Using a Geographical Information System to map and determine the extent of major soil disturbance resulting from a logging operation

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ABSTRACT

The logging extraction tracks and landings of a recently clearfelled forest compartment were mapped from aerial photographs, into a (GIS) Geographical Information System, using an analytical stereoplotter.

The GIS spatial data, combined with field measurements of track-width, were used to calculate lineal and spatial statistics of the site disturbance and to generate a digital terrain model of the compartment. The model was used to determine the distribution of extraction tracks in various slope classes and to provide a visual representation of their layout.

In this application GIS was used to map site disturbance 'after the event'. The advantages of using GIS-derived information in the harvest planning phase, to improve efficiency and to minimise disturbance during logging operations, are discussed.

KEY WORDS

Analytical stereoplotter, Geographical Information System (GIS), mapping, soil disturbance, harvesting.

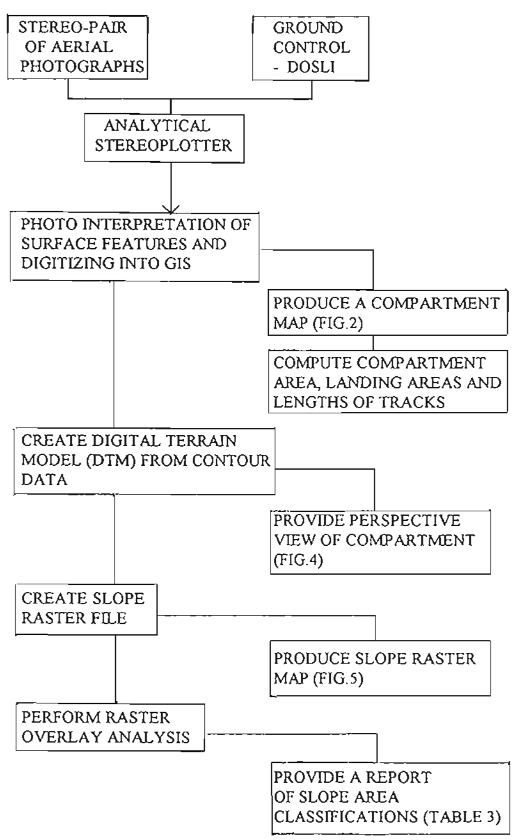

Figure 1: Flow diagram showing the procedures used for map production and terrain analysis.

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INTRODUCTION

Soil disturbance created during logging operations and subsequent loss of site productivity have been extensively researched in New Zealand and overseas (Murphy, 1984; Krag *et al.*, 1987; Senyk *et al.*, 1989; Krag *et al.*, 1991; Hall, 1993). The need to minimise such disturbance to prevent long-term site degradation, while using cost-effective methods to harvest a stand of trees, has long been an objective of the harvest planner. The introduction of GIS to the forest industry, and the consequent ability to analyse site information, open up possibilities for increasing efficiency in the harvest-planning process.

The objectives of this study were firstly to demonstrate the use of a GIS to evaluate major site disturbance resulting from logging operations, and secondly to suggest how similar GIS techniques might be used to assist operational harvest planning.

Soil disturbance has been described as "any abrupt change in the physical, chemical or biological properties of the soil" (Seynk *et al.*, 1988). Harvesting-related soil disturbance can encompass all of the above, to a greater or lesser extent. In the context of this study, soil disturbance relates to land area where the subsoil has been exposed as a result of machine traffic, or blading to provide skid roads, landings, or similar roadside work areas.

Aerial photographs of a recently logged compartment in the

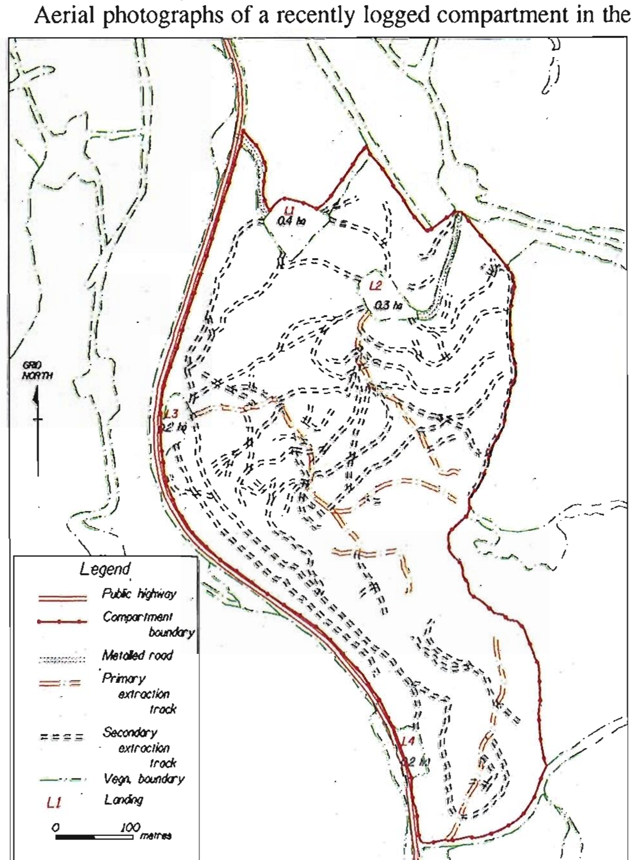


Figure 2: Compartment map showing road and track network and landings.

