Environment Waikato Technical Report 2003/14

Soil Intactness Assessment of the Waikato Region: 2003

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Executive summary

Following review of the scoping report by the Council's Resource Information Group, and after the Council's new aerial photographic coverage commenced in 2002, Dr. Hicks was contracted to undertake an initial survey of soil intactness. Survey commenced with arrival of the first orthophotos in December 2002, and continued intermittently until the last arrived in May 2003. Data processing and analysis were undertaken in June, together with preparation of a draft report. Additional data analyses and field checks took place in July and August, as Resource Information Group staff read and commented on the draft. A final report was supplied in September 2003. In August 2005 an additional analysis of bare ground was carried out for all points in the original sample, to bring measurements to the same standard as subsequent surveys carried out for other regional councils in 2004 - 2005 using an improved cluster sampling technique Data from this analysis were incorporated in the report's tables, with slight amendments to accompanying text where needed, in December 2005 (this version).

Soil intactness and disturbance

70.9% of the Waikato's soil is intact.

Of this, 41.7% is on stable sites - drained wetlands, protected floodplains, elevated terraces, rolling downlands, ridges, spurs or footslopes in hill country - that show no signs of past erosion and are currently well-vegetated. 29.2% is on unstable sites - healed erosion scars in hill country, inactive gullies on downlands, terrace edges, flood-prone river flats, undrained wetlands - that are currently inactive and well-vegetated. Here vegetation cover - whether crops, pasture, plantations, scrub or forest - is at present sufficiently dense to protect soil against disturbance.

5.9% of the Waikato's soil has been recently disturbed by human use of the land. Recently disturbed sites are those which have crops growing after cultivation or stubble after crop harvest, spelled pasture recovering from heavy grazing, and grass/legume cover oversown following forest harvest. They also include tracks and earthworks which are revegetating.

6.8% of the Waikato's soil is freshly disturbed by land use. Sites are as described above but include areas devoid of vegetation. Soil bared by fresh disturbance amounts to 1.0% of the region's area.

6.2% of the Waikato's soil has been recently disturbed by natural processes of erosion or deposition. Recently disturbed sites are revegetating mass movement scars, gullies and soil pipes, areas of scour and siltation on stream banks, areas where sand is blown away or accumulates, and miscellaneous disturbances such as rockfall on bluffs, high-altitude sheet erosion and geothermal activity.

3.1% of the Waikato's soil is freshly disturbed by natural processes. Sites are as described above but include areas devoid of vegetation. Soil bared by fresh disturbance amounts to 0.4% of the region's area.

Pressure on soil – impacts of land use

Fresh disturbance of topsoil is located mainly in dairy pasture and drystock pasture. It is caused by heavy grazing of pasture prior to spelling, and also by extensive farm tracks. Lower but still measurable percentages occur in forest plantations due to topsoil exposure by logging and associated tracking; and under intensive uses (orchards, vegetable growing, cropland) which entail soil cultivation. Under exotic scrub, also under natural vegetation cover (undrained wetland, lowland scrub and forest, mountain scrub and tussock), fresh topsoil disturbance is slight.

% of region:	in use	freshly disturbed by land use	bare surface due to land use
Intensive uses	1.9	0.1	<0.1
Dairy pasture	24.2	2.9	0.4
Drystock pasture	26.7	2.0	0.2
Forest plantations	13.7	1.2	0.2
Exotic scrub	3.4	0.2	<0.1
Natural scrub & forest	20.8	0.1	<0.1
Mountain scrub & tussock	1.7	0.1	0.0
Wetland	0.8	0.0	<0.1

Fresh disturbance of subsoil is slight under intensive uses, dairy pasture and forest plantations. It is located mainly in drystock pasture, where the causes are landslides and earthflows in hill country, or gullies and streambank erosion in pumice-mantled downlands. Under exotic scrub and natural vegetation cover, fresh subsoil disturbance is slight except in natural scrub and forest. Here its incidence is raised by landslides, gullies and streambank erosion in steep ranges.

% of region:	in use	freshly disturbed by natural processes	bare surface due to natural processes
Intensive uses	1.9	0.0	0.0
Dairy pasture	24.2	0.2	<0.1
Drystock pasture	26.7	1.8	0.1
Forest plantations	13.7	0.3	<0.1
Exotic scrub	3.4	0.1	<0.1
Lowland scrub & forest	20.8	0.6	<0.1
Mountain scrub & tussock	1.7	0.1	0.1
Wetland	0.8	0.0	0.0

Pressure on vegetation – impacts of land use

Secondary vegetation is present on a fifth of soil under intensive uses. It is present on a quarter of dairy pasture, two fifths of drystock pasture, and half of forest plantations. The proportion of planted secondary vegetation remains high for all these land uses. Conversely the proportions of induced and natural secondary vegetation remain small, but increase with the transition from intensive use through pasture to forest plantation.

Secondary vegetation is present in four fifths of the exotic scrub, half the natural scrub and forest, a fifth of the mountain scrub and tussock, and just under half the wetland. The proportion of natural secondary vegetation is high, and is successional after site disturbance by past land use e.g. logging or natural events e.g. storms. The balance is rank grass, exotic scrub or wildling trees induced as a result of similar site disturbance.

% of area in use:	with secondary vegetation			
	natural	induced	planted	total
Intensive uses	0.9	-	20.4	21.3
Dairy pasture	5.9	0.4	18.5	24.8
Drystock pasture	20.6	8.4	12.6	41.6
Forest plantations	11.7	15.7	25.3	52.7
Exotic scrub	45.6	32.6	-	78.2
Natural scrub and forest	40.7	8.7	-	49.4
Mountain scrub and tussock	18.2	-	-	18.2
Wetland	16.7	29.2	-	45.9

Response to pressure – extent of vegetative conservation measures

On land in commercial use - intensive cultivation, dairy and drystock pasture, forest plantations - primary vegetation functions as a soil conservation measure where dense, providing protective cover against surface erosion by water and wind. Secondary vegetation where dense protects against both surface and subsurface erosion; against the latter by various root reinforcement and de-watering effects. This holds true whether the vegetation has been deliberately planted to control erosion,

planted for commercial reasons, or merely retained on sites that are difficult to develop. By dense, is meant continuous primary cover or well-spaced secondary cover. By sparse, is meant depleted primary cover, or scattered secondary cover.

On land in natural cover, primary vegetation can be said to have soil conservation value. Typically it is tree or scrub cover. Whether reserved for ecological reasons/watershed management, or merely left on land that is not wanted for commercial use, it also protects against both surface and sub-surface erosion. Secondary vegetation is typically herbaceous or scrub cover. It indicates site disturbance - usually accompanied by erosion. Some kinds of natural secondary vegetation - for instance, trees emerging through scrub cover - also indicate a degree of site recovery so could be said to have soil conservation value.

% of area in use:	**with dense vegetation that: functions as a soil conservation measure (commercial land uses) or is of value for soil conservation (conservation land uses)**		
	primary	**secondary**	**Total**
Intensive uses	60.2	19.5	79.7
Dairy pasture	59.9	14.4	74.3
Drystock pasture	44.4	17.3	61.7
Forest plantations	43.2	52.6	95.8
Exotic scrub	21.8	56.8	78.6
Natural scrub and forest	50.6	44.5	95.1
Mountain scrub and tussock	67.0	33.0	100.0
Wetland	54.2	45.8	100.0

These definitions may seem broad, but they give a truer picture of conservation measures adopted by landowners and public agencies, than would be obtained by looking solely at conservation plantings. They show that the extent of vegetative conservation measures is high for all land uses, though variable. Drystock pasture stands out clearly as lower than the rest. Intensive uses, dairy pasture, and exotic scrub are somewhat lower than desirable. In forest plantations and amongst the conservation uses, almost all vegetation has a soil conservation role, although much of the secondary vegetation is exotic scrub or wildling trees, regarded as undesirable for ecological restoration.

Effectiveness of response – reductions in soil disturbance

Bare topsoil - exposure to risk of surface erosion - is high where primary vegetation cover is maintained by intensive land uses (orcharding, vegetable growing, cropping). It drops with the transition from fresh cultivation to growing crops, and rises again with crop harvest. Under all other commercial land uses, the percentage of bare topsoil is kept low where dense primary vegetation is maintained. Conversely the percentage becomes high, where sparse primary vegetation is depleted. Under conservation uses, primary vegetation generally remains dense, and bare topsoil minimal:

% bare topsoil where:	**primary vegetation is**	
	sparse	**dense**
Intensive uses	16.0	0.2
Dairy pasture	2.8	1.2
Drystock pasture	2.0	0.8
Forest plantations	5.2	0.2
Exotic scrub	-	1.5
Natural scrub	-	0.1
Natural forest	-	0.2
Mountain scrub and tussock	-	0.0
Wetland	-	0.0

Where secondary vegetation is retained or planted amongst commercial land uses, bare topsoil remains at levels intermediate between sparse and dense primary vegetation. Where secondary vegetation is present amongst conservation uses, bare

topsoil is at or close to zero except for two categories where it increases - rank grass in scrub; and exotic trees in natural forest - perhaps because in both instances, secondary vegetation is associated with site disturbance. Under all uses, the percentage of topsoil bare does not decline where secondary vegetation is dense, nor is there any trend for it to decline with the transition from herbaceous through scrubby to woody secondary vegetation.

% bare topsoil where:	**secondary vegetation is:**					
	wetland/rank grass		**scrub**		**Trees**	
	sparse	**dense**	**sparse**	**dense**	**sparse**	**dense**
Intensive uses	0.0	2.0	-	-	0.0	0.4
Dairy pasture	0.8	3.0	0.1	1.2	1.4	1.6
Drystock pasture	1.0	0.8	0.8	0.9	0.5	0.2
Forest plantations	2.2	0.8	1.9	0.6	0.0	1.0
Exotic scrub	-	0.7	-	0.0	-	0.0
Natural scrub	-	3.3	-	0.4	-	0.1
Natural forest	-	0.0	-	0.0	-	2.5
Mountain scrub and tussock	-	0.0	-	0.0	-	0.0
Wetland	-	54.0	-	0.0	-	0.0

For all land uses, bare subsoil - exposure by erosion processes - occurs in primary vegetation cover only where it is on unstable terrain. Under intensive use, dairy pasture or forest plantation, very little primary vegetation cover is on such sites, hence the zero or close to zero percentages. Bare subsoil starts to appear in drystock pasture, exotic scrub, natural scrub and forest; but becomes high only amongst mountain scrub and tussock.

% bare subsoil where:	**primary vegetation is**	
	sparse	**dense**
Intensive uses	0.0	0.0
Dairy pasture	0.1	<0.1
Drystock pasture	0.4	0.5
Forest plantations	0.0	<0.1
Exotic scrub	-	1.4
Natural scrub	-	0.2
Natural forest	-	0.1
Mountain scrub and tussock	-	11.0
Wetland	-	0.0

For all commercial uses except intensive, there are somewhat higher percentages of bare subsoil on sites where secondary vegetation is present. This is a consequence of secondary vegetation being retained, induced or planted on most of the unstable sites in commercial land use. Secondary vegetation appears through natural plant succession on unstable sites in conservation use; and here the percentages of bare subsoil are lower than where primary cover alone is present. Bare subsoil does not decline with the transition from herbaceous through scrubby to woody secondary vegetation; nor does it consistently decline with the transition from sparse to dense secondary cover.

% bare subsoil where:	**secondary vegetation is:**					
	wetland/ rank grass		**scrub**		**trees**	
	sparse	**dense**	**sparse**	**dense**	**sparse**	**dense**
Intensive uses	0.0	0.0	-	-	0.0	0.0
Dairy pasture	0.1	0.0	0.0	0.0	0.1	0.1
Drystock pasture	0.5	0.7	0.6	0.3	0.4	0.3
Forest plantations	0.2	0.0	0.1	0.5	0.0	0.0
Exotic scrub	-	0.0	-	1.6	-	0.1
Natural scrub	-	0.1	-	0.0	-	0.1

Natural forest	-	0.0	-	0.3	-	0.0
Mountain scrub and tussock	-	0.7	-	0.3	-	0.0
Wetland	-	0.0	-	0.0	-	0.0

A major innovation of the Waikato survey cf. earlier surveys undertaken for other regional councils, has been interpretation of orthophotos (aerial photographs rectified to fit a map grid) by on-screen viewing through GIS software, with direct entry of data to a GIS-linked database. The new procedure has proven better than expected as regards ease of use; partly due to high quality of the orthophoto coverage, and partly the good standard of its installation on EW's GIS.

The point sample is sufficiently representative to draw conclusions about soil intactness/disturbance region-wide, for land uses within the region, and for large sub-divisions of the region such as districts or catchment management zones,

To draw conclusions about the impacts of vegetation management or soil conservation, an additional cluster sample needs to be taken. A cluster sample produces sufficiently representative data for common types of secondary vegetation cover or soil conservation measure. For the less common, non-random clusters are needed.

For land use, secondary vegetation, and soil disturbance, photo-interpretation accuracy is better than 90%. For type of disturbance, photo-interpretation accuracy is lower than expected at 82%. For landforms, 76% photo-interpretation accuracy is a minor concern

Use of a large point size when sampling, raises the chance that soil disturbance will be recorded at a point. So percentage of points with fresh soil disturbance cannot be equated with percentage area of bare soil. To overcome this problem, a cluster analysis has been carried out for each combination of land use and soil conservation cover, by measuring bare ground on one hectare areas around each point in the original sample. The method appears to have produced a sufficient number of clusters, to provide reliable measurements of bare soil for most combinations of land use and soil conservation measure.

An additional analysis has been carried out for the Coromandel catchment management zone, to supply background information for staff who are currently preparing proposals for soil conservation and river control. This has enabled a procedure to be worked out for future sub-regional analyses. Its results furnish some useful examples of what can be extracted.

In short, the point sample has been designed to provide statistical data for the Waikato region and can also provide valid data for reasonably large subdivisions within it. However, to attempt a data analysis for points in an area of land any smaller than 400 km2 (equivalent to 100 points; there is 1 sample point per 4 square kilometres), would be pushing the point sample beyond the purpose for which it was designed.

1 Introduction

This document summarises results from Environment Waikato's survey of soil intactness in the year 2002. It follows on from the scoping report by Dr. D. Hicks of Ecological Research Associates Inc. (Hicks 2001). The survey was carried out primarily to provide information about soil disturbance, including erosion, for state of environment reporting. Survey data are also expected to be useful for other purposes, such as assessing the extent of vegetative soil conservation measures; providing more detail about the region's land use than can be gleaned from the first Land Cover Database (LCDB1); and as a source of facts and figures for the Council's policy documents and publications.

1.1 Background

Background to the survey is given in the earlier scoping report by Hicks (2001). Key points are:

- Environment Waikato (EW) has a statutory responsibility to collect information about state of the region's environment (Section 35, Resource Management Act).
- Much of the information collected in the past relates to water. In future, the Council foresees a need to collect more information about soil.
- Participation in the National Soil Quality Monitoring Programme ("500 Soils") and ongoing regional soil quality monitoring is already supplying useful base-line information about soil quality i.e. changes in soil fertility, structure and biology under different land uses.
- However, soil quality monitoring does not measure soil intactness: how well the region's soil is being kept in place as a resource for farming, forestry and conservation; and how much is being lost through erosion.
- A soil intactness monitoring programme should be technically sound, statistically robust, provide easily understandable data, within a short space of time, and at an acceptable cost.
- The scoping report (Hicks, 2001) selects techniques which meet Environment Waikato's particular needs, and recommends a practical strategy for using them within its region.

Following review of the scoping report by the Council's Resource Information Group, and after the Council's new aerial photographic coverage commenced in 2002, Dr. Hicks was contracted to undertake an initial survey of soil intactness. Survey commenced with arrival of the first orthophotos in December 2002, and continued intermittently until the last arrived in May 2003. Data processing and analysis were undertaken in June, together with preparation of a draft report. Additional data analyses and field checks took place in July and August, as Resource Information Group staff read and commented on the draft. A final report (this document) was supplied in September 2003.

1.2 Brief

The Council's brief to Dr. Hicks was to estimate and report on soil intactness (accelerated erosion) for the Waikato region. The resulting information should be able to provide information for specific management zones and interpreted land uses in the region. Specific services requested were:

- Point analysis photo-interpretation (1 point per 4 km2 using a 2 km by 2 km grid of 6,122 points) of ortho-rectified photos using on-screen analysis.

- Details included as per Wellington Regional Council's pilot survey (land use, vegetation category, soil stability and landform). These may be modified specific to Waikato region as agreed by both parties.

- Additional cluster samples to increase analysis detail, as specified by Environment Waikato, to a maximum of 4 additional days.

- Field validation of analyses and quality assurance of interpretation by Environment Waikato staff.

- Data analysis and interpretation.

- Report including results and interpretation, and raw summary and interpreted data spreadsheets. At least one draft report should be supplied to Environment Waikato for final editing prior to presentation of a final report.

These specifications have been met, except that photo-interpretation was not carried out at 10 points (on islands off the Coromandel coast, not covered by orthophotos); and field validation was by Dr. Hicks, at points randomly selected by Resource Information Group staff.

1.3 Survey design

Survey design is given in the scoping report by Hicks (2001). Key points are:

Measurement from aerial photographs

The reasons for selecting this technique are:

- New aerial photographic coverage is available.
- Current land use can be recorded from the aerial photos, simultaneous with soil surface stability.
- They enable a region-wide sample to be collected faster than by approximate field measurement at sample points.
- A region-wide sample enables firm identification of where soil disturbance occurs.

A point sample (dispersed grid) at 2 km by 2 km NZMS map grid intersections

Reasons for selecting this strategy are:

- Orthophoto coverage is amenable to direct overlay of the NZMS map grid.
- The map grid, although spatially non-random, provides a random sample of the underlying terrain, because soils and land uses are irregularly distributed in geographic space.
- 2 km by 2 km spacing will provide approximately 6100 points; sufficient to represent the region-wide figures to within +-1%.
- The sampling grid, if stored in EW's geographic information system (GIS), can be easily re-located for re-surveys.

Analysis procedure

The originally recommended analysis procedure was:

- Photo-interpretation from aerial photo prints (as done for MWRC and ARC).
- Manual recording on data-sheets (as done for ARC).
- Entry into spreadsheets (as done for MWRC and ARC).
- Pivot table sorts of spreadsheets (as done for MWRC).
- Significance tests based on proportions (as done for ARC).

