Environment Waikato Technical Report 2001/13

Soil Intactness Monitoring For The Waikato Region -

Methodology Review And Monitoring Programme Design

Final

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Environment Waikato
REGIONAL COUNCIL

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Executive Summary -Review Of Options

Background

Environment Waikato has a statutory responsibility to collect information about state of the Region's environment (Section 35, Resource Management Act). The Council's strategy for environmental monitoring is given in its draft strategic plan "The Way Forward". In future, the Council foresees a need to collect more information about soil. Environment Waikato's participation in the 500 Soils Programme is already supplying useful base-line information about soil quality i.e. changes in soil fertility, structure and biology under different land uses. However, the 500 Soils Programme does not measure soil intactness i.e. 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.

Brief

The Council has contracted Dr. Hicks of Ecological Research Associates to :

- Review options for assessing the state of and monitoring changes in soil intactness,
- Advise which options are technically sound, cost effective and statistically robust,
- In conjunction with Environment Waikato staff, design a soil intactness monitoring programme that meets the criteria in objective 2.

Concepts

Soil Intactness

The concept of soil intactness expresses whether soils are staying in place. A decrease in soil intactness 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).

Soil Accumulation

Soil intactness can also change for the better, through soil accumulation. Addition of decaying vegetable matter and weathering of regolith, deposition of soil that has been eroded from upslope, sediment transported from up-river, wind-blown dust around growing plants, and airfall volcanic ash; all can be said to improve soil intactness.

Environmental Impacts Of Intactness, Erosion And Accumulation

The rationale for EW measuring soil intactness - or erosion, or accumulation - is twofold. Firstly, a change in soil intactness is a change in one of the region's resources. Are there any parts of the region, where soil is being disturbed in a way that jeopardises productive land use?

Secondly, the erosion or accumulation of soil impacts on the region's environment. Are there any parts of the region where rates of erosion are sufficiently high to have an adverse impact on waterways? Are there places where rates of accumulation are sufficient to impact on habitats like wetlands or bush remnants?

Soil Stability

If soil intactness, or soil erosion, or soil accumulation are to be measured for state-of-environment reporting (SER), it will be more enlightening to interpret them in relation to 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? Are the erosion, accumulation or alternation rapid or slow?

Only if these questions are answered, can conclusions be drawn about whether a change in the soil indicates environmental deterioration - or improvement.

Measurements And Techniques

A reasonable amount of information is available from pilot SER surveys conducted by other Councils, or from surveys of erosion conducted by research institutes and universities. Each measurement and method that has been used in New Zealand so far - or that appears to have potential - is outlined here.

1) Field measurement with survey instruments
2) Field measurement with global positioning systems (GPS)
3) Approximate field measurement with various devices
4) Field measurement with tracers
5) Field measurement by soil profile description
6) Field measurement by soil probe or auger
7) Aerial photographic measurement with stereoplotters
8) Aerial photographic measurement by digital techniques
9) Approximate aerial photographic measurement, using dots, grids, planimeters
10) Point sample measurement from aerial photographs
11) Digital measurement from satellite images
12) Interactive measurement from satellite images
13) Measurements from runoff plots and similar
14) Measurements from stream discharge

Measurement Strategies

It is clear that each measurement technique outlined in 1d has been applied at a particular scale, and in a particular way. The reason may be cost, or time taken, or loss of accuracy if used differently. The question of measurement strategy must be considered before deciding what technique to use for SER of soil in the Waikato.

Sampling

Whatever measurement is selected, can be kept manageable by sampling. The options are:

- Mapping whole catchments,
- Mapping representative windows,
- Area samples (quadrats),
- Line samples (transects),
- Point samples.

Prioritisation of sampling

When time and money are limited, one option is to sample only those parts of a region that are perceived to be at risk of erosion. This raises the question, how to identify the parts at risk. Approaches that can be taken are:

a) Land use capability units or aggregates of them,

b) NZLRI rock types or aggregates of them,

c) NZ Soil Classification groups,

d) Soils grouped as slightly, moderately or highly susceptible to degradation.

Advice On Options For SER Of Soil In The Waikato

To facilitate comparing the options, I have rated each technique from Section 1d, relative to the following questions.

Technical Soundness

Can the method measure change in soil?
With sufficient accuracy for SER?
Over an interval of time that's realistic for detecting change?

Ease Of Data Collection

Is data collection simple?
Is it quick?

Robustness

Is statistical analysis manageable?
Does the data format enable statistical testing?
Within acceptable confidence limits for SER?

Effectiveness

Are results easily explained?
Is overall cost reasonable, relative to the usefulness of results?

Programme Design

Select A Measurement And A Measuring Technique

EW requires methods that:

- are technically sound,
- are statistically robust,
- provide easily understandable data,

- in a short space of time,
- at an acceptable cost.

Most of the techniques summarised in Section 1d can be ruled out. They fail to meet one or more of EW's criteria, for reasons that are stated in Section 2. The shortlist that remains is:

2 Field measurement with GPS
3 Approximate field measurement with various devices
5 Field measurement by soil profile description
6 Field measurement by soil probe or auger
9 Approximate aerial photographic measurement
10 Point sample measurement from aerial photographs
11 Interactive measurement from satellite images

Out of these, for EW's initial survey of soil intactness I recommend:

10 for measuring changes in area of soil eroded, deposited or intact,

2 for measuring changes in length of soil eroded, deposited or intact on streambanks,

and for feasibility investigations I recommend:

6 for measuring surface erosion on cropped land,

11 for interactive measurements of land use from satellite images.

Design A Measurement Strategy

For a measurement strategy I recommend:

10 point sample (dispersed grid) on 3 km by 3km NZMS map grid intersections, superimposed on EW's new orthophotos. This will entail 2700 points.

2 line sample (length transects), expanding the pilot network of 252 randomly located transects on streambanks (Project Watershed) to other catchments. At the same sampling density, this will entail an extra 168 transects.

6 point sample (quadrat transects), establishing a network of randomly located quadrats for field measurement of changes in soil depth, initially on orchards, market gardens, and grain crops. This will entail 60 quadrats.

11 point sample (dispersed grid) on 3 km by 3km NZMS map grid intersections, superimposed on a portion of EW's new satellite image. This will entail 100 points.

Recommend An Analysis Procedure

The most straightforward way to analyse these data will be:

Point sample of soil stability relative to land use, from orthophotos

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).

Transect sample of riverbank stability

The procedure currently used by Environment Waikato's staff and contract workers is recommended i.e. field recording with GPS, data processing with GPS software, and storage in Excel spreadsheets.

Quadrat sample of arable soil stability

The amount of data to be processed is fairly small (100 point observations of soil depth on each of 60 quadrats), so could be manually recorded on field sheets, with statistics done by calculator.

Point sample of land use, from a satellite image

The interpretations, together with cross-checks against orthophoto and field data, can be manually recorded.

Estimate Times And Costs Of Implementation

Times

Time to collect data will be 7 days for the 2700 point sample from aerial photographs, 140 days for the 420 transect sample on streambanks (about 83 days already undertaken), 60 days for the 60 quadrat sample in cropped fields, and 2 days for the 100 point sample from a new satellite image.

Time to analyse data will be 14 days for the point sample from aerial photographs, 53 days for the transect sample on streambanks (31 days already undertaken) 15 days for the quadrat sample in cropped fields, and 1 day for the point sample from a new satellite image.

Time to document results will be 16 days for the point sample from aerial photographs, 26 days for the transect sample on streambanks (16 days already undertaken or in progress to support Project Watershed), 5 days for the quadrat sample in cropped fields, and 1 day for the point sample from a new satellite image.

Costs

Costs of implementation consist almost entirely of personnel time, as methods have been selected so as to utilise equipment (GPS, augers, stereoscopes) or materials (aerial photographs) already purchased or budgeted for.

Times estimated for each stage of the survey (set out above) are just one determinant of personnel cost. It can either shrink or balloon, depending on who does the job. The options are:

- EW staff,
- University students or temporary workers,
- CRI staff under contract,
- Independent contractors.

A mix of all four may provide the best balance e.g. EW staff - co-ordination; CRI staff or independent contractor - supervision and quality control; university students or temporary workers - photo and field measurements.

1 Review Of Options

1.1 Background

Environment Waikato has a statutory responsibility to collect information about state of the region's environment (Section 35, Resource Management Act). The information is required as a contribution to national environmental indicator programmes, co-ordinated by Ministry for the Environment. By monitoring state of the region's environment, it helps the Council decide whether policies and plans are needed to protect the Region's natural resources. Most importantly, it enables the region's resource users - the ratepayers - to see whether they are sustainably managing those resources.