Bay of Plenty were used, in conjunction with an analytical stereoplotter linked to a GIS, to map and measure the extent of significant soil disturbance created by a (ground-based) logging operation. Field measurements of track width were combined with the track length and landing areas, mapped from the aerial photographs, to obtain a relationship between the area of soil disturbance and total area of the harvested block.

METHODS

An AP190 analytical stereoplotter[1] was used to interpret and digitise essential site information directly from a stereopair of aerial photographs (scale 1:15,000) into the geographical information system TerraSoft.[2]

Ground control points, necessary for scaling the stereo-model, were provided by the Department of Survey and Land Information (DOSLI), and expressed as New Zealand Map Grid (NZMG) coordinates.

The photogrammetric process provided an overall accuracy, for measurements taken from the photographs, of ±0.5 metre.

The digital mapping and analytical processes will not be described here, but a procedural outline is provided in the flow diagram (Figure 1).

Features interpreted and mapped in the GIS included:–

i) Contours, at 5 metre intervals
ii) Compartment boundary
iii) Landings
iv) Public roads
v) Metalled, access roads
vi) Primary extraction tracks (PETs) – main access to landings
vii) Secondary extraction (contour) tracks (SETs) – access to more remote parts of the compartment.

The compartment map (Figure 2) shows the location of the landings, roads, and extraction tracks after logging.

Field measurements

Track widths were measured at 50 m intervals along selected sections of PETs and SETs, and at 25 m intervals along the metalled roads. Two measurements made at each point were the **running surface**, defined as the distance from the bottom of the cut bank to the start of the fill (Figure 3); and the **disturbed width**, defined as the distance between the top of the cut bank and the toe of the fill.

Measurements derived using GIS analysis

GIS spatial analysis provided values for the area of the compartment, total areas of landings and metalled roads, and lengths of the PETs, SETs and metalled roads.

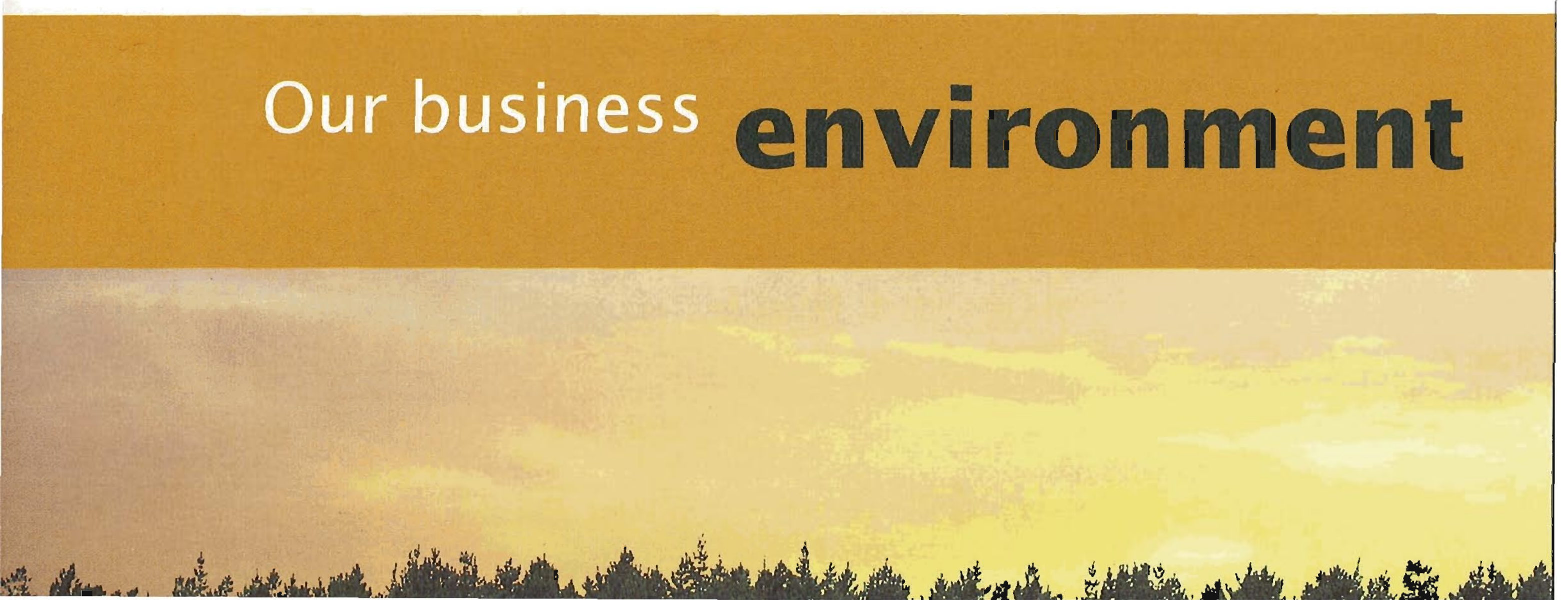
The five metre contour data were used to create a digital terrain model (DTM) of the compartment, with a grid spacing of seven metres. A perspective view of the DTM was produced with roads and tracks overlaid.

