LOGGING INDUSTRY RESEARCH ASSOCIATION

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PROJECT REPORT

THE COST OF LANDING FORMATION IN PUMICE AND CLAY SOILS

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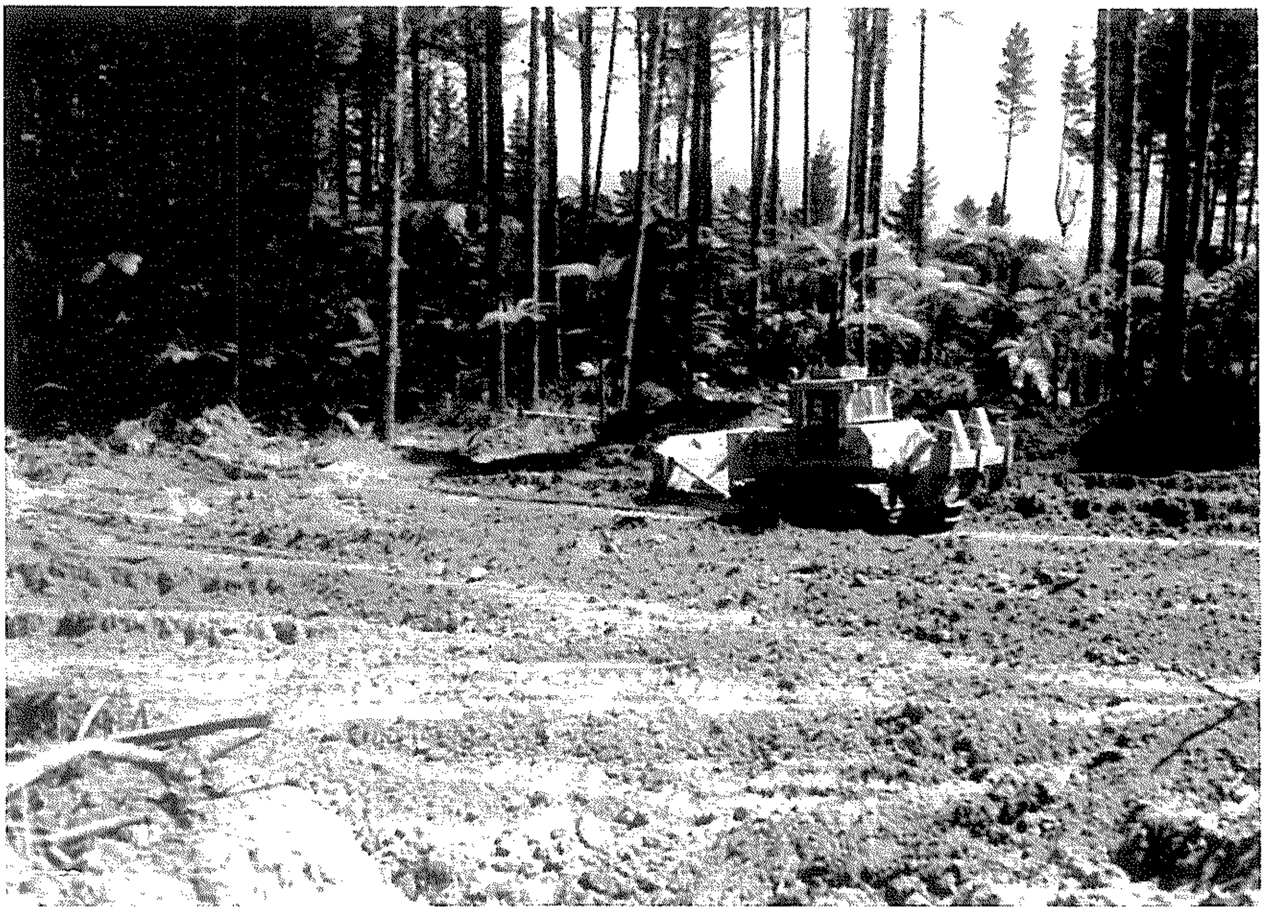

Project Report

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THE COST OF LANDING FORMATION
IN
PUMICE AND CLAY SOILS

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ABSTRACT

A study of log landing formation cost versus slope angle and soil type, in two soil types and three terrain types, was completed. Landings on coarse grained pumice soil sites with slope angles between 2 and 8 degrees, were the cheapest to construct. The cost of formation in clay soils was approximately twice that of pumice on a $/cubic metre basis.