Some changes were implemented following discussion with Resource Information Group staff. These were:

- On-screen photo-interpretation of scanned orthophotos, mounted in the GIS at Environment Waikato.
- Simultaneous keyboard data entry into a GIS database file.
- Sorts either by database query or transfer to spreadsheets.
- Significance tests to be supplemented by cluster analyses where needed.

Times and costs

These were revised from estimates in the scoping paper, in view of technical developments during the Gisborne (region-wide) and Wellington (pilot) surveys, and design changes as outlined above. Grid overlay on orthophotos, on-screen photo-interpretation, direct data entry, and pivot table analysis should enable substantial time savings.

	Old estimate	**New estimate**
Data collection, 6122 points	16 days	11 days
Additional cluster samples if needed	0 days	4 days
Field checks	0 days	3 days
Data analysis	30 days	12 days
Present & document results	16 days	10 days

Thus the new estimate of total time is 40 days.

Costs of implementation consist almost entirely of personnel time, as methods have been selected so as to utilise equipment and materials already purchased or budgeted for by Environment Waikato. Implementation has been almost entirely by independent contractor at a cost of $360 plus GST per day. There has been a small internal staff cost of 1.5 days at $800 per day, for Resource Information Group staff to set up orthophoto access and database storage in the Council's geographic information system.

1.4 What has been recorded

This section outlines what data has been recorded in Environment Waikato's geographic information system. For guidance about definitions of data items and interpretation methods, refer to technical appendices from Auckland Regional Council's survey (Hicks 2000). They are a standard reference, equally applicable to other Councils' surveys.

Point number

Unique reference number for each sample point, from 1 to 1622

Needed for sample data checks. Also useful when querying the database for points with specific features.

Grid reference

NZ Map Grid reference, stored as 8 figures e.g. 31400510

Essential if the same points are to be located for a future re-survey. Also enables point data to be analysed relative to spatial data stored in EW's GIS; for instance Land Cover Database or Land Resource Inventory.

Land use

O	Orchards and vineyards
H	Outdoor vegetable production (vegetable growing)
G	Grain crops
Gf	Greenfeed crops
D	Dairy pasture
I	Improved drystock pasture
U	Unimproved drystock pasture
E	Exotic conifer plantations
C	Exotic hardwood plantations
F	Natural forest
X	Exotic scrub
S	Natural scrub
Sa	Mountain scrub
T	Tussock grass
W	Wetland vegetation (rush, sedge, raupo, flax)
M	Coastal vegetation (sand-binding grass and scrub)

These codes are a pre-requisite for analysing soil intactness/disturbance. They provide a similar level of information about land use and primary vegetation, to the first Land Cover Database (LCDB1); though are more up-to-date (2002 cf. 1997). The codes can also be aggregated (as indicated above), to align with land use types used by EW when monitoring other state-of-environment indicators, for instance soil quality.

A second set of codes is not needed for analysing soil intactness/disturbance, but has to be used when points fall on these features:

By	Farm buildings and yards
Bh	Glasshouses and packhouses
Ba	Chicken and pig sheds
Bi	Industrial buildings on rural sites
Q	Quarries and mines
R	Roads, railways and airfields
Uo	Urban open space
Ur	Urban buildings

Secondary vegetation

The same codes as above are used, as lower-case letters, to indicate that another vegetation is intermingled with the main land use. For instance, Us denotes unimproved drystock pasture with clumps of scrub.

In scrub and forest, a lower-case code indicates canopy gaps with secondary vegetation e.g. Sx denotes natural scrub containing pockets of exotic scrub.

In forest plantations, E' denotes young trees (not yet closed canopy); E# harvested trees (not yet re-planted).

For intensive uses (O, H, G, Gf), H' etc. indicates cultivated fields, including recent plantings that do not provide complete ground cover. H# etc. indicates harvested fields.

Similarly in grassland (D,U,I), D' etc. indicates sparse pasture that does not provide complete ground cover. D# etc. indicates pasture that has been freshly harvested for silage or hay. In grassland where secondary vegetation is recorded, a dash after the second land use denotes it is scattered as opposed to clumped e.g. Us'. Shelterbelts and hedgerows are denoted by an asterisk e.g. Ic* or Ie*.

Soil disturbance

S	stable, vegetated
U	unstable but inactive, vegetated
R	recently disturbed, revegetating
E	freshly disturbed, bare

These codes are the essential ones for analysing soil intactness/disturbance. They become informative, when analysed relative to the land use and secondary vegetation codes.

Nature of disturbance

Topsoil:

t	exposed by cultivation, grazing or harvest
r	exposed by farm or forest track
e	exposed by earthworks

Subsoil:

l	landslide or slip
u	earthflow or slump
a	debris avalanche
g	gully
p	soil pipe (under-runner)

Other:

b	stream bank scour
s	stream bank deposit
w	wind-blown sand
c	rock fall
ge	geothermal disturbance

These codes are not essential. Soil intactness/disturbance can be ascertained entirely from the soil disturbance codes. However, recording nature of disturbance may enable additional analyses, if required.

Landforms

Commonly needed landform codes are:

m	mountain
r	ridge
h	hillslope
d	downland or plateau
t	terrace
f	floodplain
w	wetland

Recording them is not essential for ascertaining soil intactness/disturbance, but may be useful for subsequent analyses. Other landform codes are:

l	lake or pond
l	large river
a	small river or stream (alluvial bed)
s	small river or stream (rock bed)
E	estuary
B	beach
U	dune
C	cliff

The watercourse and coast codes are rarely needed, but have to be recorded when points fall on these features.

1.5 Data storage, statistical analysis and data presentation

Data storage

Sample point locations are stored in a Geomedia file 'grid.erosion.classification'. These are cross-referenced to an Access database file '8219.mdb' which contains raw data for all 6122 points. It is duplicated in an Excel spreadsheet file 'erosion classification.xls', which enables pivot table analysis. A master pivot table, containing point counts for all combinations of data, is contained in a second Excel spreadsheet file 'pivot table.xls'.

Raw data from a cluster analysis of bare soil (around a random selection of sample points) is stored as an Excel spreadsheet file 'cluster.xls'.

Statistical analysis

Point counts are expressed as percentages of the regional sample, for:

- land use,
- secondary vegetation,
- soil intactness/disturbance,
- type of disturbance.

Soil intactness/disturbance and type of disturbance were initially converted to percentage bare soil by area, using a scaling factor for sample point size. The scaling factor was determined by measurements at 100 randomly selected points (Appendix 2). In August 2005, direct measurements of percentage bare soil on one hectare sample areas around each sample point were substituted. This was done to ensure consistency with improved methods used in subsequent surveys for other regional councils (Appendix 5).

For percentages based on point counts, sample error has been calculated at 95% confidence level, using the formula:

$$+\text{-}\ 2\ \text{s.e.} = 1.96 * \text{sqrt}((p(100-p)/n)$$

where:

s.e.	= standard error
sqrt	= square root
p	= percentage from point count
n	= number of points

It has been calculated for percentages based on cluster samples, using the formula:

$$+\text{-}\ 2\ \text{s.e.} = 1.96 * s/\text{sqrt}(n)$$

where:

s.e.	= standard error
s	= standard deviation of mean percentage for clusters
Sqrt	= square root
N	= number of clusters

Data presentation

Pivot tables are fairly complex and hard to read, so summaries of point data for particular topics have been extracted as Tables 1 to 4h (this document). Electronic versions are stored as Sylk spreadsheets named '1.sylk' to '4h.sylk'.

Summaries of percentage data for bare soil have been extracted as Tables 5a to 5h (this document), and are stored as Sylk spreadsheets named '5a.sylk' to '5h.sylk'.

Graphs of summary data have not been included in this document. Spreadsheet versions of its tables are amenable to the usual range of graphical presentations, available through Excel if required.

1.6 Survey concepts

Before discussing survey results, it may be helpful to re-iterate some concepts from the 2001 scoping report.

Soil intactness and disturbance

The concept of soil intactness expresses whether soils are staying in place. A decrease in soil intactness occurs when soil is disturbed. The disturbance may occur under indigenous vegetation, or where land cover has been modified by uses such as farming and forestry, or where the soil itself is modified, for instance by machinery in the course of track construction, roading or urban subdivision. Soil disturbance manifests itself as:

- Changes in thickness,
- Change in exposed area,
- Movement of soil on-site,
- Removal of soil off-site.

The disturbance may reduce land's productive capacity on-site. Off-site, it may create environmental pressures, notably if soil enters waterways.

Soil erosion

Soil erosion is one way soil intactness changes for the worse. The term encompasses removal of soil particles by wind, overland flow of runoff, rills and gullies, stream bank scour and collapse, and mass movement (landslides, earthflows, slumps and debris avalanches). Part of the eroded soil is deposited on-site, but some - often most - is removed.

There are other ways for soil intactness to decline, notably:

- Break-down of structure by machine compaction or animal treading,
- Loss of nutrients by removal of produce, leaching to groundwater, or volatilisation to the atmosphere,
- Decrease in topsoil depth by oxidation of organic matter, combustion, or shrinkage after draining.

The other forms are commonly thought of as declines in soil's condition, quality or "health".

Soil accumulation

Soil intactness can also change for the better, through soil accumulation. There are several ways:

- Long-term build-up in soil depth, by addition of decaying vegetable matter and weathering of regolith,
- Deposition of soil that has been eroded from upslope,
- Deposition of sediment transported from up-river,
- Deposition of wind-blown dust around growing plants,
- Airfall volcanic ash.

All these can be said to improve soil intactness. However, they can also temporarily reduce land's productive capacity e.g. siltation of a flooded river terrace; or create different environmental pressures e.g. burial of vegetation by the silt.

Soil stability

Soil intactness, disturbance, erosion and accumulation are related concepts. Some geomorphologists and soil scientists prefer to analyse the landscape in terms of its stability. They differentiate very old surfaces where soil has remained stable for centuries if not thousands of years, from others where it is rapidly eroding or accumulating, or where it is alternating between erosion and accumulation on a time-scale of decades.

If soil intactness and disturbance, or soil erosion and accumulation, are to be measured for state-of-environment reporting, it will be more enlightening to interpret them in terms of soil stability. Is the site of the soil naturally stable? Is it naturally unstable? If so, is it a site of erosion or accumulation? Does it alternate between the two? Is the erosion, accumulation or alternation rapid or slow?

Only if data are collected in a format that enables these questions to be answered, can conclusions be drawn about whether a change indicates environmental deterioration - or improvement.

Accordingly this survey interprets soil intactness etc. using the broader framework of soil stability. It identifies whether points are on stable or unstable landforms. It then considers whether current vegetation cover (or its absence) indicates each point as being at risk of soil disturbance, or recently disturbed, or freshly disturbed. It also records whether disturbance entails the shifting around of soil by land use, or its erosion and accumulation by natural processes.

2 Survey results – soil intactness and disturbance

Table 1: Soil state throughout the region

This table summarises current state of the region's soil, for all land uses combined. It shows:

- 41.7% is intact soil, currently well-vegetated, on stable sites.

This percentage encompasses all forms of vegetation - grasses, wetland plants, scrub, trees - growing on any landform where no evidence of geomorphological instability can be seen.

- 29.2% is intact soil, currently well-vegetated, on unstable sites.

This percentage encompasses all forms of vegetation, growing on any landform with signs of geomorphological instability - healed erosion scars, inactive gullies, flood-prone river flats, vegetated river banks.

Stable sites are drained wetlands, protected floodplains, elevated terraces, rolling downlands, and ridges, spurs or footslopes in hill country that show no sign of past erosion. Unstable sites are undrained wetlands, unprotected floodplains, terrace edges, drainage hollows or gullies on downlands, hillslopes that show sign of past erosion, and mountains.

- 6.0% of soil is re-vegetating after recent disturbance by land use.

- 6.8% of soil is freshly disturbed by land use.

The recent and fresh disturbance is mostly either topsoil exposure by livestock grazing in pasture, or site disturbance by farm and forest tracks. Other land use-related disturbances - topsoil exposure by cultivation, harvest of vegetation, site disturbance by earthworks - are widespread through the region but their individual area is small. Percentage of soil actually bared by land use is 1.0%.

- 6.2% of soil is re-vegetating after recent disturbance by natural processes.

- 3.1% of soil is freshly disturbed by natural processes.

Recent and fresh disturbance is mostly mass movement. Gullies and soil pipes are a smaller - though notable - component; as is streambank scour and deposit. Other natural erosion processes - windblow of coastal sand, rockfall on bluffs, sheet erosion on mountain slopes, geothermal disturbance of soil - are scattered through the region but not individually extensive. Percentage of soil actually bared by natural processes is 0.4%.

There is 95% confidence that sample percentages are within +- 1.2% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.2% (or better) for bare surface.

3 Survey results – land use impacts on soil

Tables 2a to 2h summarise to what extent the Waikato's soil is intact or disturbed under various land uses.

Table 2a: Soil state under intensive land uses

1.9% of the Waikato's soil is currently under intensive land uses i.e. high-yielding food crops. 1.1% is grain cropping - mainly maize for stockfood - while 0.4% is greenfeed cropping - chou, rape, turnips and similar. Just 0.2% is vegetable growing with a further 0.2% in orchards and vineyards. The table summarises soil state for these uses collectively because they entail either seasonal cultivation of soil, or seasonal harvest of produce, or both.

- 1.2% is currently well-vegetated (maturing crop, or tree and vine cover) on stable sites.

- 0.1% is currently well-vegetated (maturing crop, or tree and vine cover) on unstable sites.

The unstable sites are mostly alluvial floodplains. A few are drainage hollows, stream banks, or footslopes prone to mass movement.

- 0.2% is re-vegetating after recent disturbance by land use (crop harvest, or tree/vine removal).

- 0.3% is freshly disturbed by land use (cultivation and planting).

The recent and fresh disturbance is split between topsoil exposure by cultivation or harvest machinery, and topsoil exposure by tracks. Less than 0.1% of the Waikato's soil is currently bare due to activities carried out in the course of intensive land use.

- <0.1% is re-vegetating after recent disturbance by natural processes.

- 0% is freshly disturbed by natural processes.

The <0.1% is split between fodder crop on alluvial floodplains, and grain crop on footslopes prone to mass movement. Recent disturbance is insignificant - just two sample points. None of the Waikato's soil is currently bare due to natural erosion processes occurring under intensive land use.

There is 95% confidence that sample percentages are within +- 0.3% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface.

Comments

0.5% of the Waikato's soil is freshly or recently disturbed by intensive uses. The reason why the percentage is so small, is that intensive uses occupy small parts of the region. They are almost entirely on stable sites. On most sites, growing crops - or fruit trees and vines with grass beneath - provide good ground cover. At any point in time - such as the dates when aerial photographs were taken - a small proportion of sites show topsoil freshly exposed by cultivation or harvest. The sites are at risk of topsoil erosion; but with less than 0.1% currently bare surface, their contribution to regional soil loss is slight.

Table 2b: Soil state under dairy pasture

24.1% of the Waikato is soil under dairy pasture. 19.4% is lax-grazed or spelled, 4.4% is hard-grazed, and 0.3% freshly harvested for hay or silage. The latter percentage is low because most aerial photographs were taken in late summer or autumn - some of the spelled pasture has faint machinery tracks, indicating harvest earlier in the season.

- 15.0% is currently well-vegetated on stable sites.

- 3.9% is currently well-vegetated on unstable sites.

The unstable sites are mainly unprotected floodplains or poorly drained wetlands. Some are drainage hollows on rolling downlands, mantled by ash or pumice. A few are mass movement-prone footslopes at the edge of hill country.

- 1.7% is re-vegetating after recent disturbance by land use.

- 2.9% is freshly disturbed by land use.

The recent and fresh disturbance is mainly topsoil exposure by grazing, or site disturbance by farm tracks, with site disturbance by earthworks a minor but measurable component. 0.4% of the Waikato's soil is currently bare due to activities carried out in the course of dairy farming.

- 0.4% is re-vegetating after recent disturbance by natural processes.

- 0.2% is freshly disturbed by natural processes.

Much of the recent and fresh disturbance is erosion by gullies or soil pipes. No other processes stand out. Less than 0.1% of the Waikato's soil is currently bare due to natural erosion processes on land used for dairy farming.

There is 95% confidence that sample percentages are within +- 1.1% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface.

Comments

5.2% of the Waikato's soil is freshly or recently disturbed under dairy pasture. The reasons why the percentage is so high, are firstly that it occupies a quarter of the region. Secondly while three quarters of the dairy pasture is on stable sites, a high proportion show impacts on soil from the land use. Thirdly, some of the dairy pasture on unstable sites - unprotected river floodplains, ash- or pumice-mantled hollows, mass movement-prone footslopes - shows impacts from natural processes. 0.4% is bare surface, currently contributing to regional soil loss.

Table 2c: Soil state under drystock pasture

26.8% of the Waikato' soil is under drystock pasture. 17.8% is lax-grazed or spelled, 4.6% is hard-grazed, 0.5% freshly harvested for hay or silage, and 3.9% unimproved. The hay and silage percentage is low because most aerial photographs were taken in late summer or autumn - some of the spelled pasture has faint machinery tracks, indicating harvest earlier in the season.

- 9.8% is currently well-vegetated on stable sites.

- 8.5% is currently well-vegetated on unstable sites.

The unstable sites are diverse - mass-movement prone slopes and inactive gullies in hill country; drainage hollows and inactive gullies on rolling downlands; terrace edges, unprotected floodplains and poorly drained wetlands; inactive sand dunes near the coast.

- 2.1% is re-vegetating after recent disturbance by land use.

- 2.0% is freshly disturbed by land use.

About two thirds of the recent and fresh disturbance is topsoil exposure by grazing. The balance is mostly site disturbance by farm tracks. 0.2% of the Waikato's soil is currently bare due to activities associated with drystock farming.

- 2.5% is re-vegetating after recent disturbance by natural processes.

- 1.8% is freshly disturbed by natural processes.

Half the recent and fresh disturbance is erosion by landslides, earthflows or slumps. A quarter is erosion by gullies or soil pipes. Other natural processes are not individually extensive in drystock pasture. 0.1% of the Waikato's soil is currently bare due to natural erosion processes on land used for drystock farming.

There is 95% confidence that sample percentages are within +- 1.1% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface.