The mean slope for each grid cell or raster was computed, and formed the basis for the topographical description, classification and mapping of the whole compartment (excluding landings and metalled roads).

A raster map of the PETs and SETs was produced. To demonstrate the potential for integrating data sets, slope rasters were classified to indicate areas with common slope ranges of 0-15°, 15-25°, and >25°, which were considered suited to skidder, tractor and hauler operations respectively. Using the GIS process of

[1] *Carto Instruments, Corvallis, Oregon, USA.*

[2] *Essential Planning Services Limited, Nanaimo, British Columbia. NZ agent: NZFRI Ltd, Sala St, Rotorua.*



overlay and cross-tabulation of PET/SET rasters with slope rasters, the area of track located within each of the slope classes was determined.

RESULTS

The lengths of all roads and tracks (from the GIS), and their widths (from field measurements) are shown in Table 1.

Table 1: Measurements of primary and secondary extraction tracks and metalled roads

		Disturbed width		Running surface	
Disturbance type	Total length (m)	mean width (m)	std. dev. (m)	mean width (m)	std. dev. (m)
PET	1242	7.1	1.27	3.5	0.57
SET	6877	7.1	1.27	3.4	0.38
Metalled	273	7.3	1.63	4.9	1.05

Total compartment area was 26.5 ha, and the landings occupied 1.3 ha. The proportion of the compartment in which soil was disturbed by formation of roads, tracks and landings is shown in Table 2.

Figure 4 provides a visual impression of the compartment terrain and shows the layout of PETs and SETs.

Figure 5 shows the distribution of extraction tracks in the three selected slope classes. GIS analysis of this distribution revealed that primary tracks were located mainly in areas of low and medium slope, whereas secondary tracks although more evenly distributed among the three slope classes, were most common in the medium slope and steep areas (Table 3).

Table 2: Areas of tracks, metalled roads and landings

	Disturbed width		Running surface	
Disturbance type	Area (ha)	Proportion of compartment (%)	Area (ha)	Proportion of compartment (%)
PET	0.88	3.3	0.43	1.6
SET	4.88	18.4	2.30	8.7
Metalled	0.20	0.8	0.13	0.5
Landings	1.30	4.9	1.30	4.9
Total	**7.26**	**27.4**	**4.16**	**15.7**

Table 3: Distribution of primary and secondary extraction tracks by slope

Slope class	area of compt. in slope class (ha)	% area of compt. in slope class	PET area (disturbed width)		SET area (disturbed width)	
			ha	% of total	ha	% of total
1 (<15 deg)	8.4	33	0.41	47	1.33	27
2 (15-25 deg)	10.3	41	0.42	47	1.85	38
3 (>25 deg)	6.5	26	0.05	6	1.70	35

DISCUSSION AND CONCLUSIONS

The 1991 New Zealand Resource Management Act requires forest managers to minimise environmental impacts and to monitor their effects. Soil disturbance created by logging operations is an environmental impact.

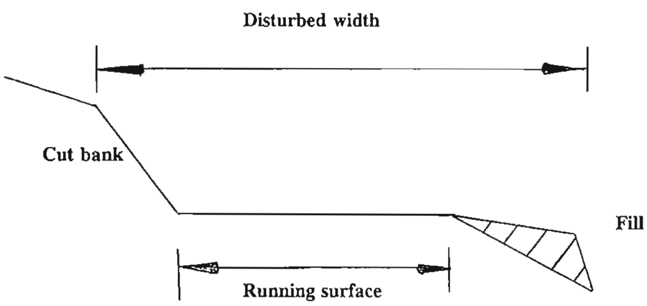


Figure 3: Cross section of a typical road cutting to show the two types of width measurement used.