INTRODUCTION

This study, to assess the time and cost of landing formation, was undertaken during December 1987 and February 1989 in two soil types :

1) Pumice
2) Clay

and three terrain types :

1) Flat
2) Ridge top
3) Mid-slope.

The objectives of the study were to obtain cost information for use in harvesting research work and to determine, within the limits of a small but detailed survey, the factors which influence the formation cost of landings.

Five sites were chosen in Kaingaroa Forest (pumice), four in Tairua Forest (clay), and one from Whaka Forest (pumice/clay mix). Landing sites were also observed at Rotoehu Forest but not measured.

The study covered the before and after measurement of ground profiles, calculation of earthwork volumes, collection of stumping, formation and mixing costs, but not the cost of aggregate surfacing. Aggregate surfacing of landings is practised at Tairua Forest, but not on the pumice soil forests. The application of an aggregate surfacing is an additional expense to be considered in the total cost of clay soil landings. It was not covered in this study.

Landing construction practices were also observed. Of particular interest was the mixing technique used on some pumice sites which contain pockets of unsuitable soil material.

Previous work on log landings, relevant to this study, includes an analysis of landing layout by Raymond (1987), loading operations on landings by Twaddle (1979), and variation in landing areas, also by Twaddle (1984).

STUDY SITES

KAINGAROA FOREST

The five sites chosen in Kaingaroa Forest were separated among the southern, northern and north-western areas. Slope angles varied from flat (0 degree slope) to 7 degrees, although one site in a dry vee-shaped gully had a side slope of up to 20 degrees on one side.

The sites were chosen to represent typical Kaingaroa pumice soils and topography and were all planned as standard size landings of 60 m x 40 m. One landing was planned for a two-stage hauler/skidder operation, but all other sites were for skidder operations.

TAIRUA FOREST

The Tairua sites included a narrow, ridgetop knob containing some hard rock and steep side slopes; a broad rounded spur (5 to 10° cross-slopes, 7 to 8° downslope; a flattish dome with 8 to 18° sideslopes; and a concave midslope site with slopes between 2 and 9 degrees. The rounded spur site was probably unusual for Tairua. Typical landing sites at Tairua vary from flat, moderate cost sites, to steep and expensive ridge top sites, containing mixed material.

WHAKAREWAREWA FOREST

The only landing studied at Whaka Forest was a midslope site with 10 degree sideslope in 50 to 60 year old transition crop radiata pine. It was constructed below Tawa Rd at an elevation of 600 m. This site was representative of higher cost landings on the steep slopes above the Waipa basin.