Comments

8.4% of the Waikato's soil is freshly or recently disturbed under drystock pasture. The reasons are firstly that it occupies a quarter of the region. Secondly, half the drystock pasture is on unstable sites - either hill country prone to mass movement, or downland prone to gullying of ash and pumice. Thirdly, of the half on stable sites, a proportion show impacts from land use. Overall 0.4% is bare surface, currently contributing to regional soil loss.

Table 2d: Soil state under forest plantations

Forest plantations are growing on 13.7% of the Waikato's soil. 4.3% is young pine plantation (prior to canopy closure), much of it second-rotation. 7.4% is maturing pine (closed-canopy). 1.5% is harvested pine, not yet re-planted. 0.5% is broadleaf plantation (gum, wattle, poplar, willow).

- 5.6% is currently well-vegetated on stable sites.

- 4.5% is currently well-vegetated on unstable sites.

Unstable sites include gullies on ignimbrite plateaux, steep slopes in the Coromandel peninsula, mass movement-prone slopes and inactive gullies in the western hill country, and gully-prone drainage hollows in the Waikato lowlands.

- 1.4% is re-vegetating after recent disturbance by land use.

- 1.2% is freshly disturbed by land use.

The recent and fresh disturbance is split between topsoil exposure by harvest, and site disturbance by tracking. Both remain discernible in young stands on re-planted sites; tracks also remain visible in maturing second-rotation stands. 0.2% of the Waikato's soil is currently bare due to activities associated with plantation forestry.

- 0.8% is re-vegetating after recent disturbance by natural processes.

- 0.3% is freshly disturbed by natural processes.

Two thirds of the recent and fresh disturbance is erosion by gullies or soil pipes, in ash or pumice. Most of the rest is miscellaneous erosion, with very little currently due to earthflows and slumps in the western hill country; or to landslides and debris avalanches in the Coromandel ranges. Less than 0.1% of the Waikato's soil is currently bare due to activities associated with plantation forestry.

There is 95% confidence that sample percentages are within +- 0.9% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface.

Comments

3.7% of the Waikato's soil is freshly or recently disturbed under forest plantations. Proportionately that is little different from pastoral land uses, when one takes their regional extent into account. However the extent of fresh disturbance is proportionately less, and its nature is different, under forest plantations. 0.2% is currently bare surface, contributing to regional soil loss.

Table 2e: Soil state under exotic scrub

Exotic scrub occupies 3.4% of the Waikato's soil. Different scrub types cannot be consistently differentiated on the aerial photographs - many patches of exotic scrub appear to be an amalgam of several species. Gorse forms pure stands in the Coromandel range and also in greywacke ranges of the lower Waikato. In hill country west of the Waikato and Waipa, gorse is mixed with blackberry, pampas grass, and native weeds such as bracken and tutu. Blackberry or bracken dominate waste ground on the central plateau, but gorse and tutu are also present.

- 1.0% is currently well-vegetated on stable sites.

- 1.5% is currently well-vegetated on unstable sites.

Unstable sites are mainly mass movement-prone hillslopes and inactive gullies in the western hill country. Exotic scrub also occupies many drainage hollows and inactive gullies on ignimbrite plateaux. In the steep ranges of Coromandel and the lower Waikato, exotic scrub tends to be on stable ridges or spurs.

- 0.2% is re-vegetating after recent disturbance by land use.

- 0.2% is freshly disturbed by land use.

The recent and fresh disturbance is mainly site disturbance by tracks, though topsoil exposure is also present where scrub cover has been cleared by earthworks. Less than 0.1% of the Waikato's soil is currently bare due to activities associated with exotic scrub.

- 0.3% is re-vegetating after recent disturbance by natural processes.

- 0.2% is freshly disturbed by natural processes.

Most of the recent and fresh disturbance is accounted for by mass movement (western hill country, greywacke ranges, Coromandel range) or gullies and soil pipes (central plateau). Less than 0.1% of the Waikato's soil is currently bare due to natural erosion processes occurring within exotic scrub.

There is 95% confidence that sample percentages are within +- 1.4% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface.

Comments

0.9% of the Waikato's soil is freshly or recently disturbed beneath exotic scrub; a high proportion relative to its regional extent. Although this land is not currently used, soil disturbance is a consequence of past use - generally clearance of native vegetation, a period of grazing (mining or quarrying at a few sites), then abandonment followed by reversion. Bare surface, at under 0.1%, makes a modest contribution to regional soil loss.

Table 2f: Soil state under natural scrub and forest

Natural scrub and forest remain on 20.8% of the Waikato's soil. 0.9% is sparse scrub regenerating in pasture. 4.7% is closed canopy scrub - most covers long-abandoned pasture; some is natural scrub on sites with shallow or stony soil. 5.7% is closed canopy scrub with emerging forest trees - many of these sites are second-growth where bush has been abandoned after timber harvest. 3.7% is forest interspersed with scrub patches - natural disturbance by landslides, debris avalanches or gullies. 5.8% is closed canopy forest - sites never disturbed by clearance, timber harvest or natural catastrophes.

- 8.4% is currently well-vegetated on stable sites.

- 9.6% is currently well-vegetated on unstable sites.

The unstable sites are diverse. On the mountains and ranges, slopes scarred by debris avalanches and valley bottoms gullied by debris flows; in the hill country, slopes disturbed by mass movement; on the ignimbrite plateaux, inactive gullies at an advanced stage of reversion. A small proportion of unstable sites are also on the lowlands - scrub or bush remnants on terrace edges and stream banks.

- 0.2% is re-vegetating after recent disturbance, some of which relates to previous land use.

- 0.1% is freshly disturbed.

The recent and fresh disturbance is mostly along tracks which remain from the days of timber harvest and scrub clearance. A few points, where topsoil is exposed away from tracks, may be naturally sparse cover, be depleted by browsing animals, or have unknown causes. Well under 0.1% of the Waikato's soil is currently bare due to activities associated with previous land use in natural scrub and forest.

- 2.0% is re-vegetating after recent disturbance by natural processes.

- 0.6% is freshly disturbed by natural processes.

The recent and fresh disturbance are overwhelmingly subsoil erosion by mass movement. Gullies are also a component - steep slopes gullied by debris flows, not gullies in pumice or ash. Streambank scour and deposit, though not regionally extensive in scrub and forest, is measurable. Less than 0.1% of the Waikato's soil is currently bare due to natural erosion processes occurring in scrub and forest.

There is 95% confidence that sample percentages are within +- 1.0% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface.

Comments

2.9% of the Waikato's soil is freshly or recently disturbed under natural scrub and forest. Proportionately that is somewhat less than under grazing, forest plantation or exotic scrub, when one takes into account the differences in their regional extent. The nature of disturbance is also different, with natural processes dominant. Somewhat under 0.1% is currently bare and contributing to regional soil loss.

The figures for scrub and forest may also be useful background data - indicating extent to which risk of topsoil erosion, and incidence of subsoil erosion, have been accelerated by various rural land uses - if they are compared with equivalent figures in Tables 2a to 2d.

Table 2g: Soil state under mountain scrub and tussock

Mountain scrub and tussock are present on 1.7% of the Waikato's soil. 1.0% is mountain scrub, notably leatherwood in the Kaimanawa, dracophyllum and high-altitude kanuka on the lower slopes of Tongariro and Ruapehu. Small patches of mountain scrub are also present on the summit of Pihanga and the highest ridges of the Kaimai and Coromandel ranges. 0.7% is tussock, either red tussock on lower slopes of Tongariro and Ruapehu, or snow tussock at higher elevations here and on the Kaimanawa summits.

- 0.7% is currently well-vegetated on stable sites.

- 0.4% is currently well-vegetated on unstable sites.

Unstable sites are typically mountain sides scarred by debris avalanches or gullied by debris flows. Some are rocky stream gorges or alluvial fans.

- 0.1% is re-vegetating after recent disturbance of topsoil, unlikely to be land use-related.

- 0.1% is freshly disturbed topsoil.

The recent and fresh disturbance is entirely topsoil exposure where cover is naturally sparse, due to altitude, and stony or free-draining soil. Less than 0.1% of the Waikato's soil is currently bare due to topsoil disturbance under mountain scrub and tussock.

- 0.2% is re-vegetating after recent disturbance by natural processes.

- 0.1% is freshly disturbed by natural processes.

The recent and fresh disturbance is diverse in nature - debris avalanches on steep slopes, gullies in volcanic ash or loose rock, scour and deposit of bank sediment by alpine streams, rockfall from bluffs. Just under 0.1% of the Waikato's soil is currently bare due to natural erosion processes occurring within mountain scrub and tussock.

There is 95% confidence that sample percentages are within +- 0.3% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface.

Comments

0.5% of the Waikato's soil is freshly or recently disturbed under mountain scrub and tussock. While the area of soil under this vegetation is small, the proportion disturbed is high. However as bare surface is just under 0.1%, its contribution to regional soil loss is slight.

As with Table 2f, the figures for mountain scrub and tussock may have some value as indicators of natural erosion in the absence of land use.

Table 2h: Soil state in wetlands

Wetland vegetation remains on 0.8% of the Waikato's soil. The only large undrained peat swamps are in the lower Waikato basin and on the Hauraki plains. Small remnants of otherwise-drained swamps persist here and elsewhere, notably in the Hamilton basin and on the Tongariro delta. Their vegetation is not necessarily intact - sedge, rush, flax, manuka, gorse and willow - singly and combined. Poorly drained wetland, where swamp vegetation persists amongst rough grass, is excluded from the table.

- 0.7% is currently well-vegetated on unstable sites.

No wetland sites have been rated as stable. By definition, wetlands are at least seasonally if not permanently flooded. A solitary sample point on a raised track has been rated as recently disturbed by land use, and a further point where wetland is being drained and cultivated has been rated as freshly disturbed. Flooding may be accompanied by sedimentation. Intact wetlands are also sites of long-term peat accumulation.

- 0.1% is revegetating after recent disturbance by natural processes.

- 0.0% is freshly disturbed by natural processes.

Recent disturbance is entirely siltation on the banks of streams which pass through, transporting sediment from higher ground. None of the Waikato's soil is currently bare due to topsoil disturbance or subsoil erosion within wetland vegetation.

There is 95% confidence that sample percentages are within +- 0.2% (or better) of the true regional figures for soil intactness or disturbance, and within +- 0.1% (or better) for bare surface

Comments

Just under 0.1% of the Waikato's soil is freshly or recently disturbed in undrained wetlands. Soil disturbance is a small proportion of their extent. Simply because there are so few wetlands left, bare surface is currently much less than 0.1%, so its contribution to regional soil loss is minimal.

4 Survey results – secondary vegetation

Tables 3a to 3h indicate whether, within each of the Waikato's land uses, secondary vegetation is present. This is not by itself an indicator of soil state, though it becomes relevant as an indicator of response i.e. extent to which vegetation has been retained to maintain soil's intactness; extent to which it has been planted to control soil disturbance.

Table 3a: Secondary vegetation amongst intensive land uses

1.8% of the Waikato's soil is used for orchards, vineyards, grain crops and greenfeed crops.

Of this, 78.8% has no secondary vegetation present. 13.3% has exotic trees, mainly shelterbelts. 7.1% has grass cover, either mown or rank. Other secondary vegetation is either insignificant e.g. 0.9% with wetland plants; or absent e.g. scrub and natural tree cover.

Comments

Clearly there has been little attempt by intensive land users, to retain or plant other vegetation. To some extent, its absence is explicable by a need to keep fields free of other vegetation so machinery can pass unhindered when cultivating or harvesting. The sites where secondary vegetation has been established, are where machinery does not operate:

- Shelterbelts on field boundaries,
- Grass cover beneath fruit trees and grape vines,
- Rank grass or wetland in drainage hollows.

Table 3b: Secondary vegetation in dairy pasture

24% of the Waikato's soil is utilised for dairy pasture.

Of this, 75.3% is open pasture with no other vegetation present.

18.5% has exotic trees. A few are trees scattered through paddocks for amenity or shade. Most are shelterbelts planted on one or more sides of a paddock. Some are riparian plantings of willows or poplars.

At 0.4%, exotic scrub cover is almost absent from dairy pasture - as would be expected on well-managed dairy farms.

1.5% has natural scrub cover present, with natural tree cover on a further 1.6%. Typically these are scattered trees or bushes, though a proportion are small clumps on floodplains and stream banks.

2.8% has wetland on drainage hollows or stream banks. Most such sites are vegetated by sparse wetland species in rank grass. From the aerial photographs, it is impossible to tell whether the wetland plants are remnant, or re-establishing.

No rank grass has been recorded on hollows or banks in dairy pasture. This is probably because in most situations where they are fenced off, rank grass is interspersed with wetland plants or scrub that has been planted or has emerged of its own accord.

Comments

Three quarters of dairy paddocks are clean pasture without secondary vegetation. This is a consequence of intensive pasture management, and also economic pressure to utilise highly valued land. Nevertheless there is plenty of evidence that dairy farmers retain or plant secondary vegetation on parts of the farm where they perceive it as useful:

- Shelterbelts along the edges of paddocks, and soil conservation plantings along stream banks or up drainage hollows,
- Natural tree and scrub cover, generally on stable sites, for stock shelter and shade,
- Sparse wetland and rank grass, generally along stream banks which have been fenced off from stock.

Table 3c: Secondary vegetation in drystock pasture

27% of the Waikato's soil is utilised for drystock pasture.

Of this, 58.2% is open pasture with no other vegetation present.

12.6% has exotic trees. Some are plantings on river terraces and downlands, scattered through paddocks for amenity or shade. A proportion are shelterbelts, generally on the same landforms. A proportion are planted for soil conservation on unstable sites - streambanks on floodplains, terrace edges, gullies in ash-mantled downland, mass movement prone slopes in hill country.

At 8.4%, exotic scrub is a significant secondary vegetation in drystock pasture. This reflects the greater difficulty of pasture management where drystock farms are located on hill country. To some extent, it is reversion on pockets of land retired from grazing e.g. gullies, unstable slopes, steep slopes with shallow or stony soil.

9.8% has natural scrub cover, with natural tree cover on a further 5.4%. Some are scattered through paddocks. Others are clumps of reverting scrub on land retired from grazing. Many are clumps of scrub or bush on land that has never been cleared.

5.4% has wetland on damp hollows and stream banks. Most are vegetated by sparse wetland species in rank grass. Few appear to have boundary fences, so the wetland plants are more likely to be remnants that survive due to low grazing pressure, than re-establishments attributable to riparian retirement.

No rank grass has been recorded on hollows or banks in drystock pasture. As with dairy farms, this is probably because at any sites that are fenced off, rank grass is interspersed with wetland plants or scrub that has been planted or has emerged of its own accord.

Comments

Secondary vegetation occurs in almost half the Waikato's drystock pasture. The high percentage partly reflects less intensive grazing management than on dairy farms. Another cause is the terrain - most sheep and beef cattle farms are on downland or hill country - where pockets of marginal land are interspersed with developed pasture.

- Natural tree cover is generally retained on steep or unstable sites that farmers recognise as not worth clearing, for the limited pasture growth they would gain. Exotic woodlots are frequently planted in rough pasture on similar sites, that were injudiciously cleared by previous owners.

- Scrub reversion was formerly viewed as a sign of poor land use. This is still the case where it is scattered through grazeable pasture. However many areas of closed-canopy scrub are on land retired from grazing, due to poor pasture growth, difficult access, or instability.

- Remnant wetland and rank grass are generally along drainage hollows on downlands and valley bottoms in hill country. In downlands, their survival may be due to riparian fencing. In hill country, it is more likely due to low grazing pressure on boggy ground.

Table 3d: Secondary vegetation in forest plantations

14% of the Waikato's soil is covered by forest plantations.

47.4% is conifer plantation, mainly radiata pine, without discernible secondary vegetation. Of this, 42.3% is dense forest i.e. the canopy appears to exclude other vegetation, but sparse secondary growth is likely present on the forest floor. 2.2% is clear-felled i.e. logging has removed forest under-storey as well as the trees. 2.2% is young pines planted on clear-felled sites, where ground cover has failed to establish.

24.2% is conifer plantation with a ground cover of rank grass and legumes. Of this, 5.1% are clear-felled sites where grass/legume cover has been sown for quick revegetation. 14.7% are similar sites where young pines have been planted. 2.9% are second-rotation pine forest with partial canopy closure but some grassed areas visible where tree growth is retarded.

15.7% is conifer plantation with a ground cover of exotic scrub. Of this, 3.0% are clear-felled sites where scrub is emerging through grass/legume cover. 9.7% are sites where scrub surrounds young pines. 3.0% are second-rotation pine forest with partial canopy closure. Species composition is mainly gorse and blackberry. Bracken and tutu are also included - these indigenous species grow on disturbed sites in association with the exotics and are not separable.

10.6% is conifer plantation with natural scrub. Of this, 0.7% are clear-felled sites where scrub is emerging through grass/legume cover. 4.9% are sites where scrub surrounds young pines. 5.0% are either second-rotation pine forest with partial canopy closure, or first-rotation forest with scrub growing in canopy gaps that have never been planted. Typically these are steep-sided gullies, very steep hillslopes with rock outcrops, or debris avalanche scars.

1.6% is conifer plantation with other trees in canopy gaps. About a third are small bush remnants on the sites described above. The balance are poplars and willows, planted along stream banks or up gullies.

Just 0.6% is conifer plantation with wetland in canopy gaps. This may under-estimate its extent, due to mature forest canopy hiding riparian wetland in hollows and gullies.

Comments

About half the forest plantations have secondary vegetation that is visible through the forest canopy. Its diversity is a clear consequence of forest management:

- Harvest sites, with as yet no ground cover,

- Re-planted sites where grass and/or legume cover has been sown for quick revegetation,

- * Slightly older plantings, still open-canopy, where exotic scrub has emerged through grass/legume cover,

- Sites where natural scrub has done likewise,

- Closed-canopy stands where exotic or natural scrub has been retained in un-planted gullies, steep faces or landslide scars,

- A small number of closed-canopy stands where soil conservation trees have been planted on streambanks or gullies, where indigenous trees have been left on similar sites, or where wetland has been retained.

Table 3e: Secondary vegetation in exotic scrub

3.4% of the Waikato's soil is occupied by exotic scrub. The primary vegetation is self-established, but induced as a result of site disturbance by a previous land use. Secondary vegetation may also be induced, or it may be natural regeneration since land was abandoned.

31.6% of the exotic scrub is sparse and contains induced secondary vegetation:

- 20.4% has rank grass in canopy gaps.

- 11.2% has exotic trees - wildling pines and willows - emerging through canopy.