The Council's strategy for environmental monitoring is given in its draft strategic plan "The Way Forward". Much of the information collected in the past relates to water, in view of this resource's importance for power generation, for farming, for industrial and urban supply, and as a sink for treated wastes. This will continue. In future, the Council foresees a need to collect more information about soil. The Region's two main land uses - farming and forestry - each impact on soil in ways which can be beneficial as well as adverse. Even on land reserved for conservation, soil keeps changing beneath its cover of bush, scrub or wetland; and still has an impact on the quality of water in lakes, rivers and streams.

Environment Waikato's participation in the 500 Soils Programme (Sparling and Schipper 1999) is already supplying useful base-line information about soil quality i.e. changes in soil fertility, structure and biology under different land uses. However, the 500 Soils Programme does not measure soil intactness i.e. 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. 43% of the region's soil is susceptible to erosion of one form or another, though erosion is slight where land is well managed. At the places where it is not, erosion can be severe; not just damaging on-site production and ecosystems, but also causing off-site sedimentation. In the region's large rivers, this leads to downstream sedimentation, which may increase flood risk as well as degrade water quality.

1.2 Brief

The Council has contracted Dr. Hicks of Ecological Research Associates to prepare a report containing:

- A review of options for assessing the state of and monitoring changes in soil intactness,
- Providing advice as to which options are technically sound, cost effective and statistically robust,
- In conjunction with Environment Waikato staff, design a soil intactness monitoring programme that meets the criteria in objective 2.

The review is not intended as a detailed reference on techniques for measuring soil intactness. These are already given in other publications, summarised in a nationwide bibliography prepared for the regional councils' land monitoring group (Lambrechtsen and Hicks 2001). This document is intended to select which of those techniques meet Environment Waikato's particular needs, and to recommend a practical strategy for using them within its region.

1.3 Concepts

1.3.1 Soil Intactness

The concept of soil intactness expresses whether soils are staying in place. A decrease in soil intactness occurs when soil is eroded. The erosion 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 disturbed, for instance by machinery in the course of track construction, roading or urban subdivision. A decrease in soil intactness manifests itself as:

- Reduced thickness
- Exposed area
- Movement of disturbed soil on-site
- Removal of disturbed soil off-site

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

1.3.2 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) (Campbell 1951, Eyles 1985). Part of the eroded soil is deposited on-site, but some - often most - is removed.

It is important to remember that 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" (Williams and Mulcock 1996, Sparling and Schipper 1998).

1.3.3 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, and create different environmental pressures e.g. burial of vegetation by the silt.

Environmental impacts of intactness, erosion and accumulation

Conservationists and environmental activists have rightly emphasised the dangers of soil erosion since the 1930s (and before). However they have done so to an extent that masks the fact that soil is created as well as destroyed. A soil scientist or geomorphologist would say that it is the balance between soil erosion and soil accumulation that matters.

Erosion is a natural occurrence in New Zealand's young, geologically active landscape. Its rate can be either accelerated or slowed by human use of the land. Whether to a degree that becomes problematical, depends on how well or badly land is managed. Likewise with accumulation.

The rationale for EW measuring soil intactness - or erosion, or accumulation - is twofold.

Firstly, a change in soil intactness is a change in one of the region's resources. Are there any parts of the region, where soil is being disturbed in a way, which jeopardises productive land use? This is sometimes claimed by agricultural scientists or soil conservators. Unless it is measured, we do not know.

Secondly, the erosion or accumulation of soil impacts on the region's environment. Are there any parts of the region where rates of erosion are sufficiently high to have an adverse impact on waterways? Are there places where rates of accumulation are sufficient to impact on habitats like wetlands or bush remnants? These adverse impacts are often alleged by biologists or environmental pressure groups. Again, unless the rates are measured, we do not know whether the deterioration is due to soil eroding or accumulating, or some other cause.

Soil stability

Soil intactness, erosion and accumulation are related concepts. Some geomorphologists and soil scientists e.g. King, Ruhe, Ollier, Shimokawa, 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, or soil erosion, or soil accumulation are to be measured for state-of-environment reporting (SER), it will be more enlightening to interpret them in relation to 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? Are the erosion, accumulation or alternation rapid or slow?

Only if these questions are answered, can conclusions be drawn about whether a change in the soil indicates environmental deterioration - or improvement.

1.4 Measurements And Techniques

A reasonable amount of information is available from pilot SER surveys conducted by other Councils, or from surveys of erosion conducted by research institutes and universities. Each measurement and method that has been used in New Zealand so far - or that appears to have potential - is outlined here.

1 Field measurement with survey instruments

Soil changes are not known to have been field-surveyed specifically for SER, but there are enough examples (most for engineering purposes) to give an idea of the technique's suitability.

Fresh alluvial erosion or deposition on riverbanks was often measured with surveying instruments by the old catchment boards, to assist design of remedial works after floods. Old plans showing this form of soil disturbance on banks must still exist in the archives of most regional councils, including Environment Waikato. The technique is highly accurate (boundaries of disturbance positioned to +- 10 cm or better; height changes to +- 5cm or better where earlier survey data available to compare). It is also high-cost due to the need for trained surveyors. The time taken by measurement - whether with old-fashioned theodolite and invar band, or more modern EDM instruments - entails several days on a short river reach. Surveying a large river takes months.

2 Field measurement with global positioning systems (GPS)

Advent of GPS in the 1980s offered the possibility of undertaking riverbank surveys much faster, but this possibility remained un-realised through the 1990s. Accuracies better than 1 metre could only be obtained by taking repeated readings with a GPS receiver while stationary at a point for 15 to 30 minutes. "Un-scrambling" of GPS signals for non-military receivers in the year 2000 has greatly increased their accuracy. A good receiver, operated on open ground, can now provide a positional accuracy of +- 7 metres from a single reading. Differential reading (with respect to repeated readings by a stationary instrument) can achieve accuracy of +- 10 centimetres. The use of GPS for engineering survey of riverbanks is now practical. Under the direction of Hill (2001 pers. comm.), EW staff recently measured length of eroded streambank on 252 randomly located reaches throughout the Waikato catchment, by a combination of pacing, taping, and GPS positioning. Field sampling took 90 days, and data processing a further 45 days (Kelly 2001).

These accuracies and times indicate that it would also be practical to use GPS for measuring gullies and mass movements on hillslopes, provided scar dimensions are several times larger than the GPS error margin.

Surface erosion or deposition, by wind and sheetwash, is typically millimetres per event. GPS might be able to detect their extent where cumulative height changes (over several years) exceed the instrument's error margin. Such height changes could be expected in mobile coastal dunes, and river floodplains with high sediment transport rates; but are unlikely in cropped fields or grazed paddocks.

3 Approximate field measurement with various devices

Over the years, government research institutes and universities have tried many approximate techniques for quick field measurement of eroded areas. Some of the better examples follow.

From the 1960s to the 1980s, working under Selby at University of Waikato, research students measured the lengths and widths of soil slips, gullies and stream bank collapses in storm-damaged areas of the Waikato and Taupo. On some sites they used hand-held measuring tapes, compasses and clinometers (for other sites, see method 9). These devices sufficed to give a statistical estimate of average slip area etc., together with standard deviation, once several hundred had been measured. Some of the data were published by Selby (1967, 1971, 1976). Similar work was done by research students at Otago (Crozier 1968), Banks Peninsula (Hosking 1967) and Hunua (Pain 1969, 1971).

Eyles (1974, 1978) together with Crozier et al (1980, 1983) used similar techniques to measure storm damage on hillslopes in Wellington and the Wairarapa. Harmsworth et al (1986) and Trustrum and Page (1991) continued their use in storm-damaged parts of Hawkes Bay. The latter also measured length and width of scar "debris tails" for a sample of scars, in order to work out the ratio of soil deposition to erosion.

A "short-cut" technique for estimating soil depth loss was employed on slips and gullies at Waitahaia by Phillips (1982,1988), elsewhere on the East Coast by Phillips et al (1989) and Marden et al (1991), at Tutira by Page and Trustrum (1991), and again on the East Coast by Reid and Page (1999). In each case, approximate measurements were made with tapes, staffs or sighting devices on the sides of scars, and measurements were averaged to obtain a mean depth change. Fairly large standard deviations are associated with the depth changes. The published papers do not plot depth distributions, so it is unclear whether they are normal (as assumed by the authors). However the technique is quick and low-cost.

An innovative departure from precedent was Hawley's and Dymond's (1986) measurement of a single hillslope eroded by slips at Ngatapa near Gisborne, by rotating a length of rope around the bole of a poplar tree and measuring the length which crossed bare ground at different angles. The technique, though time-consuming, produced accurate measurements which were easily analysed. It is not known to have been used since.