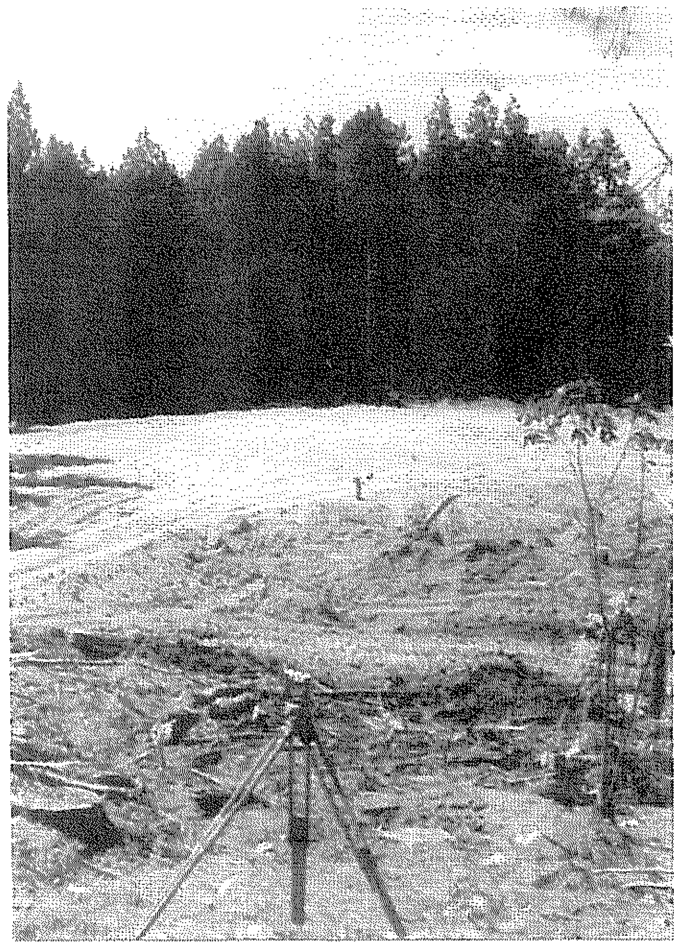

Figure 1 : Site T1 at Tairua Forest. A well chosen site for a moderate cost landing.

GENERAL

In Kaingaroa and Whaka the four corners of each landing were defined in the cleared area by marker posts or paint marks established by the logging supervisor. At Tairua a large area was cleared and it was left up to the dozer operator to site the landing. This made it difficult to place the survey reference pegs.

Each landing was surveyed by establishing reference pegs outside the proposed landing area and tying these pegs to a baseline parallel to the long axis of the landing. Cross-section spacing was determined by the topography, but was normally at 10 or 15 m intervals at right angles to the baseline. Corrections were made for elevation differences, then profiles were drawn of the ground both before and after landing formation. Earthwork quantities were calculated from these profiles using the standard Civil Engineering 'end area' method, with prismoidal corrections.

At site T4 in Tairua the reference pegs were destroyed during the formation work, but it was possible to establish levels from other ground points that were left intact. Part of the landing was formed beyond the survey line. Earthwork volume is therefore less accurate for this site. To obtain a satisfactory grade for logging trucks to service the landing, a large sidling cut was required above the landing. It was therefore difficult to determine where the road ended and the landing began.

The slope profile in pumice soil was much more uniform than for clay soils. Where the landing was formed in a dry gully the two sides did not have the same slope angle. The uniformity of slope angle in pumice soil is probably due to the nature of its very recent geological formation.

Tree type and size varied between each site. With the shallow tree roots and loose pumice soils in Kaingaroa, tree type and size did not have any significant effect on stumping time.

At Tairua Forest there was less variation in tree type and size. Stumping time was estimated at eight hours per site, but there was a practical difficulty in distinguishing between stumping and formation.

From observation there was little difference in the dimensions of skidder and hauler landings at Tairua. Landing area appeared to be a function of the topography, rather than the logging system.

At Rotoehu Forest, north of Rotorua, sites were observed but not measured. Soil type is similar to northern Kaingaroa and landing formation times average approximately nine hours using a large (234KW) bulldozer.

RESULTS

STUMPING PRODUCTIVITY

These varied from a low of 3.5 hours for a moderate slope (7°) site at Kaingaroa using a 104KW bulldozer, to an estimated average of 8 hours per landing for stumping in clay soils at Tairua. Relevant data is listed in Table 1.

At Kaingaroa two machines were used for landing formation with the larger machine (234KW) being used in the northern area of the forest on sites K4 and K5. This machine produced consistent stumping times of between 5 and 6 hours per landing and a rate of approximately 430 m²/hour on two sites. Its lower power did not reduce productivity in any way.

In the pumice soil forests of Kaingaroa, Whaka and Rotoehu, the main factor influencing stumping

Table 1 : Productivity of Stumping Operations on Log Landings. K - Kaingaroa, W - Whaka, T - Tairua)

Site	*Topography*	*Stumping Time (Hrs)*	*Machine Power (KW)*	*Stumping Area (m²) per hour*
K1	*Flat*	*7 (est)*	*104*	*285*
K2	*Slope*	*3.5*	*104*	*543*
K3	*Slope*	*4.3*	*104*	*516*
K4	*Flat*	*5.7*	*234*	*431*
K5	*Gully*	*5.5*	*234*	*425*
W1	*Slope*	*5.5*	*234*	*436*
T1	*Dome*	*8 (est)*	*147*	*300*
T2	*Ridge*	*8 (est)*	*147*	*219*
T3	*Slope*	*8 (est)*	*147*	*309*
T4	*Spur*	*8 (est)*	*147*	*312*

time was the disposal of stumps. Stump disposal time is a function of the slope angle. The ideal situation occurs on a moderate sideslope in an undercut at the base of the fill. The stumps help to retain the soil removed from the bank and reduce the risk of stream sedimentation. As a percentage of total formation time, sites that contained a moderate side slope took slightly less time to stump than flat sites.