21.8% is dense exotic scrub, with neither induced nor natural secondary vegetation.

46.8% has natural secondary vegetation of which:

- 1.0% has wetland in canopy gaps.

- 40.3% has natural scrub emerging through canopy

- 5.3% has natural trees emerging through canopy

Comments

A clear sequence is present:

- Sparse exotic scrub colonising pasture,

- Dense exotic scrub,

- Exotic scrub with emerging natural scrub,

- Exotic scrub with emerging trees (whether natural or exotic).

The secondary vegetation does not relate to present land use, so much as length of time since a former use was abandoned. On many sites, the former use has been drystock grazing. However exotic scrub with secondary vegetation is also common on steep faces and along gullies, within land that is utilised for plantation forestry. A few of the sites in exotic scrub have been extensively disturbed by quarrying or mining.

Table 3f: Secondary vegetation in natural scrub and forest

21% of the Waikato's soil is occupied by natural scrub and forest. In natural scrub and forest, the primary vegetation may be induced - for instance scrub on abandoned farmland - or natural - for instance scrub on harsh sites. The distinction becomes clearer for secondary vegetation.

8.7% of the scrub and forest is sparse and contains induced secondary vegetation:

- 2.8% has rank grass. Some is extensive ground cover in stands of open scrub, but most occurs as small patches in canopy gaps where scrub reversion has been

retarded. Visible causes are diverse - soil instability, stoniness, waterlogging - and feral mammals may also play a part.

- 2.4% has exotic scrub. The situations in which it occurs are identical to those described above for rank grass.

- 3.5% has exotic trees as a secondary vegetation. Most of these are wildling pines in scrub, though a few are willows on streambanks - more likely to be wildling than planted.

22.5% is dense scrub without visible secondary vegetation.

40.7% of the scrub and forest contains natural secondary vegetation:

- ?% has wetland in canopy gaps.

- 24.2% has forest trees emerging through scrub canopy.

- 16.5% has scrub remaining in forest canopy gaps.

28.1% is dense forest without visible secondary vegetation.

Comments

Again, a clear sequence is present. However the relative proportions - and roles - of induced and natural secondary vegetation are reversed, in comparison with exotic scrub and forest.

Open-canopy scrub, with induced secondary vegetation as an understorey, is present on just a small proportion which is abandoned farmland.

Closed-canopy scrub is extensive. It has also generally established on abandoned farmland, which landowners have recognised as too steep, infertile or unstable to attempt clearing again.

The same can also be said about scrub with emerging forest trees - with a caveat that much is actually cut-over forest which landowners have abandoned without attempting subsequent management.

Forest with scrub in canopy gaps and closed canopy forest are also extensive. On private farmland, their retention is probably due to inaccessibility for logging, or an appreciation of their scenic and ecological value on the landowner's part. The same reasons also apply to forest survival in extensive tracts of public land, now reserved (the Coromandel and Kaimai Ranges, Hakarimata Range, Mt. Karioi, Mt. Pirongia, Herangi Range, Kaimanawa Range and Mt. Tongariro).

Table 3g: Secondary vegetation in mountain scrub and tussock

1.6% of the Waikato's soil is occupied by mountain scrub and tussock.

Induced secondary vegetation has not been recorded at any sites:

- Rank grass is locally present where tussock has been burnt or grazed in past years, but was not visible at any sample points.

- One exotic scrub species, heather, is widespread on the lower slopes of Tongariro and Ruapehu. On aerial photographs, it could not be distinguished from indigenous mountain scrub.

- A few wildling pines are known on the lower slopes of Tongariro and Ruapehu. These could be recognised if they were close to sample points, but none were.

81.2% is either mountain scrub, or mountain scrub interspersed with tussock, or tussock, without visible secondary vegetation.

Two natural secondary vegetations have been recorded:

- 6.3% low-altitude scrub species colonising mountain scrub or tussock
- 12.6% low-altitude forest trees colonising mountain scrub or tussock
- Small areas of wetland exist on boggy ground, but no sample points landed on these.

Comments

Almost all the mountain scrub and tussock are on land that has been reserved because of its scenic and ecological value. All appears free of vegetation induced by site disturbance - subject to a caveat that an invasive exotic species - heather - is known to be present but could not be differentiated.

Four fifths which lacks secondary vegetation can be further differentiated as tussock (31.2%), mountain scrub scattered in tussock (12.6%), mountain scrub interspersed by patches of tussock (6.3%), and mountain scrub (31.2%). The transition is a consequence of change in altitude, possibly diversified by vegetation recovery after fires and volcanic ash falls.

The remaining fifth has emerging lowland scrub or tree species; a consequence of natural plant succession, and possibly of changing climate.

Table 3h: Secondary vegetation in wetland

0.8% of the Waikato's soil is occupied by undrained wetland.

The following induced secondary vegetation has been recorded:

- 2.1% rank grass.
- 0% exotic scrub.
- 27.1% exotic trees - wildling willows and alders.

54.2% has been recorded as dense wetland, free of induced or natural secondary vegetation.

Natural secondary vegetation has been recorded as:

- 12.5% natural scrub - mainly manuka.
- 4.2% natural trees - mainly kahikatea.

Comments

Observations about the extent and role of secondary vegetation in wetland are necessarily tentative due to small sample size.

The sample suggests that about a quarter of undrained wetland soil has been colonised by wildling willows and alders. Other induced secondary vegetation is largely absent (poorly drained wetland, vegetated by rough pasture interspersed with sparse swamp vegetation, is included in the tables for dairy pasture and drystock pasture).

The low proportion of natural secondary vegetation is as expected for undrained wetland. Emergent scrub and trees are restricted to parts which are seasonally dry.

5 Survey results – vegetative soil conservation measures

The survey data also indicate whether for each land use, various kinds of primary or secondary vegetation have maintained soil intactness/reduced soil disturbance. For some of the less common secondary covers, sub-sample sizes are small. This is not a problem when calculating percentage soil conservation cover - as n for a land use generally exceeds 100 - but becomes so when calculating percentage fresh disturbance - n for a soil conservation cover is often less than 100 and in some instances less than 10. To remedy this, a cluster sample has been obtained for most combinations of land use and soil conservation cover (see Appendix 3 and 5 for details).

The final versions of Tables 4a to 4h present two measures of soil conservation's extent, derived from the point sample:

- What percentage of each land use has vegetative soil conservation cover - either planted or retained.

- Whether the soil conservation cover is sparse or dense.

Tables 5a to 5h present two measures of soil conservation's effect, derived from the cluster sample:

What percentage of soil is bare due to fresh disturbance by activities associated with human use of land. This can be equated with topsoil exposed to risk of surface erosion.

What percentage of soil is bare due to fresh disturbance by natural processes. This can be equated with subsoil affected by erosion or deposition.

Table 4a: Extent of soil conservation cover under intensive uses

On 79% of points sampled, primary vegetation is the only ground cover. 19% is sparse i.e. emerging or harvested. 60% is dense i.e. maturing crop, or vines and trees in leaf. Dense crop cover (or tree/vine cover) is itself a de facto soil conservation measure, protecting topsoil from sheetwash and windblow.

21% of points sampled have some form of secondary vegetation which functions as soil conservation cover:

- 1% with rank grass or wetland in drainage hollows - retained on sites too damp to crop. Grassed waterways and wetlands are a recognised conservation measure in cropping and vegetable growing, but are obviously absent from many sites where they could conduct runoff and trap eroded topsoil.

- 7% with grass cover beneath fruit trees and grape vines - though maintained for weed suppression, grass cover is also recognised as a conservation measure in orchards and vineyards. It protects topsoil which would otherwise be exposed to sheetwash.

- 12% with shelterbelts on field boundaries - though established to shelter fruit trees and grain crops from wind, they also have some value as protection against wind erosion of exposed topsoil.

Table 4b: Extent of soil conservation cover in dairy pasture

On 75% of points sampled, primary vegetation is the only ground cover. 15% is sparse i.e. pasture that has been heavily grazed, or in some instances harvested for hay and silage. The balance of 60% is dense i.e. pasture that is lightly grazed or spelled. Dense pasture is a de facto conservation measure, protecting topsoil against sheetwash and windblow. The locations where pasture is sufficiently dense to protect topsoil, would clearly change as stock are rotated around farm paddocks. The overall percentage at a point in time - such as the dates of aerial photographs - is a good measure of extent to which dairy farmers are protecting topsoil by pasture management.

25% of points sampled have some form of secondary vegetation which functions as soil conservation cover:

- At 3%, wetland and/or rank grass is retained in drainage hollows or along streambanks. This may indicate extent to which Waikato dairy farmers have implemented the main soil conservation technique advocated for their farms - riparian fencing. The true percentage will be somewhat higher - riparian fences are undoubtedly present beneath some of the tree and scrub cover on banks - but cannot be consistently seen on aerial photographs.

- At 2%, scrub is retained in the same situations. Where present in drainage hollows or on stream banks, its retention constitutes a soil conservation measure, protecting hollows against gullying/soil piping and banks against scour.

- At 20% tree cover is retained or planted. While a high proportion are shelterbelts, soil conservation plantings and remnant native trees are also present. Shelterbelts, while established primarily for the benefit of livestock and to promote pasture growth, also have some soil conservation value, protecting any exposed soil in their lee against wind erosion. Soil conservation plantings are willow and poplar; on stream banks within floodplains and terraces, or up drainage hollows on downlands. Natural tree cover is generally on stable sites such as river terraces or rolling downlands, where trees are not needed to stabilise soil. However a proportion of the remnant cover is on drainage hollows and stream banks.

Table 4c: Extent of soil conservation cover in drystock pasture

On 58% of points sampled, primary vegetation is the only ground cover. 14% is sparse i.e. pasture that has been heavily grazed, or harvested for hay and silage. 40% is dense pasture. Dense pasture is a de facto conservation measure, protecting topsoil against sheetwash and windblow. As with dairy farms, the locations where pasture is sufficiently dense to protect topsoil, clearly change as stock are rotated around farm paddocks.

42% of points sampled in drystock pasture have some form of secondary vegetation which functions as soil conservation cover:

- 5% in a mix of sparse wetland and rank grass, does not indicate riparian fencing on drystock farms (for reasons already explained). However it shows that there are extensive areas - along drainage hollows on downlands and valley bottoms in hill country - where remnant wetland has some soil conservation value. Here it traps a proportion of sediment washed from slopes by sheetwash through depleted pasture. It also traps much mass movement debris during storms.

- 18% has scrub cover, with a high proportion on unstable sites. Exotic scrub, and reverting natural scrub, were formerly viewed as a sign of poor land use. This is still the case where scrub is scattered through grazeable pasture. Where emerging on land retired from grazing, it can stabilise an eroded gully or hillslope, at little cost to the farmer.

- On 18%, natural tree cover is retained or exotic tree cover is planted. Some of the exotic trees have been planted as a deliberate soil conservation measure i.e. spaced plantings of poplar or willow on unstable hillslopes; paired or line plantings of the same species, along soil pipes and gullies. Many of the remainder - woodlots on unstable land, shelterbelts whether land is unstable or not - also have some soil conservation value. Retention of natural tree cover is likely due to farmers recognising that these sites are not worth clearing, for the limited pasture growth they would gain. The decision to retain it, contributes to soil conservation on the farm.

Table 4d: Extent of soil conservation cover in forest plantations

47% of points sampled in forest plantations have, or have had, plantation trees as the only ground cover. The figure includes 4% clear-felled sites. The balance are either young trees without surrounding vegetation noticeable, or maturing closed-canopy stands. These stands are difficult to categorise. Many have been planted on stable terrain. Their canopy and under-storey protect topsoil from surface erosion, so they could be viewed as a de facto soil conservation measure. The stands planted on unstable terrain - notably mass-movement-prone hillslopes in the western hill country and Coromandel ranges - clearly have a soil conservation role, providing root reinforcement against subsoil erosion. Even here, they could be regarded as a de facto measure, because the motive for planting pines has generally been commercial.

53% of points sampled under forest plantations have some form of secondary vegetation which functions as soil conservation cover:

- 20% have rank grass around young trees - either first-rotation planted in pasture, or second-rotation where grass/legume cover has been sown on harvest sites. Here, pasture has been intentionally retained or sown, to protect against surface erosion while trees establish.

- 5% have grassed canopy gaps within maturing stands. In some instances they are tracks or firebreaks sown in grass. In others, they are sites where trees have been planted in pasture but failed to establish.

- 18% have scrub emerging around young trees - again divided between sites where it is emerging in retired pasture, and where it is emerging on former harvest sites. In neither situation has scrub been intentionally established; in both it functions as ground cover, protecting against surface erosion.

- 8% have scrub in canopy gaps within maturing stands - generally these correspond with drainage hollows or gullies, where scrub has been intentionally retained as a conservation measure.

- 2% have other trees interspersed with the plantation species - some are natural forest remnants, intentionally retained as a conservation measure on land too steep to plant. Others are soil conservation trees planted on streambanks or up gullies.

Table 4e: Extent of soil conservation cover in exotic scrub

22% of points sampled have exotic scrub as the only ground cover. Dense exotic scrub may have a soil conservation role, protecting topsoil against surface erosion, but is unlikely to provide much root reinforcement to subsoil on unstable sites.

78% of soil under exotic scrub has some form of secondary vegetation, much of which could be said to function as soil conservation cover:

- At 21% where exotic scrub is regenerating with a rank pasture under-storey or with pasture in canopy gaps - as yet little soil conservation value, but may protect topsoil against surface erosion,

- The 40% where natural scrub is emerging through exotic scrub, undoubtedly has some conservation value - provides greater root reinforcement to subsoil; though it is not necessarily on unstable sites,

- The same holds for 17% where natural tree cover or wildling exotic trees are emerging.

Table 4f: Extent of soil conservation cover in natural scrub and forest

51% of points sampled have primary vegetation only - scrub or forest, with any understorey species invisible through the closed canopy. Both the canopy and the understorey can be viewed as having a soil conservation role, protecting topsoil against surface erosion on sites that are often steep and subject to intense rainfall. Where on unstable sites, scrub and forest also provide root reinforcement to subsoil.

49% of points sampled have some form of secondary vegetation:

- 3% in open-canopy scrub or forest, with remnant grass or wetland as an understorey or in canopy gaps, is unlikely to have much soil conservation value - though rank grass provides topsoil with some protection against surface erosion, where canopy is sparse,

- Likewise the 2% where exotic scrub remains in canopy gaps,

- At 28%, trees are emerging through scrub; mainly natural regeneration, though 3% are wildling exotics. The proportion that are on unstable sites (about half?) could be regarded as soil conservation measures; particularly as they tend to occur along watercourses and up gullies,

- At a further 17%, natural scrub occupies canopy gaps within forest. The existence of canopy gaps generally indicates site disturbance by landslides, debris avalanches, or gullied debris flow tracks. Here scrub has a definite soil conservation role, colonising bare surfaces and enabling soil to re-form.

Table 4g: Extent of soil conservation cover in mountain scrub and tussock

67% of points sampled have primary vegetation as the sole ground cover (84% if scrub-tussock mixes are added). As all such land is at risk of topsoil loss if vegetation is depleted, and much is at risk of subsoil erosion by natural processes, it is appropriate to view mountain scrub and tussock as de facto soil conservation cover.

16% of points sampled have other secondary vegetation:

- 4% lowland scrub species emerging in mountain scrub,

- 12% lowland tree species emerging in mountain scrub.

This land can also be viewed as having a soil conservation role, for the reasons stated above.

Table 4h: Extent of soil conservation cover in wetlands

54% of points sampled in wetlands have primary vegetation as the sole ground cover i.e. rush, sedge, raupo, flax.

46% have other secondary vegetation, mostly of an invasive nature:

- 2% rank grass,

- 13% scrub, mainly manuka,

- 31% trees, mainly willow and alder, with some kahikatea.

Vegetation on all soil in undrained wetlands could be regarded as de facto soil conservation cover. While they have been retained primarily as flood detention areas or in some instances because of their ecological value, they also have a role as sediment traps and nutrient sinks for runoff from surrounding farmland.

Table 5a: Effect of soil conservation cover under intensive uses

Where cropland, tree or vine cover are sparse, 16.0% of topsoil is bared by fresh land use disturbance i.e. at risk of topsoil loss. Where cover is dense, the percentage at risk declines to 0.2%. Sample errors remain high, not because of cluster sample size but because of variability - a few sites where bare soil is close to 100%, are distributed amongst others where it is close to 0%.

Where wetland or grass has been retained - mainly under orchards and vineyards; also along drainage hollows in some of the cropland, bare topsoil appears absent in sparse secondary cover, and moderate at 2.0% in dense secondary cover. However, this is one of the few cluster samples which needs to be treated with caution on account of small size (n=2) for the sparse cover.

Retained scrub, in drainage hollows or adjacent to cropped fields, has not been recorded at any sample points.

Where sparse tree cover has been retained, bare topsoil is 0% but sample size is too small (n=1) to be confident of this figure. Where trees have been planted (mainly shelterbelts) the figure is 0.4%. Cluster sample size and error margins indicate the figure is reliable. It suggests that shelterbelts may increase topsoil exposure somewhat, relative to dense crops in open fields.

The cluster samples for intensive use did not detect any subsoil bared by natural erosion processes. This is not surprising given that intensive uses tend to be located on stable land. However the point sample indicated that a small proportion of cropland is located on floodplains where one might have expected some disturbance by siltation or streambank scour. The conclusion has to be that there was very little or none at the date of survey.

Table 5b: Effect of soil conservation cover in dairy pasture

In sparse dairy pasture, 2.8% of topsoil is bared by fresh land use disturbance i.e. at risk of topsoil loss. Where pasture is lightly grazed or spelled, the percentage at risk drops to 1.2%. Sample errors are low, in part because of the large number of clusters, but also because bare soil is tightly distributed, with most sites between 0 and 5%.

Where wetland or rank grass has been retained on stream banks or in drainage hollows, 0.8% of topsoil is bare where secondary cover is sparse, and 3.0% where it is dense (small cluster sample size for the latter means that this figure is unreliable). Where scrub has been retained or planted in similar situations, figures are 0.1% for sparse secondary cover, and 1.2% for dense. The figures are somewhat higher where trees have been retained or planted - 1.4% where sparse, 1.6% where dense. Overall the differences are not significant, except perhaps for dairy pasture where scrub is present.

Very little bare subsoil due to natural disturbance has been detected in open dairy pasture; less than 0.1% whether pasture is sparse or dense. Where secondary vegetation has been retained or planted, bare subsoil ranges between 0 and 0.1%.