Another departure from standard practice was Hicks' (1992) measurement of eroded streambanks around the Waipa river's confluence with its tributaries at Otorohanga, by pacing the banks and converting the number of paces on eroded banks to a percentage of total length paced. He considered this accurate, once pace variability averaged out over several hundred paces. The same technique was used in the Wairarapa to measure percentages of slope eroded, by pacing line transects across hillsides (Hicks 1995).

Some general observations about soil measurement by approximate field techniques are :

- Individual measurements are accurate only when surveying instruments are used

The approximate techniques all rely on either

- Taking a large number of measurements on a single landslide scar, gully or streambank, so as to obtain a mean area, depth or volume change with a small error term,

or :

- Taking a lesser number of measurements, on a sample of landslides, gullies or streambanks, so as to obtain a mean change (with a moderate error term) for the sample. The mean value is then applied to a number count (scars per hectare or square kilometre) to obtain an estimate of mean are, length or volume eroded catchment-wide or district-wide.

An advantage of the approximate field techniques is that they do not require trained surveyors.

A disadvantage is that all are time-consuming, so can be expensive to undertake even if unskilled or casual labour is employed.

4 Field measurement with tracers

A fourth approach has been to track movement of soil by adding detectable "tracers", or measuring ones that are already present. Caesium 137 is widely used to detect areas within cropped fields, where soil has either been eroded or deposited. The technique has been successfully used in Canterbury, the Franklin district of south Auckland, and the Ohakune district of Wanganui (Basher et al 1995, 1997, 1999).

The tracer method provides very good data about patterns of soil eroded/deposited within individual fields. Single measurements can be used to assess net change since 1968 when atmospheric atom bomb tests ceased. Repeat measurements can assess future change, as caesium has a relatively long half-life. It is however an expensive technique, as regards materials, equipment and time needed to make observations. The options are thorough site calibration at a cost of around $10,000; or approximate calibration at a cost of around $300 (Basher pers. comm. cited in Eyles et al 1993).

5 Field measurement by soil profile description

Research students under the direction of Tonkin at Lincoln University, measured soil depths at field sites in the Southern Alps throughout the 1970s and 1980s, by digging pits and describing soil profiles. They were able to establish long-term increases in soil depth on soil chronosequences i.e. soils increasing in age from a few decades (recently deglaciated sites) to soils more than 10,000 years old. Though few of the research projects are published, Tonkin and Basher (1985) give a useful overview.

Analogous profile measurement of soil depth change, moving from intact to eroded profiles, were made in the Marlborough Sounds by Laffan (1983), the Wairarapa by Vincent (1984 unpubl.), and Taranaki hill country by Blaschke (1989 unpubl.).

The technique was fairly slow, because complete profile descriptions were made at each site using procedures recommended by NZ Soil Bureau. This may be necessary for research investigations and reference sites, but it is not for SER. A modified procedure, entailing a smaller hole and simpler description e.g. soil horizons and depth, would enable a statistical distribution of topsoil depth for a single soil type. Repeat observations 5 or 10 years later, at new holes nearby, would enable a new distribution to be compared with the old. However a practical difficulty in implementing this for SER is that separate statistical distributions would be needed for each soil-land use combination. The regionwide number might be very large.

6 Field measurement by soil probe or auger

A new wave of soil depth investigation commenced on slip-prone North Island hill country in the late 1970s. Initial measurement were made with spades, then steel probes, on revegetating slip scars (Trustrum et al 1984, 1986, 1988). They indicated two clear trends :

- Rapid soil depth loss on fresh slip scars cf. adjacent uneroded ground
- Slow soil depth gain on revegetating slip scars of different age

This led to a comprehensive investigation of soil depth patterns on slip-prone hill country in Taranaki (De Rose et al 1991, 1994, 1996?). As is often the case in nature, great variability was revealed amongst soils on slopes of different angle, different position on slope, and different age. De Rose was able to establish statistically significant differences, by comparing samples which contained many hundreds of point observations.

Dymond (1998) proposed developing De Rose's technique specifically for SER by :

- Collecting c. 800 point observations of soil depth nationwide,
- Repeating the survey five years later,
- Comparing the two depth distributions to work out change in mean soil depth.

Dymond argued that this would indicate whether there has been net erosion or net accumulation of soil nationwide, to within a very small margin of error. Statistically the argument is impeccable. A practical difficulty is interpreting what the change means - it is like determining a change in average diameter for not just apples, but oranges and all the other fruit in the bins, between the start and end of a day's shopping.

This is not to say that Dymond's proposal has no merit. It shows how very accurate measurements of soil depth change could be obtained from a moderate number of easily-made field measurements. However it is more likely to be of value for SER if targeted onto particular apple varieties or at most, apples in general - soil types, or groups of soils with similar topsoil depths - instead of the whole fruit shop.

7 Aerial photographic measurement with stereoplotters

Not used for SER as yet. Several research investigations (below) indicate the technique's accuracy and cost.

In the late 1970s-early 1980s, Lands and Surveys' Photogrammetric Branch undertook experimental measurement of river channels and erosion scars for the Ministry of Works. Results are documented for streambed erosion (Stephens 1978), river aggradation (Jowett 1979, Hicks 1981a), earthflow movement (Hicks 1981b, Owen 1983) and mountain gullies (Hicks 1981c, Dymond and Hicks 1986). Some conclusions common to all the experiments are :

- Accuracy of an individual depth measurement is low, typically 0.1 to 0.3 m depending on photo scale, amount of ground control, and quality of measuring instrument.
- When several hundred measurements are taken, individual errors form a distribution around a low mean value.
- Area measurements are highly accurate.
- By combining the areas of individual scars with averaged depth measurements, it is possible to obtain a mean volume change with an acceptably small mean error attached.
- Cost of the measurement is very high, because specially-flown photography, surveyed ground control and precision instrumental measurement are required.

8 Aerial photographic measurement by digital techniques

In the late 1990s , Landcare Research tested an updated version of the photogrammetric technique. Mean depths eroded in a landslide-affected catchment in Taranaki (De Rose 1998) and a large gully near Gisborne (Betts and De Rose 1999) were calculated by computer "subtraction" of digital elevation models, prepared from successive aerial photographs by Terralink. As with the earlier studies, height accuracy of individual points in the DTM was low, but formed an error distribution with a low mean value, enabling a good estimate of mean height change in each case. Conclusions about practicality of the technique do not differ from those of the earlier studies except that :

- The DTM technique is quicker, because it substitutes automated measurement for manual operation of a photogrammetric plotter

- Its cost is lower, because DTMs can be prepared from existing aerial photographs using existing ground control? (check - this may be incorrect)

However, it remains a relatively high-cost technique, therefore applicable only to sample areas.

A modified version of method 8, based on orthophotos instead of digital terrain models, has been developed by Landcare Research for SER of eroded areas. It has been tested twice in Taranaki for TRC, with funding assistance from MfE. Landcare staff randomly selected 25 3km by 3km "windows" of hill country from a map grid overlaid on TRC's 1994 aerial photo coverage. Bare ground was initially measured by scanning these, and corresponding areas on older photography dating between 1973 and 1987, then subjecting the scanned images to digital classification. This worked reasonably well at one date, but a problem was encountered when comparing the eroded areas. All photographs were initially unrectified, and Landcare's software could not rectify the older ones sufficiently to overlay them in register with the new. Recourse to manual transfer of bare ground boundaries onto a base map solved the problem, but was time-consuming.

For a re-survey in 2000, the problem disappeared, as better software was used to rectify new photographs of the sample windows and overlay them on the 1994 similarly rectified. Nonetheless, boundaries of bare ground were identified visually rather than by digital image classification. Digital measurement was merely a last step, to measure the enclosed areas. This procedure appears to have been rather more successful and methodologically sound, than the original survey.

A slightly modified method was used to measure an additional 4 sites on coastal sand country. This entailed overlaying a dot grid on each scanned and rectified image, viewed on the computer screen - essentially a detailed point sample (see method 7).

Margins of error for bare ground measurement were acceptably small : +- 0.7% (hill country) and +-1.5% (sand country).

Time taken was about 2 days on average per quadrat (photo), at a cost of $46,000 for all 29. Acquisition of photography cost a further $18,000.

A similar survey is planned by Environment Bay of Plenty. The method will be as described, except that sample windows will be just be located on land use capability suites that EBOP regards as being at high risk of erosion.