In Kaingaroa the use of a smaller capacity bulldozer did not lead to significantly different stumping times from those achieved by the larger bulldozer. From observation of uprooted stumps, tree roots in the pumice soils of Kaingaroa tend to spread out plate-like and do not extend deeply into the soil. In these light pumice soils the use of a heavy bulldozer did not have any productivity advantage over a light machine.

Site K5 in northern Kaingaroa had a very low stocking density of eight very large old trees. These trees had large branches and an average diameter of about 1.2 metres. At this site stumping productivity was similar to other areas with high stocking density but smaller trees.

The stumping times at Tairua were estimated from the total stumping plus formation hours. This was due to the difficulty in clearly distinguishing between stumping and formation. Stumping time in m^2/hr was low in comparison to the rates achieved at Kaingaroa. Since the machine used at Tairua is in the medium size dozer range, the machine power is not a significant factor in the lower stumping productivity.

The most accurate way to compare stumping productivity on the different soil types would be to eliminate machine and operator variables by using the same machine and operator on both sites. This is not practical in a limited scale project of this nature.

The Tairua machine of 147 KW is costed out by the forest owner at a similar $/KW rate as the Kaingaroa machines. This cost is also in keeping with rates used in the East Coast North Island. This rate is 71.4c/KW for the Liebherr 741, whereas the TD25 (a contract machine) cost 68.4c/KW.

FORMATION PRODUCTIVITY

In the loose friable pumice soils of central and southern Kaingaroa, formation time varied from 4 to 9 hours. Disposal of stumps and soil was a problem on flat sites. When the slope angle increased to between 3 and 8° instead of being formed wholly in 'cut' area, spoil was used as fill to form up to one third of the landing width. Most landings had a finished slope angle of 2° to provide drainage across the site.

Due to the lack of adequate record keeping by the forest owner, the formation times recorded at Tairua are estimated. The relativity of formation time between sites is realistic, based on the topography, soil, and volume removed to form the landings.

Formation hours are listed in Table 2.

As expected, productivity was highest on pumice sites. Lowest productivity was recorded on a difficult clay/rock site where ripping was required.

Drainage is a problem with flat sites. The 2° finished slope seemed to provide adequate drainage on midslope sites. On the flat pumice sites, effective drainage was achieved by crowning the landing and forming a shallow watertable drain around the perimeter of the landing. This results in a high windrow of stumps and spoil around the landing and the need to create access tracks through these mounds for the skidder. The safety of skiddies working on a landing is reduced on these flat sites as it is often difficult to see the skidder until it has reached the landing.

In clay soils flat sites create much greater drainage problems than on the pumice. Truly flat sites are rare in most clay forests and these can usually be avoided by changing the landing location slightly.

At Tairua where most logging is done by hauler, the slight crowning of a ridge top landing or sloping of a midslope landing, is sufficient to provide effective drainage of the surface.

Table 2 : Landing Formation Times and Productivity

Site	*Topography*	*Soil Type*	*Formation (Hours)*	*Formation Productivity (m^2 /hour)*
K1	*Flat*	*Pumice*	*6.5*	*308*
K2	*Slope*	*Pumice*	*4.0*	*472*
K3	*Slope*	*Pumice*	*4.8*	*462*
K4	*Flat*	*Pumice*	*4.9*	*501*
K5	*Gully*	*Pumice*	*8.9*	*263*
W1	*Slope*	*Pumice/Clay*	*6.5*	*370*
T1	*Dome*	*Clay*	*8 (est)*	*300*
T2	*Ridge*	*Clay/Rock*	*23 (est)*	*76*
T3	*Slope*	*Clay*	*12 (est)*	*208*
T4	*Spur*	*Clay*	*24 (est)*	*104*

Disposal of logging slash creates problems on ridgetop or steep mid-slope sites. The overburden of slash and soil debris can exceed the capacity of the slope to support it. The usual mode of slip circle soil failure can cause devastating damage when the debris from the slip failure travels downslope. At Tairua the problem of logging slash was solved by burning off the 'birds nest'. This greatly reduced the potential for environmental damage.