Table 5c: Effect of soil conservation cover in drystock pasture

In sparse drystock pasture, 2.0% of topsoil is bared by fresh land use disturbance i.e. at risk of surface erosion. The figure drops to 0.3% where pasture is lightly grazed or spelled.

Where secondary vegetation has been retained, bare topsoil varies between 1.0 and 0.2%. It declines with the transition from herbaceous to scrub, and from scrub to tree cover; though error margins indicate the differences are not significant. Nor are the differences between sparse and dense secondary cover.

Bare subsoil due to natural erosion processes has been recorded at 0.4% in sparse pasture and 0.5% in dense pasture. The difference does not appear to be significant.

Where secondary vegetation has been retained or planted but is sparse, bare subsoil is at similar levels to open pasture. There does not appear to be any significant trend in subsoil disturbance, moving from sparse wetland/rank grass, through sparse scrub, to sparse trees.

Where secondary vegetation is dense, bare subsoil is less than under sparse vegetation for scrub and trees (though not for wetland and rank grass). It declines moving from wetland/rank grass to scrub, but not from scrub to trees. As error margins overlap, these declines are not significant.

Figure 5d: Effect of soil conservation cover in forest plantations

Bare topsoil is high, at 8.1% by area, on sites where pine stands have been clear-felled. The high error margin is due to variability in surface disturbance amongst sites. Extent rapidly declines to 0.3% in maturing stands which have closed canopy and no visible secondary vegetation.

Bare topsoil is moderate at 2.2% where grass has been sown as a ground cover in young replanted stands. Where grass remains in canopy gaps within maturing stands, bare topsoil is lower at 0.8%, attributable to access tracks or firebreaks. Bare topsoil is 1.9% where scrub is emerging around young second-rotation stands; this may indicate poor establishment of grass/legume cover or its suppression by scrub regrowth. Where scrub remains within canopy gaps in mature stands, the figure drops to 0.6%. It declines to 0% where native trees or soil conservation trees are present amongst young pines, but this figure should be treated with caution - an instance where few point clusters have been measured (n=2). Amongst maturing stands (n=11), bare topsoil is 1.0% in presence of other soil conservation trees or natives.

On clear-felled sites, no baring of subsoil by natural erosion processes has been measured. The conclusion has to be that subsoil erosion is currently minimal on clear-felled sites. This is more likely due to residual root strength of stumps, and prompt revegetation of clear-felled sites, than any absence of rainstorms or floods in the year prior to aerial survey. Very slight bare subsoil – less than 0.1% - is present due to natural erosion in maturing stands.

0.2% bare subsoil by area has been measured in young second-rotation stands oversown with grass-legume cover, rising to 0.1% where scrub emerges around young trees. Both figures confirm slight incidence of subsoil erosion as root strength decays beneath felled stumps, and before the new roots of young trees interlock. The 0% figure for young stands with other soil conservation trees or natives may be unreliable, given small cluster size(n=2). In mature stands where secondary vegetation is present in canopy gaps, subsoil bared by natural erosion ranges from 0.5% to 0%.

Figure 5e: Effect of soil conservation cover in exotic scrub

In sparse exotic scrub containing rank grass or wetland, topsoil bared by fresh land use disturbance is 0.7% by area. Where exotic scrub has closed canopy, the figure is higher at 1.5%. It falls to 0% where natural scrub is emerging, and is likewise 0% where natural or wildling trees are emerging.

Subsoil bared by natural erosion processes in closed-canopy exotic scrub is 1.4% by area; a moderate figure attributable to fresh landslides and gullies. The figure is 0% where grass or wetland remains as secondary cover in sparse exotic scrub, but rises to 1.6% where natural scrub is emerging, falling again to 0.1% where trees are emerging,

through an exotic scrub canopy. While there is some overlap of error margins, the trend may be real as these figures approach data for natural scrub and forest.

Figure 5f: Effect of soil conservation cover in natural scrub and forest

Sparse scrub, with remnant grass under the canopy or in canopy gaps, has 3.3% bare topsoil due to fresh land use disturbance. Sparse scrub interspersed with exotic scrub has 0.4%. The difference is insignificant (error margins overlap).

Bare topsoil drops to 0.1% where scrub has closed canopy. Here there is very little overlap with the error margins for sparse scrub. The figure drops again to <0.1% for scrub where natural forest trees are starting to emerge through the canopy. Where natural forest has scrub in canopy gaps, no bare topsoil has been measured by the cluster samples. Where forest is closed canopy and lacks visible secondary vegetation, the figure is higher at 0.2%.

In sparse scrub and forest with remnant grass, subsoil bared by natural erosion processes is low at 0% to 0.1% by area. Where sparse scrub is interspersed with exotic scrub the figure is also 0%.

As scrub closes canopy, bare subsoil rises slightly to 0.2%. The figure for natural trees emerging through scrub is 0.1%. Where scrub remains in the canopy gaps of natural forest, bare subsoil is 0.3%, and in closed-canopy natural forest, 0.1%.

Amongst themselves, the differences in these figures are statistically insignificant. All cluster sizes are large enough for the figures to be reliable; except perhaps grass or wetland remaining in forest (n=6) and exotic trees emerging in forest (n=2). They indicate that natural scrub and forest vegetation, once it closes canopy, has very low levels of fresh subsoil disturbance.

Table 5g: Effect of soil conservation cover in mountain scrub and tussock

Bare topsoil due to land use disturbance has not been detected in mountain scrub or tussock grassland.

Bare subsoil due to natural erosion processes is high at 11.0% by area in tussock grassland; the high error margin due to a small number of sites where bare subsoil is at or close to 100%. The figure drops to 1.9% for mountain scrub. Where tussock remains as secondary cover in mountain scrub, bare subsoil jumps to 2.8% compared with 0.7% where mountain scrub is present as secondary cover in tussock. Bare subsoil drops to 0.3% at sites where lowland scrub is emerging through mountain scrub, and 0% where lowland forest trees are emerging.

Although cluster sample sizes for secondary cover in mountain scrub and tussock are somewhat small, there is a clear trend for natural erosion to decline as mountain scrub becomes established in tussock, and as lowland vegetation becomes established in mountain scrub.

Table 5h: Effect of soil conservation cover in wetland

Bare topsoil due to land use disturbance is absent from wetland except at one cluster, where it is 54% by area due to drainage and cultivation.

No bare subsoil due to natural disturbance is currently present in wetland (though revegetating surfaces disturbed by recent siltation were detected at several clusters).

Natural erosion appears to remain at or close to zero in wetland, where primary cover alone is present, and also where secondary cover – whether natural or adventitious – occurs.

6 Conclusions about state of the Waikato's soil

These conclusions are for state of the Waikato's soil in 2002-2003, the years of new aerial photographic coverage. They are based on a sample of 6,122 points, taken from the coverage at 2 kilometre spacings throughout the region. The sample represents true regional figures to +-1% or better.

Soil intactness and disturbance

70.9% of the Waikato's soil is intact.

Of this, 41.7% is on stable sites - drained wetlands, protected floodplains, elevated terraces, rolling downlands, ridges, spurs or footslopes in hill country - that show no signs of past erosion and are currently well-vegetated. 29.2% is on unstable sites - healed erosion scars in hill country, inactive gullies on downlands, terrace edges, flood-prone river flats, undrained wetlands - that are currently inactive and well-vegetated. Here vegetation cover - whether crops, pasture, plantations, scrub or forest - is at present sufficiently dense to protect soil against disturbance.

5.9% of the Waikato's soil has been recently disturbed by human use of the land. Recently disturbed sites are those which have crops growing after cultivation or stubble after crop harvest, spelled pasture recovering from heavy grazing, and grass/legume cover oversown following forest harvest. They also include tracks and earthworks which are revegetating.

6.8% of the Waikato's soil is freshly disturbed by land use. Sites are as described above but include areas devoid of vegetation. Soil bared by fresh disturbance amounts to 1.0% of the region's area.

6.2% of the Waikato's soil has been recently disturbed by natural processes of erosion or deposition. Recently disturbed sites are revegetating mass movement scars, gullies and soil pipes, areas of scour and siltation on stream banks, areas where sand is blown away or accumulates, and miscellaneous disturbances such as rockfall on bluffs, high-altitude sheet erosion and geothermal activity.

3.1% of the Waikato's soil is freshly disturbed by natural processes. Sites are as described above but include areas devoid of vegetation. Soil bared by fresh disturbance amounts to 0.4% of the region's area.

Pressure on soil – impacts of land use

Fresh disturbance of topsoil is located mainly in dairy pasture and drystock pasture. It is caused by heavy grazing of pasture prior to spelling, and also by extensive farm tracks. Lower but still measurable percentages occur in forest plantations due to topsoil exposure by logging and associated tracking; and under intensive uses (orchards, vegetable growing, cropland) which entail soil cultivation. Under exotic scrub, also under natural vegetation cover (undrained wetland, lowland scrub and forest, mountain scrub and tussock), fresh topsoil disturbance is slight.

% of region:	in use	freshly disturbed by land use	bare surface due to land use
Intensive uses	1.9	0.1	<0.1
Dairy pasture	24.2	2.9	0.4
Drystock pasture	26.7	2.0	0.2
Forest plantations	13.7	1.2	0.2
Exotic scrub	3.4	0.2	<0.1
Natural scrub & forest	20.8	0.1	<0.1
Mountain scrub & tussock	1.7	0.1	0.0
Wetland	0.8	0.0	<0.1

Fresh disturbance of subsoil is slight under intensive uses, dairy pasture and forest plantations. It is located mainly in drystock pasture, where the causes are landslides and earthflows in hill country, or gullies and streambank erosion in pumice-mantled downlands. Under exotic scrub and natural vegetation cover, fresh subsoil disturbance is slight except in natural scrub and forest. Here its incidence is raised by landslides, gullies and streambank erosion in steep ranges.

% of region:	in use	freshly disturbed by natural processes	bare surface due to natural processes
Intensive uses	1.9	0.0	0.0
Dairy pasture	24.2	0.2	<0.1
Drystock pasture	26.7	1.8	0.1
Forest plantations	13.7	0.3	<0.1
Exotic scrub	3.4	0.1	<0.1
Lowland scrub & forest	20.8	0.6	<0.1
Mountain scrub & tussock	1.7	0.1	0.1
Wetland	0.8	0.0	0.0

Pressure on vegetation – impacts of land use

Secondary vegetation is present on a fifth of soil under intensive uses. It is present on a quarter of dairy pasture, two fifths of drystock pasture, and half of forest plantations. The proportion of planted secondary vegetation remains high for all these land uses. Conversely the proportions of induced and natural secondary vegetation remain small, but increase with the transition from intensive use through pasture to forest plantation.

Secondary vegetation is present in four fifths of the exotic scrub, half the natural scrub and forest, a fifth of the mountain scrub and tussock, and just under half the wetland. The proportion of natural secondary vegetation is high, and is successional after site disturbance by past land use e.g. logging or natural events e.g. storms. The balance is rank grass, exotic scrub or wildling trees induced as a result of similar site disturbance.

% of area in use:	with secondary vegetation			
	natural	induced	planted	total
Intensive uses	0.9	-	20.4	21.3
Dairy pasture	5.9	0.4	18.5	24.8
Drystock pasture	20.6	8.4	12.6	41.6
Forest plantations	11.7	15.7	25.3	52.7
Exotic scrub	45.6	32.6	-	78.2
Natural scrub and forest	40.7	8.7	-	49.4
Mountain scrub and tussock	18.2	-	-	18.2
Wetland	16.7	29.2	-	45.9

Response to pressure – extent of vegetative conservation measures

On land in commercial use - intensive cultivation, dairy and drystock pasture, forest plantations - primary vegetation functions as a soil conservation measure where dense, providing protective cover against surface erosion by water and wind. Secondary vegetation where dense protects against both surface and subsurface erosion; against the latter by various root reinforcement and de-watering effects. This holds true whether the vegetation has been deliberately planted to control erosion, planted for commercial reasons, or merely retained on sites that are difficult to develop. By dense, is meant continuous primary cover or well-spaced secondary cover. By sparse, is meant depleted primary cover, or scattered secondary cover.

On land in natural cover, primary vegetation can be said to have soil conservation value. Typically it is tree or scrub cover. Whether reserved for ecological reasons/watershed management, or merely left on land that is not wanted for commercial use, it also protects against both surface and sub-surface erosion. Secondary vegetation is typically herbaceous or scrub cover. It indicates site disturbance - usually accompanied by erosion. Some kinds of natural secondary

vegetation - for instance, trees emerging through scrub cover - also indicate a degree of site recovery so could be said to have soil conservation value.

% of area in use:	with dense vegetation that: functions as a soil conservation measure (commercial land uses) or is of value for soil conservation (conservation land uses)		
	primary	secondary	Total
Intensive uses	60.2	19.5	79.7
Dairy pasture	59.9	14.4	74.3
Drystock pasture	44.4	17.3	61.7
Forest plantations	43.2	52.6	95.8
Exotic scrub	21.8	56.8	78.6
Natural scrub and forest	50.6	44.5	95.1
Mountain scrub and tussock	67.0	33.0	100.0
Wetland	54.2	45.8	100.0

These definitions may seem broad, but they give a truer picture of conservation measures adopted by landowners and public agencies, than would be obtained by looking solely at conservation plantings. They show that the extent of vegetative conservation measures is high for all land uses, though variable. Drystock pasture stands out clearly as lower than the rest. Intensive uses, dairy pasture, and exotic scrub are somewhat lower than desirable. In forest plantations and amongst the conservation uses, almost all vegetation has a soil conservation role, although much of the secondary vegetation is exotic scrub or wildling trees, regarded as undesirable for ecological restoration.

Effectiveness of response – reductions in soil disturbance

Bare topsoil - exposure to risk of surface erosion - is high where primary vegetation cover is maintained by intensive land uses (orcharding, vegetable growing, cropping). It drops with the transition from fresh cultivation to growing crops, and rises again with crop harvest. Under all other commercial land uses, the percentage of bare topsoil is kept low where dense primary vegetation is maintained. Conversely the percentage becomes high, where sparse primary vegetation is depleted. Under conservation uses, primary vegetation generally remains dense, and bare topsoil minimal:

% bare topsoil where:	primary vegetation is	
	sparse	dense
Intensive uses	16.0	0.2
Dairy pasture	2.8	1.2
Drystock pasture	2.0	0.8
Forest plantations	5.2	0.2
Exotic scrub	-	1.5
Natural scrub	-	0.1
Natural forest	-	0.2
Mountain scrub and tussock	-	0.0
Wetland	-	0.0

Where secondary vegetation is retained or planted amongst commercial land uses, bare topsoil remains at levels intermediate between sparse and dense primary vegetation. Where secondary vegetation is present amongst conservation uses, bare topsoil is at or close to zero except for two categories where it increases - rank grass in scrub; and exotic trees in natural forest - perhaps because in both instances, secondary vegetation is associated with site disturbance. Under all uses, the percentage of topsoil bare does not decline where secondary vegetation is dense, nor is there any trend for it to decline with the transition from herbaceous through scrubby to woody secondary vegetation.

% bare topsoil where:

	secondary vegetation is:					
	wetland/rank		scrub		Trees	

	grass					
	sparse	**dense**	**sparse**	**dense**	**sparse**	**dense**
Intensive uses	0.0	2.0	-	-	0.0	0.4
Dairy pasture	0.8	3.0	0.1	1.2	1.4	1.6
Drystock pasture	1.0	0.8	0.8	0.9	0.5	0.2
Forest plantations	2.2	0.8	1.9	0.6	0.0	1.0
Exotic scrub	-	0.7	-	0.0	-	0.0
Natural scrub	-	3.3	-	0.4	-	0.1
Natural forest	-	0.0	-	0.0	-	2.5
Mountain scrub and tussock	-	0.0	-	0.0	-	0.0
Wetland	-	54.0	-	0.0	-	0.0

For all land uses, bare subsoil - exposure by erosion processes - occurs in primary vegetation cover only where it is on unstable terrain. Under intensive use, dairy pasture or forest plantation, very little primary vegetation cover is on such sites, hence the zero or close to zero percentages. Bare subsoil starts to appear in drystock pasture, exotic scrub, natural scrub and forest; but becomes high only amongst mountain scrub and tussock.

% bare subsoil where:	**primary vegetation is**	
	sparse	**dense**
Intensive uses	0.0	0.0
Dairy pasture	0.1	<0.1
Drystock pasture	0.4	0.5
Forest plantations	0.0	<0.1
Exotic scrub	-	1.4
Natural scrub	-	0.2
Natural forest	-	0.1
Mountain scrub and tussock	-	11.0
Wetland	-	0.0

For all commercial uses except intensive, there are somewhat higher percentages of bare subsoil on sites where secondary vegetation is present. This is a consequence of secondary vegetation being retained, induced or planted on most of the unstable sites in commercial land use. Secondary vegetation appears through natural plant succession on unstable sites in conservation use; and here the percentages of bare subsoil are lower than where primary cover alone is present. Bare subsoil does not decline with the transition from herbaceous through scrubby to woody secondary vegetation; nor does it consistently decline with the transition from sparse to dense secondary cover.

% bare subsoil where:	**secondary vegetation is:**					
	wetland/ rank grass		**scrub**		**trees**	
	sparse	**dense**	**sparse**	**dense**	**sparse**	**dense**
Intensive uses	0.0	0.0	-	-	0.0	0.0
Dairy pasture	0.1	0.0	0.0	0.0	0.1	0.1
Drystock pasture	0.5	0.7	0.6	0.3	0.4	0.3
Forest plantations	0.2	0.0	0.1	0.5	0.0	0.0
Exotic scrub	-	0.0	-	1.6	-	0.1
Natural scrub	-	0.1	-	0.0	-	0.1
Natural forest	-	0.0	-	0.3	-	0.0
Mountain scrub and tussock	-	0.7	-	0.3	-	0.0
Wetland	-	0.0	-	0.0	-	0.0

Technical conclusions about survey method

Use of orthophotos

A major innovation of the Waikato survey cf. earlier surveys undertaken for other regional councils, has been interpretation of orthophotos (aerial photographs rectified to fit a map grid) by on-screen viewing through GIS software, with direct entry of data to a GIS-linked database. The new procedure has proven better than expected as regards ease of use; partly due to high quality of the orthophoto coverage, and partly the good standard of its installation on EW's GIS.