9 Approximate aerial photographic measurement using dots, grids, planimeters

From the 1940s onwards, catchment boards and MWD used aerial photographs to assess erosion, prior to planning soil conservation measures. These were, in effect, SER surveys though not called such at the time. Most entailed ranking extent or severity of erosion on hillslopes, not measuring it. A few individuals, dis-satisfied with the inadequacy of this method, attempted direct measurement of eroded areas from photographs, with a variety of devices in common use overseas - dot matrices, grid squares, mechanical planimeters, and eventually electronic planimeters. Such devices were successfully used in the Waikato (Selby 1967, 1976), Hunua (Pain 1969, 1971), Tangoio (Eyles 1971), Ruahines (Stephens 1976, Moseley 1978), Canterbury foothill ranges (Harvey and Whitehouse 1977 unpubl.), Wellington (Eyles 1974, 1978, McConchie 1977), Wairarapa (Crozier et al 1980, Stephens et al 1981) central Otago (Barringer 1985 unpub), Hawkes Bay (Eyles and Eyles 1982, Harmsworth et al 1986), Gisborne (Phillips et al 1988, Hicks 1989, Marden et al 1991), Taranaki (Hicks 1990), Wairarapa (Hicks 1991), and Rangitikei (Hicks et al 1993).

It is possible to obtain approximate measurements of height change from aerial photographs by using parallax bars. There are no instances known of their successful use for measuring erosion or deposition in New Zealand. Staff of the MWD's Remote Sensing Group evaluated them in the late 1970s, concluding that measurement errors exceeded any height changes that were likely to have occurred. This led to experiments using more precise photogrammetric instruments (see method 7).

That approximate photographic measurements are practical, is indicated by their ongoing use by professional geomorphologists since the 1960s, in preference to "high-tech" alternatives. This is not to say that the measurements are without their defects which are :

- A time-consuming and tedious procedure,
- Requires great care and patience, to obtain accurate measurement,
- Can only be done by geomorphologists who know what they are looking at.

10 Point sample measurement from aerial photographs

This method amalgamates several features from 8 and 9. It was developed by D. Hicks of Ecological Research Associates.

Gisborne District Council (GDC) undertook the initial trial. It randomly selected ten 3 km by 3 km quadrats, initially taking small-format aerial photos (1995), and later using its new large-format colour coverage (1999). Assisted by D. Hicks, GDC staff :

i. mapped hillslope boundaries onto photos by field-viewing them, then estimated percentage bare ground in five size classes,

ii. mapped hillslope boundaries onto photos by stereoscopic interpretation, then measured percentage bare ground with an electronic planimeter,

iii. overlaid a point grid onto several photos, assessed points as either stable, revegetated, revegetating or eroded by stereoscopic interpretation, and converted o percent bare ground for various categories in the bulked sample (landforms, vegetation covers, presence/absence of conservation measures),

iv. did the same, by field-viewing as many points as possible on the same photos.

The most accurate technique is (iv). Technique (iii) achieves soil stability measurement that are about 85-95% accurate compared with (iv). Technique (ii) is more accurate, but time-consuming, as each scar is individually measured. Technique (i) is least accurate; only 50% of field-estimated size classes corresponded with photo-measured percentages.

GDC has commenced an SER survey using measurements (iii) and (iv), but has made little progress due to staff's other work commitments.

Manawatu-Wanganui Regional Council (MWRC) has used point sampling for SER, to measure % of soil freshly or recently eroded and also % intact (either stable or revegetated) in hill country and sand country. The surveys were undertaken by Crippen 1999 based on an earlier pilot survey by Hicks 1998. Points were clustered on 43 aerial photographs randomly selected from the region-wide coverage of hill country, and 10 randomly selected for the sand country. Conclusions were that :

- Areas stable cf. areas eroded can be measured by point samples from black and white aerial photographs.

- Accuracy of measurement (photo-interpretation versus field) is 92-96%, provided changes in land use between date of photography and date of field check are taken into account.

- 1000 points, clustered in groups of 100, give a 4.3% margin of error. 1500 points, clustered in groups of 33 to 36, give a 3.5% margin of error at 95% confidence.

- Margins of error for sub-samples remain satisfactory when the soil stability data are split for one of the other parameters collected (landform, vegetation type, vegetation condition). Margins of error become greater - unacceptably so - when the data are split two ways.

- Time required is approximately 2 days per photo for a small number of windows (interpretation, data analysis, field check and write-up are combined), dropping to c. 1 day per photo for a large number.

- Speed and accuracy of photo-interpretation could be improved by using a better scale e.g. 1:10,000 contacts or 1:10,000 photographic enlargements (not photocopies), and by using colour photography

- Changes in soil stability can be detected by comparison of samples taken at two different dates, from photos at two different scales. Statistical problems with interpretation of the changes would need to be avoided by taking region-wide coverage in the same year, instead of spread over 4 years.

The Auckland Regional Council (ARC) has also undertaken point sample surveys of erosion in hill country, sand country and lowlands. The method (Hicks 2000) is similar to MWRC's, the only differences being :

- Photography - 1 : 10,000 enlargements from 1 : 27,500 colour positives

- Sampling grid - 1 km NZMS map grid intersections region-wide

- Some additional details on type of bare ground :

  - surface erosion
  - tracking, earthworks or other site disturbance
  - landslides
  - earthflows
  - gullies
  - stream bank erosion
  - stream bank deposition

These changes enabled some additional conclusions cf. the MWRC surveys :

- A dispersed sampling grid produces measurement with lower margins of error than the MWRC random "point clusters". Margin of error for fresh erosion in hill country region-wide is +- 0.2% (2500 points). For data split according to a single parameter e.g. soil group or vegetation cover, it is in the range 0.3 to 0.7% where subsample size is 235 to 883 points; but increases above +-1% for subsample sizes less than 200 points.

- Field checks can be avoided by using large-scale colour photos (quality of the photos is so good, there is very little possibility of mis-interpreting them)

- In the case of surface disturbance (sheetwash etc.), what is being recorded is exposure of bare ground to risk of surface erosion. Whether it has actually occurred in cropped fields, depleted pasture, or earthworks, cannot be seen on the photos

- In the case of subsoil disturbance (landslides etc.), what is being recorded is actual erosion or deposition.

- Likewise for streambank erosion or deposition.

11 Digital measurement from satellite images

Landcare Research used LANDSAT and SPOT satellite images to measure bare ground district-wide or region-wide for several councils in the 1980s-1990s - South Canterbury, Marlborough, Gisborne, Auckland. Although not initially undertaken for SER, the figures have been cited in several of the Councils' SER reports, which indicates that they may be useful for this purpose. Key features of the method are summarised by Dymond et al (2000) as :

- direct measurement of land surfaces
- at regional or national scale
- integrated with measurement of vegetation cover
- data can be automatically classified by computer software
- it can be spectrally rectified to remove sun angle and terrain shadow effects
- it can be spatially rectified to fit maps
- data format lends itself to a range of spatial sampling techniques
- it is amenable to statistical analysis and error testing

Other points made by Dymond et al (2000)are that while unit cost of acquiring and processing a satellite image is high, its cost per square kilometre is much lower than the alternatives (aerial photography or field mapping). A new generation of sensors, now being launched, offer a greater range of sensors, resolutions of up to 1 metre, and the prospect of near real-time image availability over the internet.

However, Dymond et al (2000) are also realistic about remote sensing's drawbacks. Many of the new sensors still have resolutions in the 100-1000 m range, designed for integrated measurement of atmosphere or ocean rather than the 1 to 100 metres needed for terrain observation. In practice, acquisition and delivery of images still takes weeks or months. Image processing and classification are still done by remote sensing specialists rather than end-users, which often entails using overly complicated and expensive techniques where simpler ones would suffice.

The various regional councils' staff have experienced some difficulties when explaining data supplied by Landcare. Automatic classification typically mis-classifies 10% or more pixels (image elements). While most of an individual landowner's property is correctly identified, part is usually classed as something it is not. If several landowners point out errors in the map at a public meeting, the map - and the method - lose credibility. It becomes subject to criticism that it's been done from afar by satellites and computers instead of by looking at what's on the ground and utilising local knowledge.

A second problem is that areas classified as bare ground may be erosion, or deposition, or something else again - a road surface, or a cropped field, or a depleted paddock with bare earth showing through between the grass. Digital classification simply cannot make these distinctions.

A third is that digital classification cannot detect ground that is eroding but still partly vegetated - always the case with earthflows, often the case with small gullies, and sometimes the case with stream banks.

12 Interactive measurement from satellite images

In 2000 Terralink produced similar measurement of bare ground regionally and nationwide from SPOT satellite images, as a component of its National Land Cover Database. District and regional councils are starting to cite these figures for SER also.

Terralink's measurements are essentially the same thing as Landcare's, achieved by different paths. Landcare's are derived by computer software which classifies each pixel in the satellite image as either bare ground or one of several vegetation types, according to its reflectance (the signal received by the satellite, which once digitised and stored, constitutes an element in the image). The computer-classified image is checked visually by interpreters familiar with the terrain. A limited field check is carried out for quality control. Terralink's are derived by computer software which enables its staff to classify bare ground or vegetation types by visual interpretation of the satellite image - in effect, drawing a map on the computer screen. It is reputedly backed up by a similar field check to Landcare's, though extent of field checking is unstated.

