five years. It is of course possible to re-survey every time fresh aerial or satellite coverage is taken, even annually; but do Regional Councils need to, in order to detect changes in state of their environment? One problem with survey at increasingly short intervals of time is that the percentage changes become smaller. There is greater likelihood that they will be insignificant, once sampling error, precision, and measurement error are taken into account. A genuine change is more likely to be detected over long time intervals. This is particularly the case with erosion, which is episodic i.e. likely to occur in short bursts associated with heavy rainfall in a wet year, separated by normal years or dry years when very little happens.

I am reluctant to recommend a fixed time interval for SER of erosion, but can say that in high-rainfall parts of Auckland e.g. the Hunua and Waitakere ranges, the return period of erosion-inducing rainfalls is about once every 3 years on average. In the driest parts of the region e.g. the Hauraki Gulf peninsulas and islands, it is about once every 8 years. Thus, re-survey at 5 year intervals may not detect any changes in erosion in some parts of the region, simply because there have not been any erosion-inducing events. In contrast, a re-survey at 10 year intervals will detect the cumulative annual erosion of fields that are cropped or heavily grazed; the frequent erosion of steep land by high rainfall most years; and the occasional erosion of hill country or rolling footslopes by exceptional rainstorms that may only occur once a decade.

5 Technical appendix five

Trial of methods for eroded area measurement on sand country

5.1 Introduction

A Trial of Methods for Eroded Area Measurement on Sand Country was carried out using a portion of photo enlargement R12 1.4 which covers Colin Hull's farm at Awhitu (erosion ranging from slight to severe) together with the properties of his neighbours Alan McGill and Lance Giltrap (each with slight to moderate erosion).

5.2 Delineating eroded areas

Bare sand drifts, even where small, were easily delineated due to their strong colour contrast with adjacent pasture. Locations and areas on the attached overlay should be accurate.

As regards depleted pasture - where sand is showing through sparse grass cover - large patches on sunlit faces were easily delineated. Where faces were shaded at time of photography, it was difficult to draw boundaries around some extensive patches that I know to be present on these properties. On sunlit and shaded faces alike, it was near-impossible to discern small patches of depleted pasture only a few metres across. For these reasons, I suspect there are many more small patches than are shown on the overlay.

5.3 Area measurement

Areas were initially measured with ARC's Koizumi electronic planimeter (Table 1). The measurements took 60 minutes. However, testing the instrument's resolution revealed that one increment equals 10 square millimetres. For large patches of bare or depleted ground on the overlay, this resolution converts to an error of less than 1%. Unfortunately, for small patches - less than 100 square millimetres - the error of individual measurements is greater than 10%, so I cannot recommend this instrument for erosion measurement.

In the absence of a planimeter with 1-2.5 mm2 resolution, one alternative is manual measurement with a fine dot pattern or grid. This produces accurate measurements (Table 1), but to measure the A4-size overlay took 45 minutes. Measuring individual areas of bare sand throughout the coastal sand country (8 A4 overlays times' 36 1:10,000 enlargements) would clearly take a great deal of time.

5.4 Area estimation from a point sample

Point sampling cannot supply areas for individual patches of bare sand, but will provide estimates that are close to cumulative area eroded, when points are aggregated for a particular district or property. By way of example, Table 2 compares cumulative area of bare sand for the three properties, estimated using points on a 2 cm grid (200 metre spacing at 1:10,000 photo scale) with cumulative area from Table 1. Obtaining the estimate took 10 minutes.

5.5 Effect of image displacement

The enlargements are un-rectified, so shapes and areas on them are slightly distorted by camera geometry and ground relief. Location of intersection points from the NZMS260 map grid indicated that these were generally within 0.5 cm of a nominal 10 cm grid overlaid on the enlargements (+- 50 metres at 1 : 10,000 photo scale). On steep terrain, some points were displaced up to 1 cm (+- 100 metres), but this was not the case on sand country where relief is generally subdued.

Most patches of bare ground or depleted cover are sufficiently small, that they lie on a single face, and points along their boundary are similarly oriented with respect to interaction between camera geometry and ground relief.

For these reasons, measurements made directly from the enlargements will be very close to true ground areas.

If areas are to be estimated from a point sample, the initial measurement - percentage of points eroded/depleted - may be converted to an area in hectares, by applying it to the true ground area of whichever property or paddock is being measured. The latter - if not already available on a survey plan - can be obtained by planimetry from a NZMS 260 topographic map.

5.6 Conclusions

ARC's 1:10,000 enlargements (from 1:50,000 colour aerial photographs) are sufficiently good for a photo-interpreter to delineate areas of bare sand drift. Where bare sand is interspersed with depleted vegetation, it can be clearly delineated on sunlit terrain, but there is difficulty in doing the same on shaded terrain e.g. gully sides and cliffs.

Automated (digital) classification of bare ground, after scanning the enlargements, is not an option. Area of sand drifts would be inflated by inclusion of other kinds of bare ground e.g. cultivated fields, vehicle tracks, cliff faces, beaches. Area of depleted cover would be under-measured, because of the shadow problem already referred to.