Time taken for photo-interpretation was similar to earlier methods, varying from about 600 points per day when hardware and software were fully functional, down to about 200 when glitches were experienced. This compares with 400-600 points per day for photo-interpretation by viewing paper prints, and 200-400 for stereoscopic viewing of unrectified aerial photographs.

The main time saving has been through direct data entry. No time had to be spent transcribing data from manual data recording sheets into the computer. Data could be sorted by pivot table analysis, followed by manual addition of totals for various combinations of data items, from the printed pivot tables.

Overall, the new procedure enabled time and budget for the survey to be reduced from 64 days (as estimated in the 2001 scoping report), down to 40 days (as done in 2003).

Representativeness of results

Error analysis has been carried out for all tables in the survey report.

For soil disturbance region-wide there is 95% confidence that sample data are representative of true figures to +- 1% or better.

For soil disturbance by land use there is 95% confidence that margins of error are less than 1%, so long as figures are expressed as percentages of the region. Expressed as percentages of each land use, error margins are similar for common land uses. For those that are less common, for instance wetlands, error margins are in the 1 to 5% range - somewhat higher but still acceptable.

For soil disturbance by secondary vegetation, or by various standards of conservation measure, margins of error exceed 5% where sub-sample sizes are small. To overcome this problem, cluster samples have been built up from one-hectare areas around each sample point, specifically to measure bare soil for various combinations of land use and conservation measure. Its error margins are less than 1% in most instances; rising above 1% for some, and exceeding 5% for a few combinations where bare soil is abnormally distributed e.g. cropland, or where the sampling method did not build up enough e.g. remnant grass in sparse scrub.

To summarise:

- The point sample is sufficiently representative to draw conclusions about soil intactness/disturbance region-wide, for land uses within the region, and for large sub-divisions of the region such as districts or catchment management zones,

- To draw conclusions about the impacts of vegetation management or soil conservation, an additional cluster sample needs to be taken on areas around each point. A cluster sample produces sufficiently representative data for common types

of secondary vegetation cover or soil conservation measure. For a few which are less common, non-random clusters are needed.

Photo-interpretation error

For land use, secondary vegetation, and soil disturbance, photo-interpretation accuracy is better than 90%. Few errors are repeated more than once in the course of a hundred points, for these three parameters. This being the case, it is unlikely that they will cause problems for any future analysis of the point sample. The exceptions are extent of broadleaved exotic plantings (may be slightly over-estimated), and extent of stable surfaces (may be slightly under-estimated).

For type of disturbance, photo-interpretation accuracy is lower than expected at 82%. Of the 18% balance, 9% are additions or deletions of type codes and 9% are true photo-interpretation errors. Caution should be exercised if analysing type of disturbance on unstable but inactive land, where most of the errors occur. Instances of mis-classification are minimal on recently disturbed or freshly disturbed surfaces, where type of disturbance can be seen clearly. Here, the point sample data can be safely analysed.

For landforms, 76% photo-interpretation accuracy is a concern. 24% of points have been classified as being on a landform adjacent to where they are actually located. The reason for these errors is that orthophotos cannot be viewed stereoscopically, when interpreting them on the computer screen. Subtle changes in relief, close to hillfoots, terrace edges and streams, are hard to detect. The data can provide at best an approximate guide to proportion of landforms present region-wide, or in some particular part of the region. However, it would be inadvisable to attempt analysis of other parameters - for instance soil disturbance - categorised according to landform.

Calibration of data for sample point size and cluster analysis of bare soil

Use of a large point size when sampling, raises the chance that soil disturbance will be recorded at a point. So percentage of points with fresh soil disturbance cannot be equated with percentage area of bare soil.

Two options have been identified for calibrating percentages:

- Apply the ratio graphed in Figure 1 (Appendix 2) to percentages calculated from point counts. For 12mm2 circles used as “points” (this survey), the appropriate scaling factor is 0.23. This converts summary percentages to % area bare soil.

- Treat each “point” as a cluster i.e. measure % area bare soil for each, and calculate the average for all (Appendix 3).

The first option is acceptable where n is large and the sampling error small i.e. the regional sample and the land use sub-samples. It may be satisfactory where n and the sampling error are moderate i.e. the secondary vegetation sub-samples. It was carried out for the 2003 survey. Data from the first option appear in the draft report.

The second option is needed where n is small and the sampling error becomes large i.e. the soil conservation sub-samples. It was carried out in August 2005, for all points in the original 2003 survey (see Appendix 5). Data from the second option have been incorporated in the final report.

Procedure for extracting regional subsets

Sub-regional analyses are not part of the contract. Nevertheless, an analysis has been carried out for the Coromandel catchment management zone, to supply background information for staff who are currently preparing proposals for soil conservation and river control. This has enabled a procedure to be worked out for future sub-regional

analyses. Its results also furnish some useful examples of what can be extracted. The procedure for extracting regional subsets is provided in Appendix 4.

It is safe to conduct sub-regional analyses for:

- Local authority districts, large territorial areas, catchment management zones, or fairly large sub-catchments where n>100,
- but it would be unwise to conduct them for:
- For small territorial areas or sub-catchments where n<100.
- Similarly, it is safe to express sub-totals as:
- A proportion or percentage of total points in a sub-set, or of a category within a sub-set, for which n>100,
- but unwise to do so for:
- Sub-sets or categories for which n<100.

In short, the point sample has been designed to provide statistical data for the Waikato region, and can also provide valid data for reasonably large subdivisions within it. However, to attempt a data analysis for points in an area of land any smaller than 400 km2 (equivalent to 100 points; there is 1 sample point per 4 square kilometres), would be pushing the point sample beyond the purpose for which it was designed.

References

Hicks, D.L. 2000 Technical Appendices to: Rural land use on Auckland's soils; Soil erosion in Auckland's hill country; Soil erosion in Auckland's sand country. Contract reports prepared for Auckland Regional Council.

Hicks, D.L. 2001 Scoping Paper: Point sample survey of soil stability from orthophotography. Contract report prepared for Environment Waikato.

Appendix I Field check of randomly selected sample points

A field check has been carried out to supply estimates of photo-interpretation error for the main point sample. Environment Waikato staff randomly selected 100 points from the 6122, subject to a filter criterion that the points be located within 200 metres of a road. This criterion was imposed to enable speedy field checking. While it makes the field-checked points non-random with respect to roads, it is not expected to alter their random nature with respect to the parameters recorded - land use, secondary vegetation, soil disturbance, nature of disturbance, landform. It is possible that soil disturbance and nature of disturbance might be influenced by a road, where a point lands on it or immediately next to it. This is the case for 27 out of the 100.

Points were viewed by driving around the region in the course of five days. Paper prints of the orthophoto surrounding each point enabled exact location once in the vicinity. Viewing each point from the road, photo-interpreted parameters were either confirmed or altered.

3 points could not be viewed because of signs prohibiting access along private roads. Data at these points has been assumed correct. The alternative will be to substitute another 3 random points.

Land use

Correct at 92 points. Photo interpretation errors are:

- wrong pasture type e.g. unimproved recorded as improved (4 points),
- young pines not spotted in other vegetation (2 points),
- forest mistaken for scrub (1 point),
- conifer plantation mistaken for broadleaved (1 point).

Secondary vegetation

Correct at 90 points. Photo interpretation errors are:

- spaced trees in pasture mis-identified e.g. natives as broadleaved exotics (7 points),
- exotic scrub reversion not spotted in pasture (2 points),
- native scrub reversion not spotted (1 point).

Soil disturbance

Correct at 91 points. Photo interpretation errors are:

- stable soil mistaken for unstable (5 points),
- unstable soil mistaken for stable (1 point),
- unstable soil mistaken for recently disturbed (1 point),

- * unstable soil mistaken for freshly disturbed (1 point),
- freshly disturbed soil not spotted (1 point).

Type of disturbance

Correct at 82 points. Photo interpretation errors are:

- Type of disturbance omitted/added due to prior error recording soil disturbance (9 points),
- Type of disturbance mis-identified e.g. landslide mistaken for slump (7 points),
- Type of disturbance not recorded (2 points).

Landform

Correct at 76 points. Photo interpretation errors are:

- confusion between downland and terrace (5 points),
- confusion between downland and hillslope (8 points),
- other landform mistaken for alluvial streambank (4 points),
- other landform mistaken for rock streambank (2 points),
- miscellaneous mistakes (5 points).

Overall comments on photo-interpretation error

For land use, secondary vegetation, and soil disturbance, photo-interpretation accuracy is better than 90%. The figures are comparable with other point sample surveys from aerial photographs, recently carried out for regional councils' state of environment monitoring (Manawatu-Wanganui 1999, Auckland 2000, Gisborne 2001).

Few errors are repeated more than once in the course of a hundred points, for these three parameters. This being the case, it is unlikely that they will cause problems for any future analysis of the point sample. The exceptions are extent of broadleaved exotic plantings (may be over-estimated), and extent of stable surfaces (may be under-estimated).

For type of disturbance, photo-interpretation accuracy is lower than expected at 82%. Of the 18% balance, 9% are additions or deletions of type codes, due to a prior error in recording presence or absence of disturbance - almost all, surfaces that are either stable or unstable but inactive. 9% are true photo-interpretation errors. The majority of these also relate to surfaces that are unstable but inactive - revegetated surfaces where disturbance type can be hard to pick.

Caution should be exercised if analysing type of disturbance on unstable but inactive land, for all the preceding reasons. Fortunately, instances of mis-classification are minimal on recently disturbed or freshly disturbed surfaces - where type of disturbance can be seen clearly. Here, the point sample data can be safely analysed.

For landforms, 76% photo-interpretation accuracy is a concern. Most of the errors are confusion of downland with adjacent terraces or hillslopes; or recording of streambanks within point circles where true streambank positions are outside the circles. The reason for these errors is that orthophotos cannot be viewed stereoscopically, when interpreting them on the computer screen. Subtle changes in relief, close to hillfoots, terrace edges and streams, are hard to detect.

Caution needs to be exercised, if the point sample data are analysed according to landform. The data can provide an approximate guide to proportion of landforms present region-wide, or in some particular part of the region. However a sub-sample of points on hillslopes will contain some that are really on downland - and vice versa. Similarly a sub-sample of points on streambanks will contain some that are really on other landforms within a short distance of the banks. For this reason, it would be inadvisable to attempt analysis of other parameters - for instance soil disturbance - categorised according to landform.

Appendix II: Calibration of data for sample point size

The same 100 random points selected for field checking (Appendix 1), have been used to calibrate data for sample point size.

Points were sampled on-screen using a circle 4 mm in diameter, superimposed on the orthophotos, viewed at 1:10,000 scale. The circle area was equivalent to approximately 1200 square metres on the ground. A point was recorded as having fresh soil disturbance, if bare soil was observed anywhere within the circle. Provided a circular area of 1200 square metres can be treated as an infinitesimal point, relative to the Waikato Region's total area which is 24488 square kilometres, a large number of such points (n>1000) should provide a good estimate of percentage soil disturbance.

However the question arises, whether treating a small circular area as a point, may over-estimate the percentage of soil that is freshly disturbed. To find out, soil disturbance at the 100 random points was measured with dot grids of successively greater size, from 1 mm2 to 100 mm2. Table 1 and Figure 1 give the results:

Table 1: Fresh soil disturbance, measured using various dot grid sizes

Dot grid size (mm2)	1	4	16	36	64	100
% of "points" with fresh disturbance	7	21	43	54	62	73
Av. % of "point" area freshly disturbed	7	7.8	6.3	6.1	5.9	5.9
Ratio	1.00	0.37	0.15	0.11	0.10	0.08

The equation of Figure 1 is $y = 72.03x^{-0.1486}$

The experiment clearly shows that increasing point size does raise the chance that soil disturbance will be recorded at a point; and will cause over-estimation of percentage area affected, if percentage area is calculated from a point count as opposed to a dot/cell measurement at the points.

It also indicates two options for calibrating percentages:

- Apply the ratio graphed in Figure 1 to percentages calculated from points - for instance where 12mm2 circles are used as "points", the appropriate scaling factor is 0.23

- Treat each "point" as a cluster i.e. measure % area freshly disturbed for each and calculate the average for all.

The first option is acceptable where n is large and the sampling error small i.e. the regional sample (Table 1 of main report), and the land use sub-samples (Tables 2a to 2h). It may be satisfactory where n and the sampling error are moderate i.e. the secondary vegetation sub-samples (Tables 3a to 3h).

The second option is needed where n is small and the sampling error becomes large i.e. the soil conservation sub-samples (Tables 4a to 4h).

As mentioned in Section 4 of the main report, once number of points declines below about 100, the sampling error attached to sub-samples (points with various standards of soil conservation cover) becomes unacceptably large. Also as discussed in

Appendix 2, percentage area affected by soil disturbance will be an over-estimate, if points are sampled using a device that has appreciable area e.g. a circle or a grid.

To supply measurements with acceptable sample errors, and to overcome the over-estimation problem associated with use of 12mm2 circles as "points", a cluster analysis has been carried out for each combination of land use and soil conservation cover. This has been done by re-sampling land uses around the 100 random points selected for field checking (Appendix 1). The procedure was:

- Overlay a 1 hectare grid on an area of 100 hectares, centred on each random point,

- Overlay a grid of 100 points on the central grid cell,

- Proceeding clockwise from the centre, perform a point count of any bare ground within any grid cell which has a new combination of land use and secondary vegetation,

Thus a variable number of clusters, ranging from 3 to 20, was measured around each random point. A total 1035 clusters were measured.

Cluster sample results are given in Tables 1 to 6. The method appears to have selected a sufficient number of clusters, to provide reliable measurements of bare ground for most combinations of land use and soil conservation measure. The exceptions are:

- Secondary vegetation covers which are genuinely rare - for instance, scattered scrub in cropland,

- Natural vegetation covers restricted to small parts of the region - mountain scrub and tussock, coastal scrub, and wetland.

Tables 1 to 6 appeared in the draft report (September 2003) as Tables 5a to 5f. Section 5 of the draft discussed the significance of variations in bare ground, in terms of different standards of soil conservation cover.

These tables have been superseded by a new cluster analysis around all 6122 points in the original sample (see Appendix 5 for discussion of the reasons, and how it was done). New Tables 5a to 5h have been substituted in the final report, and Section 5's discussion has been slightly amended to accord with their content.

Table 1: Intensive uses

Fresh disturbance by:		clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:						
Crop, fruit trees, vines	sparse	14	32.8	22.5	0.0	0.0
	dense	18	6.4	9.8	0.0	0.0
Secondary vegetation:						
Wetland/grass	sparse	0				
	dense	3	59.3	47.7	0.0	0.0
Scrub	sparse	0				
	dense	6	4.5	5.4	0.0	0.0
Trees	sparse	4	2.5	2.0	0.0	0.0
	dense	17	13.0	11.8	0.0	0.0

Table 2: Dairy pasture

Fresh disturbance by:		clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes bare surfaces as % of area	+-2s.e.
Primary vegetation:						
Pasture	sparse	25	2.8	1.4	0.0	0.0
	dense	35	1.2	0.8	0.0	0.0
Secondary vegetation:						
Wetland/grass	sparse	13	1.2	1.2	1.3	1.4
	dense	9	1.1	1.3	1.0	1.4
Scrub	sparse	7	0.5	1.0	0.8	0.9
	dense	28	0.6	0.6	0.4	0.5
Trees	sparse	36	1.6	1.2	0.7	0.5
	dense	60	1.8	1.0	0.2	0.2

Table 3: Drystock pasture

Fresh disturbance by:		clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:	sparse	51	5.9	2.4	1.3	2.1
Pasture	dense	54	1.2	0.6	1.6	1.7
Secondary vegetation:						
Wetland/grass	sparse	24	1.9	3.4	1.9	2.9
	dense	19	1.6	1.1	1.4	1.6
Scrub	sparse	39	2.6	1.3	2.4	1.3
	dense	61	2.7	1.3	0.7	0.4
Trees	sparse	74	2.5	0.8	2.1	0.9
	dense	109	2.9	0.9	0.5	0.2

Table 4: Forest plantations

Fresh disturbance by:	clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:					
Plantation trees					
harvested	10	11.2	5.1	0.0	0.0
maturing stands	13	0.4	0.6	0.0	0.0
Secondary vegetation:					
Wetland/grass in					
young stands	9	1.1	2.1	1.4	2.6
maturing stands	6	3.5	4.3	0.0	0.0
Scrub					
in young stands	10	2.6	2.3	2.3	2.3
maturing stands	12	1.2	1.5	0.4	0.8
Other trees					
in young stands	0				
maturing stands	3	0.0	0.0	0.3	0.5

Table 5: Exotic scrub

Fresh disturbance by::	clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:					
Exotic scrub	4	0.5	0.8	2.8	2.1
Secondary vegetation:					
Wetland/grass in exotic scrub	2	5.0	6.9	0.0	0.0
Natural scrub in exotic scrub	7	0.7	1.3	0.6	0.8
Trees in exotic scrub	10	1.8	2.3	0.8	1.5

Table 6: Natural scrub and forest

Fresh disturbance by:	clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:					
Scrub	23	0.5	0.6	0.4	0.5
Forest	13	0.0	0.0	0.5	0.4
Secondary vegetation:					
Wetland/grass in scrub	6	2.2	2.9	3.7	5.3
Wetland/grass in forest	3	0.0	0.0	5.0	3.2
Exotic scrub in scrub	8	2.0	1.9	0.3	0.5
Scrub in forest	16	0.0	0.0	0.7	0.5
Trees in scrub	18	0.2	0.3	0.6	0.5
Other trees in forest	1	0.0	0.0	0.0	0.0

Appendix III: Cluster analysis of fresh soil disturbance under various soil conservation covers

As mentioned in Section 4 of the main report, once number of points declines below about 100, the sampling error attached to sub-samples (points with various standards of soil conservation cover) becomes unacceptably large. Also as discussed in Appendix 2, percentage area affected by soil disturbance will be an over-estimate, if points are sampled using a device that has appreciable area e.g. a circle or a grid.

To supply measurements with acceptable sample errors, and to overcome the over-estimation problem associated with use of 12mm2 circles as "points", a cluster analysis has been carried out for each combination of land use and soil conservation cover. This has been done by re-sampling land uses around the 100 random points selected for field checking (Appendix 1). The procedure was:

- Overlay a 1 hectare grid on an area of 100 hectares, centred on each random point,

- Overlay a grid of 100 points on the central grid cell,

- Proceeding clockwise from the centre, perform a point count of any bare ground within any grid cell which has a new combination of land use and secondary vegetation,

Thus a variable number of clusters, ranging from 3 to 20, was measured around each random point. A total 1035 clusters were measured.