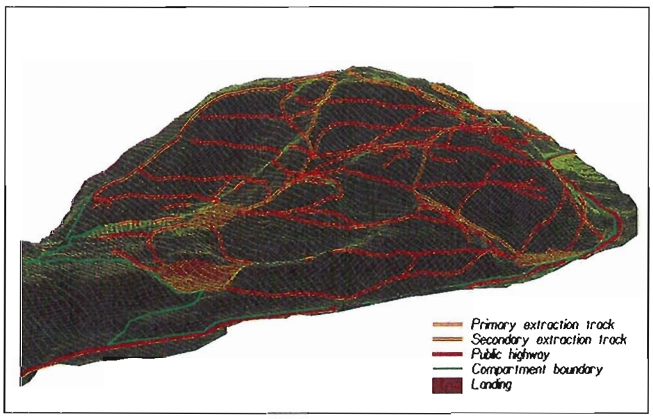


Figure 4: Perspective view of digital terrain model (DTM) showing road and track network. View direction is SE.

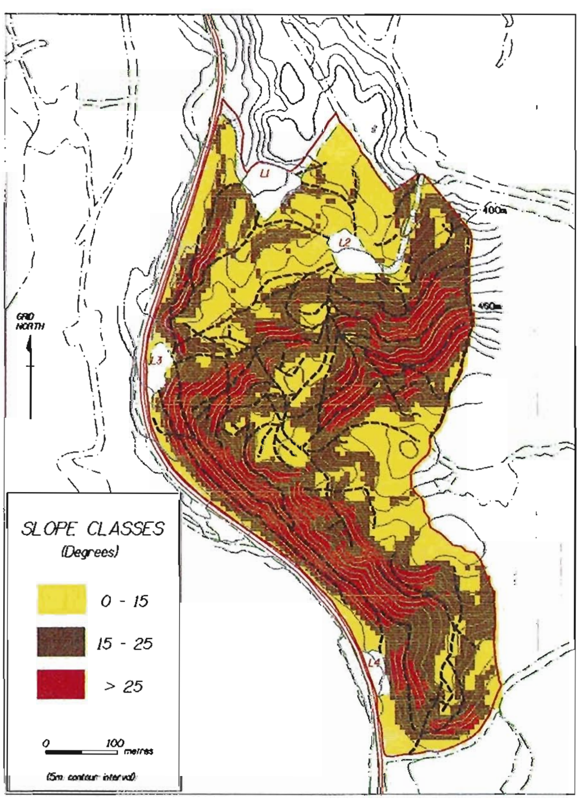


Figure 5: Compartment terrain classified by slope.

Of the study area, 5.7% was occupied by metalled roads and landings, and 21.7% by formed extraction tracks. This amounted to 27% of the compartment having received some form of disturbance, of which 57% was compacted running surface and, arguably, lost to production. It should be noted that this compartment is not necessarily typical of current practice but was well suited to the objectives of this study.

In this paper we have shown how aerial photo-interpretation and GIS can be used to measure the extent of site tracking after logging and provide a spatially referenced database of site information that can easily be re-examined.

A forest company could use the GIS analytical processes outlined here to compare soil disturbance resulting from different harvesting alternatives on a range of sites with different terrain, soil and forest characteristics. For example, slope thresholds for replacing one harvesting system with another could be determined for specific combinations of site factors and used to keep soil disturbance within acceptable limits. A database could be developed to assist in planning the harvesting of new areas and to help in avoiding situations where excessive disturbance might occur. After harvesting, GIS systems could be used to monitor the actual effect of planned operations.

From the 'visual impacts' point of view, excessive tracking on steep slopes during logging operations could attract adverse criticism. The ability to create a three-dimensional model showing a 'site-specific' range of road, track and landing options, should help the planners to locate these in the least visually obtrusive positions.

At present, use of GIS analytical and 'data visualisation' procedures is limited by the cost of data entry for the creation of DTMs. Contour information must meet certain standards of accuracy (i.e. no significant vegetation should be present on aerial photographs used for contour mapping) and resolution (i.e. 5 metre intervals or less). In future, it is likely that the new generation of fully-digital photogrammetric workstations and associated image-processing software will enable 'auto-correlation' techniques to be used to produce DTMs (and as a byproduct, contour maps) directly from digitally scanned, stereo pairs of aerial photographs. These tools and procedures should reduce the need for time-consuming, manual, contour mapping. However, accuracy of contour information will continue to influence the final accuracy of any DTM produced.

Integrated application of photogrammetry, GIS, terrain modelling and harvest planning software should increase understanding of site potential, maximise operational efficiency, minimise adverse impacts on the environment, and in the long term help to sustain productivity.

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