Interactive classification can produce measurements of bare ground for much the same cost per square kilometre, as digital classification. Field checks indicate classification accuracies of between 85 and 95%. As bare ground is typically a small percentage of a region (or catchment), this translates to a small measurement error e.g. if bare ground is 5% of a catchment, the error is +- 0.25 to 0.75%.

The interactive method is clearly accurate enough for statistical comparison between two dates, or two land uses. Residual problems are the same as for the digital method :

- Explaining mis-classified blocks of pixels to local residents.
- The effect of these upon significance of comparisons amongst land uses, if made at a local level. Clearly error will be high, if one of the land uses includes a block of mis-classified pixels.
- Uncertainty whether bare ground equates to erosion.
- Uncertainty about the extent of erosion beneath partly vegetated ground.

One reason for poor performance of the interactive method is that again, it appears to have been done by cartographic personnel who have been trained in image interpretation but may have little training in botany or geomorphology, and no knowledge of local terrain. Examination of satellite images like those available for the Waikato, suggests that considerably better results might be obtained if the land cover mapping were done by local botanists, and the erosion mapping by local geomorphologists. This possibility should be checked out.

Satellite measurement of soil depth change is not known to have been attempted in New Zealand. Data from satellite-mounted radar altimeters has a height accuracy of 10 to 15 cm over a footprint of c. 30 m by 30m. Such data could theoretically be used to measure height changes on bare ground, by taking many hundreds of measurement on erosion scars and averaging them, so as to derive a mean height change with an associated error term. In practice, the obstacles to doing this are great :

- Data from instruments with a footprint of c. 1 km by 1 km is available for civilian use. The data from instruments with smaller footprints is classified for military purposes.
- Even were it to become available, directing the instrument to sight on several hundred scattered erosion scars during an overpass (instead of its normally straight line of sight) would be a complex exercise.

- Spatial rectification of radar data processing is complex, time-consuming and costly.

13 Measurements from runoff plots and similar

In the 1950s-1960s a few NZ researchers measured changes in soil depth incidental to calculating soil loss rates. A variety of techniques were used on small plots of ground : watering cans (Campbell 1945), spade investigation (Hayward 1969), runoff plots (Hayward 1969, Scarfe 1971, Cathcart 1973), erosion pins (Soons 1967, Owens 1967), sequential photographs (?). The published accounts indicate great spatial and chronological variation in soil loss rates. A frequent comment is that the variation is so great, that no clear trends can be discerned in the data. Presumably this applies to the depths of soil eroded, as much as the volumes.

Small plots, whatever the measurement technique, have two great limitations. One is that if long-term average losses are required, a plot must be monitored for years. Year-to-year variations are too great for a single year's observations to be regarded as typical. Secondly, where two or more plots are monitored in proximity on slopes that appear identical, soil loss can be quite different. Statistical considerations suggest a moderate number of replicates (between 10 and 20) would be needed at a site, to calculate average soil loss within an acceptably small error margin.

Good results have been reported from runoff plots overseas, notably by United States Department of Agriculture (USDA). It should be noted that the USDA data were obtained from an extremely large nationwide network, monitored for many years on end.

In short, this is not a suitable way to measure soil loss either, short-term or intermittently.

14 Measurements from stream discharge

By the 1970s, enough years of suspended sediment data had been collected at river gauging stations by MWD and catchment boards, that calculation of average annual sediment yields became possible. Early calculations were published by Thompson and Adams 1979, Adams 1980, Griffiths 1982, Griffiths 1983 and Griffiths and Glasby 1985. Updated data, with longer record lengths and smaller error margins, have been published by D.M. Hicks et al 1996, 1998. Annual suspended sediment yields from small catchments under different land uses have been published by various MWD and catchment board hydrologists and are reviewed by Moseley et al 1992.

These yields are frequently cited in regional councils' reports and publications. Strictly speaking they are sediment transport rates in cubic metres per km2 per year or tonnes per km2 per year. However they are often used as surrogate soil erosion data, to illustrate differences in erosion rates between catchments under different land uses as well as those with different geologies or rainfalls.

Their citation for the purpose of SER - which has happened - is fraught with difficulty. They could be quite mis-leading as indicators of environmental change, for several reasons :

- How much of the sediment is river-derived cf. slope derived, is unknown.

- Much of the soil eroded from slopes is stored further down the slopes, or in colluvial valley bottoms, for long periods before it enters rivers.

- Even then, it may be stored for a long time in floodplain deposits, or permanently stranded in terraces raised above river level.

Thus the quantity of sediment transported out of a catchment may be very much greater - or very much less - than the quantity of soil eroded from its slopes. About the most that can be inferred from river sediment data, is that a catchment with a high yield is geomorphologically active, so it is likely to have high rates of soil disturbance - both erosion and deposition - within it.

For these reasons, river sediment discharges ought not to be used as indicators of soil erosion when undertaking SER. Their use as indicators is best restricted to riverine instability or water quality.

1.5 Measurement Strategies

It is clear that each measurement technique outlined in 1D has been applied at a particular scale, and in a particular way. The reason may be cost, or time taken, or loss of accuracy if used differently. The question of measurement strategy must be considered before deciding what technique to use for SER of soil in the Waikato.

1.5.1 Mapping Whole Catchments

This encompasses mapping large catchments in their entirety, and also small sub-catchments within them which may be randomly selected and regarded as representative.

None of the techniques for mapping soil depth or soil volume have been applied catchment-wide.

Areas of eroded soil have been mapped at catchment scale by

- visual interpretation of aerial photographs,
- visual interpretation of satellite images,
- digital classification of aerial photographs,
- digital classification of satellite images.

Digital classification has not provided good measurements of soil area because it simply does not provide the level of information needed - whether soil is stable or unstable, whether vegetated ground is unstable; whether bare ground is erosion, deposition or something else.

Visual interpretation of aerial photographs can definitely provide these details. Skilled personnel with local knowledge may be able to do the same from satellite images.

1.5.2 Mapping Representative Windows

Small "windows" of terrain are selected either randomly region-wide, or randomly within strata such as land use capability suites. Typical window sizes are 1 to 10 km^2. None of the field techniques for measuring area, depth or volume are practical to apply at this scale.

What have been used, are :

- visual interpretation of aerial photographs (area)
- digital classification of aerial photographs (area)
- photogrammetric measurement of aerial photographs (area, depth and volume)

- digital measurement of terrain models prepared by automated photogrammetry (area, depth and volume).

Digital classification has not provided good measurements for SER, because classification software cannot discriminate the level of detail required. Photogrammetric measurement has not been attempted for SER on grounds of cost. Digital measurement of terrain models may be an alternative way to obtain area, depth and volume measurements, at lower cost. Visual interpretation has been successfully used to obtain soil area measurements for two SER surveys, provided orthophotos are available. In another two instances, its use has been limited by the technical difficulty of transferring boundaries from unrectified photos onto a base map.

1.5.3 Area Samples (quadrats)

Soil depths, areas or volumes may be measured on even smaller “quadrats”, somewhat larger than botanical sampling quadrats, but otherwise identical in concept. Typical sizes are 10 x 10 metres to 100 x 100 metres. Again, the selection process must be either random region-wide, or random within strata.

Here the field measurement techniques, though not yet used specifically for SER, appear practical :

- approximate field measurement with tapes, staffs, sighting devices and similar (area, depth and volume)

- field measurement with GPS receivers (area, possibly depth and volume)

- field measurement with spade, auger or probe (depth only)

as does one of the aerial photo techniques :

- approximate measurement with dots, grids or planimeters (area only)

Field measurements while simple may have a high time requirement, to produce a sufficient number of quadrats for SER. Approximate photographic measurement can produce soil area data in a much shorter time, but will not supply depths or volumes.

Quadrat data have the advantage of being amenable to many types of statistical analysis.

The more sophisticated aerial photo techniques (photogrammetry and digital terrain models) are technically feasible on quadrats. However, their use for SER remains precluded by high cost.

The resolution of satellite images currently available in NZ (10 to 30 metres) is too coarse for meaningful measurement of areas at quadrat scale. This is likely to change with the advent of high-resolution satellite images (1 metre or better). However, depth measurement from satellite data remains infeasible, for technical reasons already discussed.

1.5.4 Line Samples (transects)

The same techniques as outlined for quadrats, also appear practical for measuring soil depths, areas or volumes along “transects”, similar to botanical sampling transects. These are typically 100 metres or longer.

Time required to measure line transects - whether in the field or from aerial photos - is generally lower than quadrats.

However, the statistical analyses that may be performed on line transect data are more restricted.

1.5.5 Point Samples

The field techniques also appear practical for point-sampling soil. The aerial photographic one has already been used for three SER surveys of soil area. Layout of point samples is flexible - random points scattered irregularly, systematic points laid out in a grid pattern, clusters of points within quadrats, lines of points along transects.