Cluster sample results are given in Tables 1 to 6. The method appears to have selected a sufficient number of clusters, to provide reliable measurements of bare ground for most combinations of land use and soil conservation measure. The exceptions are:

- Secondary vegetation covers which are genuinely rare - for instance, scattered scrub in cropland,

- Natural vegetation covers restricted to small parts of the region - mountain scrub and tussock, coastal scrub, and wetland.

Tables 1 to 6 originally appeared in the main report, as Tables 5a to 5f. Section 5 discusses the significance of variations in bare ground, in terms of different standards of soil conservation cover. Tables 5a to 5f have been replaced by new Tables 5a to 5h based on an improved sampling method (see Appendix 5).

Table 1: Intensive uses

Fresh disturbance by:		clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:						
Crop, fruit trees, vines	sparse	14	32.8	22.5	0.0	0.0
	dense	18	6.4	9.8	0.0	0.0
Secondary vegetation:						
Wetland/grass	sparse	0				
	dense	3	59.3	47.7	0.0	0.0
Scrub	sparse	0				
	dense	6	4.5	5.4	0.0	0.0
Trees	sparse	4	2.5	2.0	0.0	0.0
	dense	17	13.0	11.8	0.0	0.0

Table 2: Dairy pasture

Fresh disturbance by:		clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes bare surfaces as % of area	+-2s.e.
Primary vegetation:						
Pasture	sparse	25	2.8	1.4	0.0	0.0
	dense	35	1.2	0.8	0.0	0.0
Secondary vegetation:						
Wetland/grass	sparse	13	1.2	1.2	1.3	1.4
	dense	9	1.1	1.3	1.0	1.4
Scrub	sparse	7	0.5	1.0	0.8	0.9
	dense	28	0.6	0.6	0.4	0.5
Trees	sparse	36	1.6	1.2	0.7	0.5
	dense	60	1.8	1.0	0.2	0.2

Table 3: Drystock pasture

Fresh disturbance by:			Land use:		Natural processes:	
		clusters sampled	bare surfaces as % of area	+- 2 s.e.	bare surfaces as % of area	+-2s.e.
Primary vegetation:	sparse	51	5.9	2.4	1.3	2.1
Pasture	dense	54	1.2	0.6	1.6	1.7
Secondary vegetation:						
Wetland/grass	sparse	24	1.9	3.4	1.9	2.9
	dense	19	1.6	1.1	1.4	1.6
Scrub	sparse	39	2.6	1.3	2.4	1.3
	dense	61	2.7	1.3	0.7	0.4
Trees	sparse	74	2.5	0.8	2.1	0.9
	dense	109	2.9	0.9	0.5	0.2

Table 4: Forest plantations

Fresh disturbance by:	clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:					
Plantation trees					
harvested	10	11.2	5.1	0.0	0.0
maturing stands	13	0.4	0.6	0.0	0.0
Secondary vegetation:					
Wetland/grass in					
young stands	9	1.1	2.1	1.4	2.6
maturing stands	6	3.5	4.3	0.0	0.0
Scrub					
in young stands	10	2.6	2.3	2.3	2.3
maturing stands	12	1.2	1.5	0.4	0.8
Other trees					
in young stands	0				
maturing stands	3	0.0	0.0	0.3	0.5

Table 5: Exotic scrub

Fresh disturbance by::	clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:					
Exotic scrub	4	0.5	0.8	2.8	2.1
Secondary vegetation:					
Wetland/grass in exotic scrub	2	5.0	6.9	0.0	0.0
Natural scrub in exotic scrub	7	0.7	1.3	0.6	0.8
Trees in exotic scrub	10	1.8	2.3	0.8	1.5

Table 6: Natural scrub and forest

Fresh disturbance by:	clusters sampled	Land use: bare surfaces as % of area	+- 2 s.e.	Natural processes: bare surfaces as % of area	+-2s.e.
Primary vegetation:					
Scrub	23	0.5	0.6	0.4	0.5
Forest	13	0.0	0.0	0.5	0.4
Secondary vegetation:					
Wetland/grass in scrub	6	2.2	2.9	3.7	5.3
Wetland/grass in forest	3	0.0	0.0	5.0	3.2
Exotic scrub in scrub	8	2.0	1.9	0.3	0.5
Scrub in forest	16	0.0	0.0	0.7	0.5
Trees in scrub	18	0.2	0.3	0.6	0.5
Other trees in forest	1	0.0	0.0	0.0	0.0

Appendix IV: Procedure for extracting regional sub-sets

This appendix suggests what types of data and levels of data analysis are appropriate to use, when extracting regional sub-sets - for instance, catchment management zones or local authority districts - from the main point sample. Now that the data are on Environment Waikato's GIS, it is likely to be used for this purpose from time to time by staff, so some guidance as to procedures is needed.

Sub-regional analyses are not part of the contract. Nevertheless, an analysis has been carried out for the Coromandel management zone, to supply background information for staff who are currently preparing proposals for soil conservation and river control.

This has enabled a procedure to be worked out for future sub-regional analyses. Its results also furnish some useful examples of what can be extracted.

Procedure

The first step is to extract a sub-set of points with attached data, for the area to be analysed. This is done on the GIS using the Geomedia programme:

- Open file "complete.gws" in the RIG soil intactness folder,
- Find boundary of area,
- Use the Geomedia function to select all points in "complete.gws" that are within the boundary selected,
- Use the Geomedia "attribute query" function to select data matching these points, from the Access database file "8219.mdb",
- Store the sub-set of selected points as a separate database file with a recognisable name e.g. "Coromandel point data".

The second step is to obtain total point numbers for each parameter. While this can be done in Geomedia by repeated use of the "query" function, it is actually quicker to convert the subset database file to an Excel spreadsheet (done using the Access "office links" function). Total point numbers can be obtained in a single operation, using the Excel "pivot table" function:

- Landform by page,
- Land use and secondary vegetation by row,
- Soil disturbance and type of disturbance by column.

For a catchment management zone/district, this generates a pivot table which can be printed on around 4 sheets of A4 paper.

The third step is to read point totals for categories of interest from the pivot table. This can be done to various levels e.g.

- Drystock pasture,
- Drystock pasture with remnant natural tree cover,
- Drystock pasture with dense remnant natural tree cover,

- Freshly disturbed points in any of the above,

- Nature of fresh disturbance in any of the above e.g. topsoil exposure, tracking, earthworks, various categories of natural disturbance to subsoil.

A note of caution - it is safe to conduct sub-regional analyses for:

- Local authority districts, large territorial areas, catchment management zones, or fairly large sub-catchments where n>100,

- but it would be unwise to conduct them for:

- For small territorial areas or sub-catchments where n<100

Similarly, it is safe to express sub-totals as:

- A proportion or percentage of total points in a sub-set, or of a category within a sub-set, for which n>100,

  but unwise to do so for:

- Sub-sets or categories for which n<100.

The reason for this is that when a sub-set of points is broken down into detailed categories of interest, point numbers in each category become small. This is not a problem so long as the sub-set is large; preferably several hundred points; one hundred as an absolute minimum. So long as this criterion is observed, category totals can be expressed as a proportion of the sub-set, and sample error will remain less than 10% (+- 2 s.e. @ 95% confidence) - much less, if dealing with a small proportion. Likewise, category totals can be expressed as a proportion or percentage of another category, so long as the other category contains over a hundred points. Any smaller, and sample error may exceed 10% - particularly if the proportion is large.

In short, the point sample has been designed to provide statistical data for the Waikato region, and can also provide valid data for reasonably large subdivisions within it. However, to attempt a data analysis for points in an area of land any smaller than 400 km2 (equivalent to 100 points; there is 1 sample point per 4 square kilometres), would be pushing the point sample beyond the purpose for which it was designed.

The following examples, from the Coromandel data analysis conducted in July 2003, illustrate the level to which data may be safely analysed.

Land use

The point sample contains sufficient points to analyse land use for sub-sets at the level of catchment management zones or districts. For instance in the Coromandel:

	n	**%**	**+-2s.e.**
Agricultural land	119	20.5	3.3
Forest plantations	78	13.4	2.8
Exotic scrub	53	9.1	2.3
Natural scrub	206	35.4	3.9
Natural forest	104	17.9	3.1
Natural bare surfaces	6	1.0	0.8
Man-made surfaces	16	2.7	1.3
Total	582	100.0	0.0

Secondary vegetation

The point sample contains sufficient points to analyse secondary vegetation at the level of catchment management zones or districts. Results are best expressed as a percentage of the management zone's/district's land area. For instance, for agricultural land in the Coromandel:

	n	% of cmz	+-2s.e.
Agricultural land with:			
No secondary vegetation	63	10.8	2.5
Wetland	5	0.9	0.8
Rank grass	0	0.0	0.0
Exotic scrub	14	2.4	1.2
Natural scrub	12	2.1	1.1
Exotic trees	23	4.0	1.7
Natural trees	2	0.3	0.4
Sub-total	**119**	**20.5**	**3.3**

Results can also be expressed as a percentage of each land use, but sample error becomes higher:

	n	% of agr. land	+-2s.e.
Agricultural land with:			
No secondary vegetation	63	52.9	9.0
Wetland	5	4.2	3.6
Rank grass	0	0.0	0.0
Exotic scrub	14	11.8	5.8
Natural scrub	12	10.1	5.4
Exotic trees	23	19.3	7.1
Natural trees	2	1.7	2.3
Sub-total	**119**	**100.0**	**0.0**

Extent of soil conservation cover can be obtained by analysing the codes for secondary vegetation, relative to those for land use. For instance for agricultural land in the Coromandel:

	Sparse			Dense		
	n	%	+-2s.e.	n	%	+-2s.e.
Without secondary vegetation:						
Crops, orchards, vineyards	1	0.8	1.6	1	0.8	1.6
Dairy pasture	9	7.6	4.8	11	9.2	5.2
Drystock pasture (improved)	13	10.9	5.6	20	16.8	6.7
Drystock pasture (unimproved)	2	1.7	2.3	6	5.0	3.9
Sub-total for primary vegetation	**25**	**21.0**	**7.3**	**38**	**31.9**	**8.4**

	Sparse			Dense		
	n	%	+-2s.e.	n	%	+-2s.e.
With secondary vegetation:						
Wetland/rank grass	4	3.4	3.3	1	0.8	1.6
Scrub	13	10.9	5.6	13	10.9	5.6
Trees	6	5.0	3.9	19	16.0	6.6
Sub-total for secondary vegetation	**23**	**19.3**	**7.1**	**33**	**27.7**	**8.0**

Soil disturbance

The point sample contains sufficient points to analyse soil disturbance at the level of catchment management zones/districts. Results are best expressed as a percentage of points in the catchment management zone/district. For example in the Coromandel:

	n	% of points	+-2s.e
Stable	257	44.2	4.0
Unstable inactive	207	35.6	3.9

Recently disturbed	68	11.7	2.6
Freshly disturbed	28	4.8	1.7
Natural bare surfaces	6	1.0	0.8
Man-made surfaces	16	2.7	1.3
Total sample	**582**	**100.0**	**0.0**

It is also possible to break down these figures according to other categories, for instance fresh disturbance by land use. Again, they can be expressed as a percentage of points in a catchment management zone/district. They can also be converted to percentage areas, by applying the appropriate scaling factor for point size (see Appendix 2). For example, for fresh disturbance:

	n freshly disturbed	**% of points in cmz**	**+-2s.e.**	**% of cmz area**
Agricultural land	14	2.4	1.2	0.6
Forest plantations	3	0.5	0.6	0.1
Exotic scrub	5	0.9	0.8	0.2
Natural scrub	3	0.5	0.6	0.1
Natural forest	3	0.5	0.6	0.1
Natural bare surfaces	-	-	-	-
Man-made surfaces	-	-	-	-
Sub-total	**28**	**4.8**	**1.7**	**1.1**

Fresh disturbance etc. can also be expressed as a percentage of each land use, though the sampling error becomes rather high if this is done:

	n in use	**n freshly disturbed**	**as % of points in use**	**+-2s.e**	**as % of area in use**
Agricultural land	119	14	11.8	5.8	2.7
Forest plantations	78	3	3.8	4.0	0.9
Exotic scrub	53	5	9.4	7.9	2.2
Natural scrub	206	3	1.5	1.7	0.3
Natural forest	104	3	2.9	3.2	0.7
Natural bare surfaces	6	-	-	-	-
Man-made surfaces	16	-	-	-	-
Total	**582**	**28**	**4.8**	**1.7**	**1.1**

Effect of soil conservation cover can be obtained, if fresh disturbance is analysed by land use and secondary vegetation. Using agricultural land as an example:

	Sparse cover				Dense cover			
	n	**fresh dist.**	**% of points**	**% of area**	**n**	**fresh dist.**	**% of points**	**% of area**
Without secondary vegetation:								
Crops, orchards, vineyards	1	1	100	23	1	1	100	23
Dairy pasture	9	2	22	5	11	1	9	2
Drystock pasture (improved)	13	0	0	0	20	1	5	1
Drystock pasture(unimproved)	2	1	50	12	6	2	33	8
Sub-total	**25**	**4**	**16**	**4**	**38**	**4**	**11**	**2**
With secondary vegetation:								
Wetland/rank grass	4	1	25	5	1	0	0	0
Scrub	13	3	23	5	13	0	0	0
Trees	6	1	17	4	19	1	5	1
Sub-total	**23**	**5**	**22**	**5**	**33**	**1**	**3**	**<1**

Percentage of points with fresh disturbance, and percentage of surface freshly disturbed, appear to decline as the standard of conservation cover improves. However the number of points in each category is small, and in most instances, a single point increase/decrease would greatly alter the percentage. Sample errors (not shown) are in all cases excessive - for the largest category, n=38, +-2s.e. is 10%. Analysing a sub-set to this level of detail, is clearly pushing it too far. This is an instance where additional cluster sampling would be necessary (see Appendix 3).

Type of disturbance

The point sample contains sufficient points to analyse type of disturbance, at the level of catchment management zones/districts. For fresh soil disturbance in the Coromandel:

	n	**% of points**	**+-2s.e.**
Topsoil exposure	4	0.7	0.7
Farm or forest tracks	8	1.4	1.0
Earthworks	2	0.3	0.4
Landslide/debris avalanche scars	8	1.4	1.0
Gully and streambank scars	3	0.5	0.6
Bluffs and rockfalls	3	0.5	0.6
Sub-total freshly disturbed	28	4.8	1.7
Total	**582**	**100.0**	**0**

Point numbers in each category are quite small. They can be expressed as percentages of the sub-total, but sample errors become excessive:

	n	**% of points freshly disturbed**	**+-2s.e.**
Topsoil exposure	4	14.3	13.0
Farm or forest tracks	8	28.6	16.7
Earthworks	2	7.1	9.5
Landslide/debris avalanche scars	8	28.6	16.7
Gully and streambank scars	3	10.7	11.4
Bluffs and rockfalls	3	10.7	11.4
Sub-total freshly disturbed	**28**	**100**	**0.0**

Type of disturbance should definitely not be split further e.g. fresh disturbance by type by land use; as point numbers in each category would be so small as to be quite unreliable. For this level of detail in a catchment management zone/district, it will be necessary to resort to additional cluster sampling.

Landforms

The point sample contains sufficient points to analyse landforms, at the level of catchment management zones/districts. For the Coromandel:

	n	% of points	+-2s.e.
Alluvial streambank	8	1.3	0.9
Floodplain	18	3.1	1.4
Wetland	6	1.0	0.8
Terrace	4	0.7	0.7
Downland	47	8.1	2.2
Rock streambank	13	2.2	1.2
Hillslope	390	67.0	3.8
Ridge	72	12.4	2.7
Mountain	0	0.0	0.0
Bluff and cliff	10	1.7	1.1
Dune	4	0.7	0.7
Beach	3	0.5	0.5
Stream and river	4	0.7	0.7
Other	3	0.5	0.6
Total	**582**	**100**	**0.0**

but bear in mind a cautionary note in Appendix 1 - reliance on monoscopic interpretation of photos from a computer screen, has resulted in some confusion of points close to landform boundaries. A proportion of streambank points are in fact a short distance away from streambanks (on floodplains or the feet of hillslopes). A proportion of points on downland are in fact on the upper margins of terraces or the feet of hillslopes - and vice versa.

Provided this limitation is kept in mind, single categories of data in the sub-set - land use, secondary vegetation, soil disturbance, type of disturbance - can be analysed by landform. For instance, fresh soil disturbance:

	n on landform	n with fresh soil disturbance	% of points in cmz	+-2s.e.
Alluvial streambank	8	0	0.0	0.0
Floodplain	18	4	0.7	0.7
Wetland	6	1	0.2	0.4
Terrace	4	0	0.0	0.0
Downland	47	4	0.7	0.7
Rock streambank	13	1	0.2	0.4
Hillslope	390	12	2.1	1.2
Ridge	72	3	0.5	0.6
Mountain	0	0	0.0	0.0
Bluff and cliff	10	-		
Dune	4	-		
Beach	3	-		
Stream and river	4	-		
Other	3	-		
Total	**582**	**28**	**4.8**	**1.7**

though bear in mind that the appropriate scaling factor for point size (from Appendix 2) would need to be applied, to convert % of points freshly disturbed to % of surface area bare. More detailed break-downs e.g. fresh disturbance by type for each landform, are best avoided because point numbers in categories become small, and sample errors excessive. This is another instance where additional cluster sampling would be needed, to obtain statistically reliable data at the level of a catchment management zone/district.

Appendix V: Cluster analysis of fresh soil disturbance under various soil conservation covers

SOIL DISTURBANCE BY LAND USE AND NATURAL PROCESSES IN THE WAIKATO

Contract Report for :

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August 2005

INTRODUCTION

This report has been prepared at Environment Waikato's request, as an addendum to a survey of soil intactness in the Waikato, carried out in 2003 by a point sample survey of the region's new aerial photographic coverage.

The earlier survey (Hicks 2003) remains a primary source of information for data about :

* Stable, unstable but inactive, recently disturbed and freshly disturbed soil region-wide (Table 1),

* Stable, unstable but inactive, recently disturbed and freshly disturbed soil under different land uses (Tables 2a to 2h),

* Extent of primary and secondary vegetation amongst different land uses (Tables 3a to 3h),

* Extent and standard of vegetative soil conservation cover amongst different land uses (Tables 4a to 4f).