Should the ARC wish to obtain measurements of eroded area for individual farms on sand country - or for the sand country as a whole - then visual identification (photo-interpretation) of bare ground and/or depleted cover is recommended. Any of the three methods tried can provide acceptable accuracy:

- Electronic planimetry: provided a planimeter with sufficient resolution is used,
- Grid overlay: provided a sufficiently fine grid is used,
- Point count: provided a sufficiently close point sample is taken.

Of the three, a point sample count is clearly the quickest. It can be used equally well on an overlay after delineating boundaries of bare sand and depleted cover; or directly on the enlargement.

Table 1 Comparative measurements of bare sand

	Planimeter (10 mm2) ha.	Fine grid (1 mm2) ha.
Largest patch	17.8	16.5
Medium patch	1.6	1.3
Small patch	0.1	0.04
Cumulative area, all patches	49.4	44.5
RMS error	+-0.9	+-0.1
Time taken, all patches	60 minutes	45 minutes

Table 2 Comparative accuracy of area measurements and area estimate from point sample

	Area bare	As % of area measured	Sample error
Planimeter (10 mm2)	49.4 ha	8.1%	+-1.8%
Fine grid (1 mm2)	44.5 ha	7.3%	+-0.2%
Point sample (2 cm intervals)	48.8 ha	8.0%	+-1.0%

6 Technical appendix six

Trial of method for measuring erosion in cropland

6.1 Introduction

On 7 January I undertook some trial photo-interpretation and measurement on enlargement R12 6.3, using a selection of cropped fields on Pukekohe Hill which I had viewed shortly after the January 1999 rainstorm.

Patches of soil accumulation (dark) and soil loss (pale) could be clearly seen on the fields, contrasting with the "normal" brown colour of less-disturbed soil. It proved relatively easy and quick to measure what percentage of each field showed recent accumulation or loss (Table 1), with a dot pattern at 2 mm spacing. Precision of measurement was +-2% (1/53) for the smallest field (no. 4). It took 16 minutes to measure 9 fields.

However, having viewed these particular fields in January, I know that areas of deposited or eroded soil were somewhat more extensive than are visible in the photographs taken in April. Comments about each field follow, giving reasons why the photos do not show true extent of soil disturbance:

- 1: Extensive dark soil on low ground in east half of paddock. Fresh soil deposits about 150 mm thick here in January 1999. Higher ground in west half of paddock had numerous shallow rills; now completely obscured by cultivation, except along two wheel-tracks.
- 2: Extensive dark soil on low ground through middle of paddock. Complex pattern of deposition and shallow rilling here in January 1999; now mixed together by cultivation.
- 3&4: No evidence of erosion or deposition in these fields at date of photography. In January 1999, erosion was minimal (onion crop not yet pulled, and much plant trash lying about); band of deposited soil about 2 - 3 metres wide at bottom of fields appeared to have been there for some time prior to storm.
- 5: Extensive dark soil in grass/weed-covered north-east quarter. This area was waterlogged in January 1999 and apparently had not been cultivated for some time. It was acting as a trap for soil washed from rest of paddock, which had several shallow rill networks; these were not visible at date of photography, but one patch of pale soil was present in north-west quarter.
- 6: No evidence of erosion or deposition in this field at date of photography. However in January 1999 it had a complex pattern of shallow rills and soil deposits in amongst pulled onion rows.

- 7&8: Normal soil colour in left-hand paddock, apart from a small regularly-shaped dark patch, probably topsoil placed by machine. Pale patches in bare parts of right-hand paddock run through its cover crop, as areas of water-stressed vegetation. In January 1999 the left-hand paddock had been roughly ploughed, the right-hand was under cover crop (unidentified legume); neither had any significant erosion or deposition.
- 9: A small pale patch behind sheds may indicate either topsoil removal or compaction; either way, likely to be result of concentrated machine traffic. Otherwise, soil colour is normal, beneath freshly-sprouted crop rows. In January 1999 this paddock had been harvested, and had several severe rills 300 - 600 mm deep running from top to bottom.

The implications are:

- The aerial photos show some areas where the soil is clearly darker, and others where it is lighter than the typical colour of Patumahoe clay loam.
- In view of their slope position, these particular areas are likely to be sites of long-term accumulation (dark, moist topsoil) or long-term loss (pale, dry subsoil).
- Other areas, where there was recent deposition or erosion in the January storm, have been completely obscured by subsequent cultivation and crop growth.
- This raises the possibility that what can be seen, are just some of the long-term accumulation or loss sites. Others may have been obscured by cultivation practices - or the local custom of scraping soil from the bottom of a field every few years and spreading it upslope.

For these reasons, areas visible on aerial photographs could easily lead to erroneous conclusions about the extent of soil accumulation/loss.

A field sampling programme which entails soil cores or holes at regular intervals may be a better way to determine whether apparently-intact soil has been disturbed.

Table 1 A selection of cropped fields on Pukekohe Hill

Field	Area	Long term soil accumulation?	Long term soil loss?
1	4.5	2.0	0.3
2	8.2	2.2	0
3	3.2	0	0
4	2.1	0	0
5	4.2	1.0	0.3
6	5.2	0	0
7	3.4	0.4	0
8	2.9	0	2.1
9	5.5	0	0.3
	ha.	ha.	ha.

7 References

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