Time needed to field-measure point samples is unlikely to be less than measuring areas within quadrats or lengths along transects, as the same distances must be walked. In the case of dispersed point samples, it mat be necessary to drive long distances from one point to the next. In contrast, the time needed to photo-measure point samples is much shorter regardless of how they are laid out.

However, the range of statistical analyses that can be performed on point sample data is even more restricted than for transects.

1.5.6 Prioritisation Of Sampling

When time and money are limited, one option is to sample only those parts of a region that are perceived to be at risk of erosion. This raises the question, how to identify the parts at risk. Approaches taken are:

a) Land use capability units or aggregates of them

Proposed in sampling designs commissioned from Landcare Research by Environment Waikato (Eyles et al 1993), Taranaki (Stephens et al 1995), Environment Bay of Plenty (Harmsworth et al 1998), and Hawkes Bay (? 1999). Used by TRC for its pilot erosion survey in 1996; also for a follow-up in 2000. Used by EW, EBOP and HBRC to select sites for soil quality sampling (500 Soils Programme); but no erosion surveys implemented in those regions yet.

b) NZLRI rock types or aggregates of them

Proposed in a sampling design commissioned from Landcare Research by Manawatu-Wanganui Regional Council (Jessen et al 1994). Not used for the eventual erosion survey in 1998-99.

c) NZ Soil Classification groups

Not known to have been proposed as a framework specifically for regional SER of soil erosion, but this would be possible. The groups are used as a framework for nationwide analysis of soil quality data collected for the 500 Soils Programme.

d) Soils grouped as slightly, moderately or highly susceptible to degradation

Proposed in a sampling design commissioned from Ecological Research Associates by Auckland Regional Council (Hicks 1994). Not used to select sample, but used to analyse it, when the survey took place in 2000. Also used by Auckland Regional Council, Wellington Regional Council and Marlborough District Council to select sampling sites for the 500 Soils Programme.

Approach a can be supported by examining erosion severities recorded for each land use capability unit in the NZ Land Resource Inventory. Approach b identifies some rock types as more erodible than others, but masks great variation in erodibility within each rock type. This is even more the case for approach c, where each soil group contains some which are erodible but many which are not. Approach d assesses an individual soil type's susceptibility to erosion, as well as nutrient loss and structural breakdown. It has the disadvantage that for many soil types, limited information is stored in the National Soils Database. This necessitates reliance on generalised descriptions contained in the bulletins that accompany each soil survey.

Prioritisation has the disadvantage, that it focuses monitoring onto particular parts of a region where erosion is perceived as a problem. In the absence of comparative measurements, there is no way to verify that the perception is correct. In most instances it will be, but prioritised monitoring runs a risk - failure to detect where erosion is on the increase in other parts. This seems rather to defeat the purpose of SER.

In two pilot SER surveys of erosion (Gisborne, Manawatu-Wanganui) Councils opted for samples distributed throughout their regions, and did not analyse data according to the proposed prioritisation framework. In Taranaki's case, a sample was restricted to LUC units regarded as erosion-prone (hill country and sand country), so produced the expected results. In Auckland's case, the prioritisation framework was used to stratify a region-wide sample, at the stage when data were analysed. It confirmed that soil groups identified as highly susceptible to erosion do indeed have the highest percentages under some land uses - but quite low ones under others. It also showed that erosion is more widespread than thought, where land use is intense on some of the soil groups identified as slightly or moderately susceptible.

To summarise, a prioritised sampling strategy is not recommended as a way to ascertain a region's erosion state, because it entails guessing where the priorities lie. The value of overlays based on land use capability, geology or soils, is that they assist analysis of erosion data once collected. In this sense, they may help prioritise parts of a region where response is needed.

2 Advice On Options For SER Of Soil Intactness In The Waikato Region

To facilitate comparing the options, I have rated each technique from Section 1d, relative to the following questions.

Technical soundness

Can the method measure change in soil?
With sufficient accuracy for SER?
Over an interval of time that's realistic for detecting change?

Ease of data collection

Is data collection simple?
Is it quick?

Robustness

Is statistical analysis manageable?
Does the data format enable statistical testing?
Within acceptable confidence limits for SER?

Effectiveness

Are results easily explained?
Is overall cost reasonable, relative to the usefulness of results?

In the following tables where a technique cannot meet the criterion, it receives a N (no) and drops out. Further questions in the sequence are not answered, and marked by a - (dash).

Where a technique may meet the specified criterion if survey design is well thought out in advance, it receives a M (maybe), is retained as an option, and further questions are answered.

Where a technique can definitely meet the criterion even if survey design is poor, it receives a Y (yes), and is retained.

The basis for the answers is broadly outlined in Sections 1d and 1e, but is also based on reading the source documents about each survey. Many of them are summarised in the bibliography by Lambrechtsen and Hicks (op. cit.).

2.1 Can The Method Measure Change In Soil?

Method applicable to	area	depth	volume
1) Field measurement with survey instruments	Y	Y	Y
2) Field measurement with global positioning systems	Y	Y	Y
3) Approximate field measurement with various devices	Y	Y	Y
4) Field measurement with tracers	Y	Y	Y
5) Field measurement by soil profile description	N	Y	N
6) Field measurement by soil probe or auger	N	Y	N
7) Aerial photographic measurement with stereoplotters	Y	Y	Y
8) Aerial photographic measurement by digital tech.	Y	Y	Y
9) Approximate aerial photographic measurement	Y	N	N
10) Point sample measurement from aerial photographs	Y	N	N
11) Interactive measurement from satellite images	M	N	N
12) Digital classification of satellite images	M	N	N
13) Measurement from runoff plots	M	M	M
14) Measurement from stream discharge	N	N	M

2.2 Accurately Enough?

Method applicable to	area	depth	volume
1) Field measurement with survey instruments	Y	Y	Y
2) Field measurement with global positioning systems	Y	Y	Y
3) Approximate field measurement with various devices	Y	Y	Y
4) Field measurement with tracers	Y	Y	Y
5) Field measurement by soil profile description	-	Y	-
6) Field measurement by soil probe or auger	-	Y	-
7) Aerial photographic measurement with stereoplotters	Y	Y	Y
8) Exact aerial photographic measurement by digital tech	Y	Y	Y
9) Approximate aerial photographic measurement	Y	-	-
10) Point sample measurement from aerial photographs	Y	-	-
11) Interactive measurement from satellite images	M	-	-
12) Digital classification of satellite images	N	-	-
13) Measurement from runoff plots	Y	Y	Y
14) Measurement from stream discharge	-	-	M

2.3 Over An Interval Of Time That's Realistic?

Method applicable to	area	depth	volume
1) Field measurement with survey instruments	Y	Y	Y
2) Field measurement with global positioning systems	Y	Y	Y
3) Approximate field measurement with various devices	Y	Y	Y
4) Field measurement with tracers	Y	Y	Y
5) Field measurement by soil profile description	-	Y	-
6) Field measurement by soil probe or auger	-	Y	-
7) Aerial photographic measurement with stereoplotters	Y	Y	Y
8) Aerial photographic measurement by digital tech	Y	Y	Y
9) Approximate aerial photographic measurement	Y	-	-
10) Point sample measurement from aerial photographs	Y	-	-
11) Interactive measurement from satellite images	M	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	N	N	N
14) Measurement from stream discharge	-	-	N

2.4 Is Data Collection Easy?

Method applicable to	area	depth	volume
1) Field measurement with survey instruments	N	N	N
2) Field measurement with global positioning systems	M	M	M
3) Approximate field measurement with various devices	Y	Y	Y
4) Field measurement with tracers	N	N	N
5) Field measurement by soil profile description	-	Y	-
6) Field measurement by soil probe or auger	-	Y	-
7) Aerial photographic measurement with stereoplotters	N	N	N
8) Aerial photographic measurement by digital tech.	M	M	M
9) Approximate aerial photographic measurement	Y	-	-
10) Point sample measurement from aerial photographs	Y	-	-
11) Interactive measurement from satellite images	Y	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	-	-	-
14) Measurement from stream discharge	-	-	-

2.5 Is Data Collection Quick?

Method applicable to :	area	depth	volume
1) Field measurement with survey instruments	-	-	-
2) Field measurement with global positioning systems	M	M	M
3) Approximate field measurement with various devices	Y	Y	Y
4) Field measurement with tracers	-	-	-
5) Field measurement by soil profile description	-	Y	-
6) Field measurement by soil probe or auger	-	Y	-
7) Aerial photographic measurement with stereoplotters	-	-	-
8) Aerial photographic measurement by digital tech.	M	M	M
9) Approximate aerial photographic measurement	Y	-	-
10) Point sample measurement from aerial photographs	Y	-	-
11) Interactive measurement from satellite images	M	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	-	-	-
14) Measurement from stream discharge	-	-	-