Tables 1 to 2h also contained estimates for the percentage of soil actually bare within freshly disturbed areas. These were derived by applying a calibration curve for bare ground relative to point size, determined by measuring bare ground percentages at 100 randomly selected points, to all 608 freshly disturbed points (see Appendix 2 of the 2003 report).

Tables 5a to 5f contained measurements of bare soil for the various categories of soil conservation cover in Tables 4a to 4f. These were derived by cluster sampling different land uses and categories of soil conservation cover, at 1035 one-hectare squares distributed around the 100 randomly selected points (see Appendix 3 of the 2003 report).

Since 2003 point sample surveys in two other regions (Wellington and Bay of Plenty) have employed an improved version of the cluster sampling technique, whereby cluster samples are built up from one-hectare squares surrounding all freshly disturbed points in the region-wide sample. This has the advantages that :

* no calibration for point size need be applied,

* additional cluster sampling around randomly selected points can be avoided.

The improved technique has now been applied to Environment Waikato's 2003 survey. This report contains up-dated versions of Tables 1, 2a to 2h, and 5a to 5h, incorporating new bare soil percentages.

NOTES ON NEW TABLE ONE

Soil freshly disturbed by land use is down from 1.6% of the region's area to 0.99% +- 0.15%. Half the reduction is grazing disturbance, with the other half tracks. Disturbance by cultivation and harvest are greater than the original measurements. Disturbance by earthworks is about the same.

Soil freshly disturbed by natural processes is down from 0.7% of the region's area to 0.39% +-0.09%. Two-thirds the reduction is mass movement, with the balance gullies and streambanks. Other natural disturbances (individually small in extent) are cumulatively greater than the original measurements.

Region-wide bare soil is down from 2.3% to 1.37% +- 0.19%. Note that the totals in Table 1 are slightly greater than equivalent totals when Tables 2a to 2h are added together. This is because Table 1 includes - but 2a to 2h exclude - areas of bare soil associated with land in non-rural use (bare mountain-tops, coastal cliffs, sand dunes, quarries and urban areas).

NOTES ON NEW TABLE TWO SERIES

2a Intensive land uses

Soil freshly disturbed by land use is down from 0.1% of the region's area to 0.06% +- 0.05%. Actual reduction is less than the change caused by rounding to two decimal points instead of one. Soil freshly disturbed by natural processes remains 0%.

2b Dairy pasture

Soil freshly disturbed by land use is down from 0.7% of the region's area to 0.36% +- 0.08%. Most of the reduction is grazing disturbance and tracks. Reductions in harvest disturbance and earthworks are less than the changes caused by rounding to two decimal points instead of one. A new sub-total for cultivation disturbance is due to transfer of 5 points cultivated for pasture renewal out of the grazing disturbance sub-total.

Soil freshly disturbed by natural processes is down from 0.1% of the region's area to 0.01% +- 0.01%. Actual reduction is less than the change caused by rounding to two decimal points instead of one.

2c Drystock pasture

Soil freshly disturbed by land use is down from 0.5% of the region's area to 0.25% +- 0.07%. Most of the reduction is grazing disturbance and tracks. Increases in harvest and earthworks appear due to rounding to two decimal points instead of one. A new sub-total for cultivation disturbance is due to transfer of 8 points cultivated for pasture renewal out of the grazing disturbance sub-total.

Soil freshly disturbed by natural processes is down from 0.4% to 0.13% +- 0.03%. Half the reduction is in mass movement, with the balance split between gullies and streambanks. Increase in other natural disturbance appears due to rounding to two decimal points instead of one.

2d Forest plantation

Soil freshly disturbed by land use is down from 0.3% of the region's area to 0.19% +- 0.05%. The reduction is almost entirely in track disturbance. Increase in earthworks disturbance appears due to rounding to two decimal points instead of one. Harvest disturbance remains the same. New (very

small) sub-totals for cultivation and grazing are due to separation of two disturbed points on firebreaks from the harvest sub-total.

Soil freshly disturbed by natural processes is down from 0.1% of the region's area to 0.01% +- 0.01%. The overall reduction, plus actual increases for individual disturbance sub-totals, are less than the changes caused by rounding to two decimal points instead of one.

2e Exotic scrub

Soil freshly disturbed by land use changes from <0.1% of the region's area to 0.03% +- 0.02%. Overall increase, plus increases for individual disturbance sub-totals, appear due to rounding to two decimal points instead of one; except for the harvest sub-total where increase is due to separation of a point where scrub has been cleared, from the earthworks sub-total.

Soil freshly disturbed by natural processes is down from 0.1% of the region's area to 0.03% +- 0.02%. Overall reduction, plus actual increases for individual disturbance sub-totals, are less than the changes caused by rounding to two decimal points instead of one.

2f Natural scrub and forest

Soil freshly disturbed by land use changes from <0.1% of the region's area to 0.03% +- 0.03%. Overall increase, plus actual increases for individual disturbance sub-totals, appear due to rounding to two decimal points instead of one; except for the harvest sub-total where increase is due to separation of five points where scrub has been cleared, from the landslide sub-total.

Soil freshly disturbed by natural processes is down from 0.1% of the region's area to 0.03% +- 0.02%. Overall reduction, plus actual increases for individual disturbance sub-totals, are less than the changes caused by rounding to two decimal points instead of one.

2g Mountain scrub and tussock

Soil freshly disturbed by land use remains 0%.

Soil freshly disturbed by natural processes changes from <0.1% of the region's area to 0.08% +- 0.06%. Increases for individual disturbance sub-totals appear due to rounding to two decimal points instead of one; except for the gully sub-total (one point transferred from bare mountain slopes in the 2003 analysis) and the other disturbance sub-total (5 points transferred from bare mountain slopes). The latter account for the bulk of the overall increase.

2h Wetland

Soil freshly disturbed by land use changes from <0.1% to 0.01%+-0.02%. The change appears due to rounding to two decimal points instead of one, and is caused by a single point where semi-drained wetland is being cultivated.

Soil freshly disturbed by natural processes remains 0%.

NOTES ON NEW TABLE FIVE SERIES

5a Intensive land uses

Substantial reductions in bare soil percentages for primary cover (crop, fruit trees, vines) are probably due to increased sub-sample sizes. The error margin for sparse primary cover remains high because some of the one-hectare squares have close to 100% bare soil cf. others which are close to 0%. The bare soil percentage for dense primary cover appears considerably improved as regards reliability, in view of its error margin (now 0.22%).

Bare soil percentages for secondary cover also reduce. However the sub-sample sizes remain small. So although error margins appear tighter, new data are no more reliable than the original cluster sample; except perhaps for dense trees amongst intensive uses.

5b Dairy pasture

No change in bare soil percentages for primary cover, except for detection of slight natural disturbance. Error margins are tighter.

Bare soil percentages for secondary cover reduce somewhat, with the exceptions of land use disturbance amongst dense wetland/rank grass and dense scrub. Apart from these two, error margins are considerably tighter, so the new figures are more reliable than the originals.

5c Drystock pasture

Substantial reduction in bare soil percentage for land use-related disturbance in sparse primary cover. Modest reductions in bare soil percentages for other disturbance categories in primary cover. Error margins are tighter in all instances, so the new figures are more reliable.

Bare soil percentages for secondary cover reduce by half or more in all instances. Error margins are also tighter, so the new figures are more reliable.

5d Forest plantations

The reduction in bare soil percentage for land use-related disturbance in harvested forest is probably due to increased sub-sample size. Here the error margin remains high because some of the one-hectare squares have 50% or more bare soil while others have less than 10%. No significant change in bare soil percentages for other disturbance categories in primary cover, except for detection of slight natural disturbance in maturing stands. Error margins are tighter.

Bare soil percentages for secondary cover reduce, with the exceptions of land use-related disturbance amongst grass sown in young stands; also amongst other trees retained in maturing stands. The former increase is associated with substantially greater sub-sample size, and has a moderate error margin, so may be regarded as reliable. The latter is associated with a sub-sample which remains small, and has a large error margin. Likewise the zero percentages for other trees retained in young stands. These exceptions apart, sub-sample sizes are larger and error margins are tighter, so the new figures are more reliable than the originals.

5e Exotic scrub

An increased bare soil percentage for land-use related disturbance in closed-canopy primary cover is associated with a greatly increased sub-sample size. Somewhat high error margins for it, and for bare soil due to natural disturbance, are attributed to high bare soil percentages at the few points disturbed cf. zero percentages at the rest. The new figures appear more reliable than the originals.

Bare soil percentages for secondary cover reduce, with the exception of disturbance in natural scrub emerging through exotic scrub. For this category, the higher percentage and error margin are due to two points with extensive geothermal activity. Other new figures appear more reliable than the originals, in terms of sub-sample sizes and error margins. However the 2003 cluster sample detected some land-use related disturbance amongst secondary cover in exotic scrub, which did not show up in the much larger point sample.

5f Natural scrub and forest

Bare soil percentages for primary cover are somewhat reduced, except for land use-related disturbance in forest, which is up from 0 to 0.16%. In view of sub-sample sizes and error margins, all new figures are more reliable than the originals.

Bare soil percentages for secondary cover reduce, with the exceptions of land use-related disturbance amongst grass/wetland remaining in scrub; also amongst exotic trees emerging in forest. The former is attributed to a few points where scrub has been partly cleared, leaving a high percentage of bare soil cf. most other points where bare soil is zero. This also accounts for the high error margin. The latter is due to track disturbance at a single point out of two in the sub-sample. Clearly it is unreliable; as is the zero percentage for natural disturbance in this category of cover. All the other new figures for bare soil amongst secondary cover appear more reliable than the originals, in terms of sub-sample sizes and error margins, except for grass/wetland remaining amongst forest, where sub-sample size is too small to be confident of the zero percentages.

5g Mountain scrub and tussock

The 2003 cluster sample did not pick up any one-hectare squares amongst mountain scrub and tussock. The new cluster sample (around the 2003 point sample) picked up 103, enabling data analysis for table 5g.

Substantial bare soil due to natural disturbance has been detected amongst primary tussock cover. The wide error margin is due to a few points which have close to 100% bare soil cf. most which have close to zero. So it reflects genuine variability in the data. Likewise the wide error margin for bare soil amongst primary mountain scrub cover.

Bare soil percentages due to natural disturbance amongst secondary cover are low to moderate. No points have been detected for two categories of cover, and sub-sample sizes for the others are small, though just one category has a wide error margin.

For these reasons the new figures may be reliable regional estimates for bare soil amongst primary cover, but not for secondary. What they indicate, is that :

* there is currently no land use-related disturbance in mountain scrub and tussock,

* natural disturbance is high amongst primary tussock cover, substantially reduces amongst primary mountain scrub cover, rises where tussock occupies gaps in mountain scrub, and falls again where lowland scrub or trees are emerging through mountain scrub.

5h Wetlands

The 2003 cluster sample did not pick up enough one-hectare squares amongst wetlands to enable bare soil measurements. The new cluster sample (around the 2003 point sample) picked up 48, enabling data analysis for table 5h.

No bare soil due to land use or natural disturbance has been detected amongst primary wetland cover. Sub-sample size appears large enough for the zero percentage to be regarded as reliable.

Bare soil percentages due to land use or natural disturbance amongst secondary cover in wetlands are zero, with the exception of grass amongst wetland (54% bare soil). However just one point has been detected in this category, so the figure is unreliable. Sub-sample sizes are also somewhat small for scrub and trees in wetland, so the zero figures here may be unreliable.

At best, what the figures indicate is that :

* there is currently no bare soil due to natural disturbance in wetlands,

* bare soil due to land use-related disturbance is absent from primary wetland cover, and may be absent from wetlands colonised by scrub and trees (whether natural or exotic). It may be high where grass is colonising wetlands as a result of drainage.

CONCLUSIONS - SOIL DISTURBANCE

New bare soil percentages in Tables 1 and 2a to 2h are consistently lower than percentages obtained by applying the original calibration curve to point counts.

Likewise new bare soil percentages in Tables 5a to 5h are mostly lower than percentages obtained from the original cluster sample. For most categories of soil conservation cover in the tables, sub-sample sizes in the new cluster sample are larger, and have tighter error margins.

So the new tables in this report should now be used as the primary source of information about :

* Bare soil due to different types of disturbance region-wide (new Table 1),

* Bare soil due to land use and natural processes under different land uses (new Tables 2a to 2h),

* Bare soil associated with different standards of vegetative soil conservation cover (new Tables 5a to 5h).

Reasons for the reduced bare soil percentages relate to accuracy of the two measurement techniques. They are discussed in the 'Conclusions - Technical' section at end of this report.

Trends in the new data - moving from one type of disturbance to another, from one land use to another, or from one standard of soil conservation to another - remain the same. Therefore this report does not contain any new or altered conclusions about soil disturbance in the Waikato. The 2003 report's discussions of trends in data, and conclusions about nature and extent of soil disturbance in the Waikato, stand.

CONCLUSIONS - TECHNICAL

The new analysis raises two technical questions :

* Why did point size calibration (measurements of bare ground relative to point size at 100 random points) produce bare soil percentages for land use (Tables 2a to 2h) that are typically a third higher than what has been measured by cluster analysis around all freshly disturbed points?

* Why has the new cluster analysis (613 one-hectare squares around all freshly disturbed points) produced bare soil percentages for soil conservation cover (Tables 5a to 5h) that are generally lower - though sometimes the same or higher - and with tighter error margins - than the original cluster analysis (1035 one-hectare squares around 100 random points)?

Point size calibration

One would expect a bare soil percentage at any one point to depart from the average figure for point size used in the 2003 survey (23% for a 12 mm2 circle). However from statistical theory, one would also expect, for a number of points e.g. land use-related disturbance for all points in dairy pasture (n =1480), that the bare soil percentage would be indicated by number of disturbed points times the average (n=193 x 23%/1480 = 3.0%).

The calibration curve was derived from repeated measurement of bare soil on areas increasing in size from 1mm2 to 100mm2, around 100 randomly selected points. Standard error varies along the curve, and close to 12mm2 it is +- 8% at 95% confidence. So sampling error may explain part of, but not all the discrepancy.

Another possibility is that if average bare soil per hectare varies greatly from one land use to the next, the point size calibration curve's shape could be influenced by the mix of land uses at the 100 randomly selected points used to derive it. This would not be a problem if the mix is the same as in the main sample, but would become problematical if it differs. Comparing percentage composition :

	Random points	Main sample
Intensive uses	0	2
Dairy pasture	24	24
Drystock pasture	36	27
Forest plantations	7	14
Exotic scrub	4	3
Natural scrub and forest	7	18
Mountain scrub and tussock	0	2
Wetland	0	2
Other	22	7

Clearly other uses (rural buildings and yards, roads, urban areas) are over-represented. Conservation uses are under-represented. For rural land uses, differences are not as great but still present.

A third possibility is that the point size calibration curve's shape could be weighted by types of disturbance present at random points, if they differ from the main sample's disturbed points in this respect. Comparing percentage composition :

	Random points	Main sample
Cultivation	0	1
Grazing	31	21
Harvest	30	6
Tracks	12	36
Earthworks	17	4
Mass movement	6	14
Gullies	1	9
Stream disturbance	2	5
Other disturbance	1	4

Differences are present for all categories of land use-related and natural disturbance. Some are large. They may be the largest sources of error in the calibration curve; particularly if (as is likely) average bare soil percentage per point differs for the various disturbance types.

Dr. Chris Frampton expressed reservations about use of the calibration curve, when Waikato survey results were presented at a meeting of the National Land Monitoring Forum in March 2004. The new analysis shows that Dr. Frampton's reservations are correct. Appropriate modifications to the point sample survey technique are either :

* Use a point size calibration curve, only if composition of the points from which it is derived closely mirrors composition of the sample to which it is applied,

* Preferably, desist entirely from its use, and apply cluster analysis to areas of known size around all freshly disturbed points in the sample.

The latter modification has already been used for two subsequent surveys (Wellington and Bay of Plenty). Measurements documented in this report upgrade Waikato's survey to the same standard.

Bare soil percentages for soil conservation cover

The 2003 cluster analysis (1035 one-hectare squares around 100 randomly selected points) was intended to overcome small sub-sample sizes for several categories of soil conservation cover in the 6122-point sample. It produced sub-sample sizes ranging from 0 (no one-hectare squares detected for a category) up to 109, with most ranging between 10 and 30. The new cluster analysis (one-hectare squares around all 6122 points) has also produced sub-sample sizes ranging from 0 to very large (n=886). The percentage frequency distributions are :

	1035 squares	6122 squares
0	7	7
1 to 9	34	20
10 to 19	30	12
20 to 29	9	7
30 to 39	7	13
40 to 49	0	4
50 to 99	11	7
> 100	2	30

The first distribution produced bare soil measurements with acceptable error margins (less than 1%) for most categories, notable exceptions being those where n is less than 10, and those where a few points have high bare soil and the rest are zero or close to it.

The second produced bare soil measurements which are often lower - though sometimes the same or higher - than the 2003 analysis. Reasons for the changes are :

* Improved error margins. Changes are generally inside error margins attached to the 2003 sub-samples. Most of the new sub-sample error margins are tighter - a few tenths of 1%. Exceptions are the sub-samples with bimodal distributions (a few points at or close to 100% bare soil) where error margins although improved still exceed 1%.

* Better sub-sample sizes. The assumption made in 2003, that repeated cluster sampling around a limited number of points would produce improved sub-sample sizes, does not hold when sub-sample size distributions (tabulated above) are compared.

This comparison partly supports Dr. Chris Frampton's suggestion at the March 2004 meeting, that greatly increased cluster sampling would be needed to obtain acceptable bare soil percentages for those soil conservation categories for which n is small in the main point sample. However the new analysis also shows that acceptable error margins (a few tenths of a percentage point) can be derived for most of the main sample's categories (92 out of 112). Appropriate modifications to the point sample survey technique are :

* Obtain the cluster sample from one-hectare squares around each point in the main point sample.

* Undertake additional cluster sampling only for sub-samples where n is less than 10.

There will be a few sub-samples where, irrespective of size, error margins will remain high because the bare soil distribution is bi-modal. For these, the average bare soil percentage may be a good indicator of the region-wide figure for that category of soil conservation cover; but one should bear in mind that most such points will have little or no bare soil and a few will have a great deal.

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