2.6 Is Data Analysis Manageable?

Method applicable to :	area	depth	volume
1) Field measurement with survey instruments	-	-	-
2) Field measurement with global positioning systems	M	M	M
3) Approximate field measurement with various devices	Y	Y	Y
4) Field measurement with tracers	-	-	-
5) Field measurement by soil profile description	-	Y	-
6) Field measurement by soil probe or auger	-	M	-
7) Aerial photographic measurement with stereoplotters	-	-	-
8) Aerial photographic measurement by digital tech.	Y	Y	Y
9) Approximate aerial photographic measurement	Y	-	-
10) Point sample measurement from aerial photographs	M	-	-
11) Interactive measurement from satellite images	M	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	-	-	-
14) Measurement from stream discharge	-	-	-

2.7 Does Data Format Enable Statistical Testing?

Method applicable to :	area	depth	volume
1) Field measurement with survey instruments	-	-	-
2) Field measurement with global positioning systems	Y	Y	Y
3) Approximate field measurement with various devices	M	M	M
4) Field measurement with tracers	-	-	-
5) Field measurement by soil profile description	-	Y	-
6) Field measurement by soil probe or auger	-	Y	-
7) Aerial photographic measurement with stereoplotters	-	-	-
8) Aerial photographic measurement by digital tech.	Y	Y	Y
9) Approximate aerial photographic measurement	M	-	-
10) Point sample measurement from aerial photographs	Y	-	-
11) Interactive measurement from satellite images	Y	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	-	-	-
14) Measurement from stream discharge	-	-	-

2.8 Within Acceptable Confidence Limits?

Method applicable to :	area	depth	volume
1) Field measurement with survey instruments	-	-	-
2) Field measurement with global positioning systems	M	M	M
3) Approximate field measurement with various devices	M	M	M
4) Field measurement with tracers	-	-	-
5) Field measurement by soil profile description	-	M	-
6) Field measurement by soil probe or auger	-	M	-
7) Aerial photographic measurement with stereoplotters	-	-	-
8) Exact aerial photographic measurement by digital tech.	M	M	M
9) Approximate aerial photographic measurement	M	-	-
10) Point sample measurement from aerial photographs	M	-	-
11) Interactive measurement from satellite images	M	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	-	-	-
14) Measurement from stream discharge	-	-	-

2.9 Are Results Easily Explicable?

Method applicable to :	area	depth	volume
1) Field measurement with survey instruments	-	-	-
2) Field measurement with global positioning systems	Y	Y	Y
3) Approximate field measurement with various devices	Y	Y	Y
4) Field measurement with tracers	-	-	-
5) Field measurement by soil profile description	-	Y	-
6) Field measurement by soil probe or auger	-	Y	-
7) Aerial photographic measurement with stereoplotters	-	-	-
8) Aerial photographic measurement by digital tech.	M	M	M
9) Approximate aerial photographic measurement	Y	-	-
10) Point sample measurement from aerial photographs	M	-	-
11) Interactive measurement from satellite images	Y	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	-	-	-
14) Measurement from stream discharge	-	-	-

2.10 Are Costs Reasonable, Relative To Usefulness Of Results?

Method applicable to :	area	depth	volume
1) Field measurement with survey instruments	-	-	-
2) Field measurement with global positioning systems	M	M	M
3) Approximate field measurement with various devices	M	M	M
4) Field measurement with tracers	-	-	-
5) Field measurement by soil profile description	-	M	-
6) Field measurement by soil probe or auger	-	M	-
7) Aerial photographic measurement with stereoplotters	-	-	-
8) Aerial photographic measurement by digital tech.	M	M	M
9) Approximate aerial photographic measurement	M	-	-
10) Point sample measurement from aerial photographs	M	-	-
11) Interactive measurement from satellite images	M	-	-
12) Digital classification of satellite images	-	-	-
13) Measurement from runoff plots	-	-	-
14) Measurement from stream discharge	-	-	-

3 PROGRAMME DESIGN

3.1 Select A Measurement And A Measuring Technique

EW requires methods that:

- are technically sound
- are statistically robust
- provide easily understandable data
- in a short space of time
- at an acceptable cost.

Most of the techniques summarised in Section 1d can be ruled out. They fail to meet one or more of EW's criteria, for reasons which are stated in Section 2. The shortlist that remains is:

2 Field measurement with GPS
3 Approximate field measurement with various devices
5 Field measurement by soil profile description
6 Field measurement by soil probe or auger
9 Approximate aerial photographic measurement
10 Point sample measurement from aerial photographs
11 Interactive measurement from satellite images

Out of these, I recommend:

10 - for measuring changes in area of soil eroded, deposited or intact.

The reasons for selecting this technique are:

- New aerial photographic coverage will soon be available (see below).

- 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.

The new photos have been commissioned by Environment Waikato, to be taken in colour at a scale of 1 : 40,000. They will be converted to orthophotos, by scanning at 1 metre resolution, and rectifying with a software fit to the Land Information New Zealand (LINZ) digital terrain model. The photos are scheduled to be taken in spring 2001 as weather conditions permit, and should be available in April or May 2002 once orthophoto conversion is complete.

2 - for measuring changes in length of soil eroded, deposited or intact on streambanks

The reasons for selecting this technique are :

Streambank erosion cannot be seen clearly on 1:40,000 aerial photographs.

Streambank transects (length samples) with GPS are as fast as, and more accurate than, approximate field measurements on sample transects.

I recommend a feasibility investigation of :

6 - for measuring surface erosion on cropped land

The reasons for this recommendation are :

- Aerial photographs merely indicate bare soil exposed to risk of surface erosion, not whether it is actually occurring.

- Topsoil depth measurements with an auger are faster than approximate field measurements with spades, tapes etc.

- They are much faster than field measurements by soil profile description.

- Extension of the sampling network to pasture and forest sites could be contemplated, to measure soil depth change under these land uses (not essential for SER, but may be useful to find out).

A feasibility investigation will resolve uncertainty about extent and severity of surface erosion on cropped land in the Waikato i.e. whether or not it needs to be measured for SER. A certain amount of experimentation is needed, in order to design a sufficiently accurate sampling strategy (see later discussion).

I also recommend a feasibility investigation of :

11 - Interactive measurements of land use from satellite images

The reasons for this recommendation are :

- Attempts to measure land use, vegetation cover and its condition, bare ground etc. from satellite images have so far been by digital classification, or unchecked interactive measurement, leading to unacceptably high margins of error.
- In principle, point sampling of land use from satellite images, followed by adequate field checking, should provide better accuracy.
- This would open up the possibility of attaching field-sampled soil areas, lengths and depths to satellite-derived estimates of region-wide land use.

Environment Waikato has been considering acquisition of one or more Landsat images, in October 2001 and April 2002 at a cost of $1500 per image, to measure extent of cropland in its region. The images would afford an opportunity for EW staff, who are familiar with local terrain, to undertake a better evaluation of satellite images' potential.

3.2 Design A Measurement Strategy

For a measurement strategy I recommend :

Point sample (dispersed grid) : 3 km by 3km NZMS map grid intersections, superimposed on EW's new orthophotos.

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.
- 3 km by 3 km spacing will provide approximately 2700 points. Distributed across the region's land uses (old NZLRI areas), this will provide erosion measurements that represent the region-wide figures to within :

	Minimum	**Maximum**
	(+- 2 std. err. @ 95% conf.)	
Arable pasture and cropland	0.7%	2.0%
Improved hill pasture	1.0%	3.0%
Unimproved hill pasture	1.0%	3.0%
Pine plantation	1.1%	3.4%
Scrub	0.9%	2.7%
Forest	1.1%	3.4%
Swamp	3.4%	10.4%

Other (grouped)	2.6%	7.8%

- The sampling grid, if stored in EW's GIS, can be easily re-located for re-surveys. Re-survey at 10 year intervals is suggested. Pilot surveys in other regions suggest that changes can be detected by re-survey at lesser intervals, but that they will be close to or within margins of error.

Line sample (length transects) : expand the pilot network of 252 randomly located transects on streambanks (Project Watershed) to other catchments. At the same sampling density, this will entail an extra 168 transects.

Reasons for this selection are :

- The pilot network has provided some very useful data. It represents the current state of riverbanks catchment-wide. If waypoints are treated as individual observations, the data's margin of error will be moderate on each sample reach, and will become quite small when they are bulked.

- Similar data can be obtained region-wide at little added cost, relative to what has already been spent (its acquisition is already scheduled for 2001-2002).

- The reaches are relocatable using GPS for re-survey. Given the instability of riverbanks, re-survey at annual intervals will detect significant changes, but this frequency is probably not necessary for SER. Re-survey once a decade (as already proposed by EW staff) should suffice, and would be synchronous with the point sample survey.

Point sample (quadrat transects) : establish a network of randomly located quadrats for field measurement of changes in soil depth, initially on orchards, market gardens, and grain crops. Consider expanding to other land uses (improved pasture, unimproved pasture, pine plantations, scrub, bush, wetland).

Reasons for this selection are :

- Quadrats (point clusters) will enable measurement of variability in topsoil depth at each sample site; something which cannot be done by sampling single points on a dispersed grid.

- Topsoil depths from soil profile descriptions at existing "500 Soils" sites can be used as reference standards.

- Cost of data collection is about the same as for the existing streambank transects i.e. one quadrat per day.

- Provided GPS is used to record a central reference point, quadrats can be located for re-survey. Re-survey at an interval of 10 years or greater is suggested, because significant changes in topsoil depth are unlikely within the space of a decade (though possible).

Random location of sites will be difficult, in the absence of up-to-date information about cropland's location. However it should become possible, once the new aerial photographs and satellite images are taken next spring.

A certain amount of experimentation will be needed to design a sampling strategy. Options are to locate sample sites on a single soil type, or on a group of related soils, or randomly irrespective of soil type. The second option is likely to be an acceptable compromise between obtaining data at a level of stratification that permits meaningful comparison of sites, and keeping number of sites manageable. 20 sites on each land use are recommended i.e. 60 total for orchards, market gardens and grain crops (the

500 Soils Programme data suggests between-site differences become apparent, once data can be plotted for 10-20 sites under a given use on a particular soil group).

Point sample (dispersed grid) : 3 km by 3km NZMS map grid intersections, superimposed on a portion of EW's new satellite image

Reasons for selecting this strategy are similar to those stated for the region-wide point sample from orthophotos. Visual interpretation of land use on a portion of the satellite image, at the same points as used for the region-wide survey of soil disturbance (which entails recording land use), will enable :

- Comparison of land use interpreted from the satellite image, with land use interpreted from the orthophotos.

- Comparison of both, with land use viewed on the ground.

A 30 by 30 kilometre area i.e. 100 points, will be the minimum needed to calculate percentage classification accuracy. The number of points required to do this is fairly small, so long as accuracy can be validated by field check (though there might be a case for field-checking several 30-by-30 km areas, so that variations in accuracy can also be determined).

3.3 Recommend An Analysis Procedure

The most straight-forward way to analyse these data will be :

Point sample of soil stability relative to land use, from orthophotos

- 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).

Although database programmes are currently fashionable, there seems no need to use one for SER when a swifter and less complicated alternative is available. The current procedure is documented in a report to ARC by Hicks (2000).

Transect sample of riverbank stability

The procedure currently used by Environment Waikato's staff and contract workers is recommended i.e. field recording with GPS, data processing with GPS software, and storage in Excel spreadsheets. The procedure is documented in a report to EW by Kelly (2001).

Quadrat sample of arable soil stability

This survey will be a feasibility investigation, so the data analysis procedure remains to be determined. The amount of data to be processed is fairly small (100 point observations of soil depth on each of 60 quadrats), so could be manually recorded on field sheets, with statistics done by calculator. If the method is scaled up for use on other soil groups and land uses, data quantities would become larger, and spreadsheets would be the easiest way to store and analyse.

Point sample of land use, from a satellite image

This survey will also be a feasibility investigation. Unlike digital classification, which entails computer-processing reflectance for a vast number of pixels (image elements), point-sampling a hard-copy satellite image entails interpreting a few hundred. The interpretations, together with cross-checks against orthophoto and field data, can be manually recorded. In the event that this method proves suitable for routine use, number of points sampled would increase to the same as the orthophoto-based survey i.e. 2700, and the same analysis procedure would become appropriate.

3.4 Estimate Times And Costs Of Implementation

Time to collect data will be :

Region-wide point sample from photographs: (based on time taken by Hicks for ARC's survey)	for n =	2700	6100
		7 or	16 days
Region-wide transect sample on streambanks: (based on time taken by EW staff for Project Watershed survey @ 3 sites per day)		420 transects	140 days
Pilot study quadrat sample in fields :(based on estimate of 1 day per field site)		60 quadrats :	60 days
Pilot study point sample from satellite image (based on estimate of 1 day for interpretation & 1 day for field check)		100 points :	2 days

Time to analyse data will be :

Region-wide point sample from photographs: (based on time taken by Hicks for ARC's survey)	for n =	2700	6100
	data entry	3.5	7.5
	soil overlay	3.5	7.5
	point count	3.5	7.5
	stat. tests	3.5	7.5
		14 or	30 days
Region-wide transect sample on streambanks: (based on time taken by EW staff for Project Watershed survey @ 8 sites per day)		420 transects:	53 days
Pilot study quadrat sample in fields : (based on estimate of 0.25 days per field site)		60 quadrats :	15 days
Pilot study point sample from satellite image: (based on estimate of 1 day)		100 points :	1 day

Time to document results will be:

Region-wide point sample from photograph: (based on time taken by Hicks for ARC's survey)		draft	final
	land use	3	2
	soil disturbance	7	4
		10 +	6 days
Region-wide transect sample on streambanks :(based on time taken by EW staff for Project Watershed survey @ 16 sites per day)		420 sites:	26 days
Pilot study quadrat sample in fields: (based on estimate of 5 days for writing report)		60 quadrats:	5 days
Pilot study point sample from a satellite image (based on estimate of 1 day for writing report)		100 points:	1 day

Costs of implementation consist almost entirely of personnel time, as methods have been selected so as to utilise equipment (GPS, augers, and stereoscopes) or materials (aerial photographs) already purchased or budgeted for.

Times estimated for each stage of the survey (set out above) are just one determinant of personnel cost. It can either shrink or balloon, depending on who does the job. The options are :

3.4.1.1 EW Staff

Likely to be accurate, given knowledge of local terrain. May be high cost, when salaries plus overheads are charged against project budget. Entails either slow progress in between other duties, or diverting staff onto project for several weeks every 10 years.

1. University students or temporary workers

Low cost - wage or contract payment. Risk of inaccuracy - some will be very good; others may be very bad. Careful selection and close supervision needed.

2. CRI staff under contract

Likely to be accurate, given experience of techniques. Very high cost, due to CRI charge rates. Progress can be fast, if full-time commitment is specified in contract. Able to work without supervision.

3. Independent contractors

Moderate cost. Need to be carefully selected, as some will have experience of techniques but others won't. Progress can be fast if full-time commitment is specified in contract. Able to work without supervision.

4. A mix of all four may provide the best balance e.g.

- EW staff - co-ordination

- CRI staff or independent contractor - supervision and quality control

University students or temporary workers - photo and field measurements.

4 Concluding Remarks

Section 1.1 has explained why Environment Waikato monitors soil as part of its statutory responsibility to undertake state-of-environment reporting (SER). Section 1b has summarised the Council's brief for this scoping paper, commissioned from Ecological Research Associates.

Section 1.3 has discussed how the concepts of soil erosion, soil accumulation, and soil intactness can be used for SER. It advises that they are three aspects of the same thing - soil stability - and that all three really need to be measured rather than one in isolation.

Sections 1.4 and 1.5 have drawn on pilot SER surveys, and other relevant investigations, to illustrate how other Councils measure - or propose to measure - the three. It identifies 14 techniques.

Section 2 has drawn some conclusions about what has worked and what has not, by evaluating each technique against 10 questions which pose criteria for successful SER of soil stability.

Section 3.1 has recommended two techniques for immediate region-wide use - point sampling from aerial photographs, and field transects along riverbanks. These can meet all the criteria, provided a survey is well-designed. They have been selected because, unlike some other options which also meet the criteria, these two can be implemented with resources which EW has already acquired or intends to acquire.

Section 3.1 has also recommended two additional techniques - field quadrats to measure soil depth in cropland, and point sampling of land use from satellite images. These do not presently meet all the criteria in Section 2. However they show promise as sources of useful supplementary information for SER of soil stability, provided a survey method can be refined by pilot study in each case.

A basic survey design has been outlined in Section 3.2. It can provide measurements of change in soil stability under different land uses, within an acceptable margin of error, at intervals of time which will enable meaningful interpretation of results.

Data analysis procedures have been recommended in Section 3.3, with a view to keeping analysis time short, and presentation of results simple.

Time estimates have been provided in Section 3.4, for data acquisition, analysis, and presentation. These will enable EW staff to prepare cost estimates, which may vary a great deal depending on which personnel are proposed to undertake the survey. A mix of EW staff, temporary workers, and contracted scientists is suggested as likely to provide a good balance between the need to maximise skills and minimise costs.

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