SOIL MIXING

The technique of mixing pumice soils containing pockets of clay or other inferior material, by tumbling action from the dozer blade, was only used at the Whaka site. It is periodically used in Kaingaroa Forest when required.

Unsuitable material includes organic matter, volcanic ash and silty clays. These materials generally appear in small pockets or thin layers. If left in place they create soft spots during wet periods due to an increase in water content and a commensurate loss of strength. These materials are often deceptive, since their bearing capacity when dry is considerable, but is drastically reduced when the material becomes saturated.

The mixing technique requires careful identification of soil type and properties by both the logging supervisor and machine operator.

The effectiveness of mixing and compaction was well demonstrated on the Whaka site where heavy rain (approximately 200mm) fell over several days soon after the landing was completed. Throughout this period the landing retained a hard, well compacted surface and remained in full operation. The access strip from the metalled road onto the landing did not fare so well. This was partly on natural ground and partly on poorly compacted fill, which became badly scoured and very soft, making access for the trucks difficult.

At the Whaka site mixing took 5.8 hours but, due to the relatively steep side slope angle of 9° and depth of ash over pumice, a large quantity of material was mixed. It is unlikely that mixing would normally take this long. The

Figure 2 : Site W1. Mixing action after basic formation.

value of mixing material lies in the fact, that, when suitable soils are selected, a uniformly compacted all weather surface is formed. This technique increases the cost of a landing but the benefits of reduced landing maintenance and production delays, particularly in the wet winter months, outweigh the extra cost. This extra cost saving could be easily identified by simple cost tracking on selected landing sites.

Mixing is an old technique which is more often used in the manufacture of basecourses where small quantities of fine material are sometimes added to improve the grading and properties of the basecourse.

Mixing may also be useful in clay soils when combined with mechanical compaction of the subgrade. Where the cost of an aggregate surfacing is high, this mixing technique can have very easily identified cost benefits.

SOIL VOLUME

The cut volume of soil varied from a low of 760 m^3 to a high of 4450 m^3. Values for each landing are listed in Table 3. The total unit cost per cubic metre varied from $0.45 to $1.32 with an average of $0.58 for pumice soils, to $1.20 for Tairua clay soil. The high of $1.32 per cubic metre involved a flat site with high stocking where stumping time was high.

The volumes of spoil shifted per hour varied greatly on the pumice sites. Except for site K1, they were also much greater than the volume measured at the Tairua sites. This is to be expected since the light and free draining nature of pumice makes it an exceptionally easy material to shift. As expected, the larger machine used in Kaingaroa shifted more material, but was not any cheaper on a cubic metre basis than the smaller machine.

The measured volume of material removed at site K1 was low. A slight slope across the site reduced the need for a perimeter drainage ditch. This site contained a high stocking of relatively small trees but the root depth was also shallow. None of these factors can account for the high number of formation hours.

Table 4 lists formation and total unit costs. It illustrates the significantly higher cost of forming landings in clay soils. The

Table 3 : Soil Volumes Moved in Landing Formation

Site		*Ave Slope Angle (°)*	*Dimension (m)*	*Volume (m^3)*	*Volume per Hour (m^3)*
K1	*Flat*	*1*	*50 x 40*	*770*	*57*
K2	*Slope*	*7*	*45 x 42*	*980*	*131*
K3	*Slope*	*4*	*60 x 37*	*1340*	*147*
K4	*Flat*	*0*	*63 x 39*	*2840*	*268*
K5	*Gully*	*10/20*	*60 x 39*	*2600*	*180*
W1	*Slope*	*10*	*65 x 37*	*4020*	*226*
T1	*Dome*	*7*	*60 x 40*	*1430*	*90*
T2	*Ridge*	*15/35*	*50 x 35*	*2720*	*88*
T3	*Slope*	*6*	*55 x 45*	*1800*	*150*
T4	*Spur*	*5/9*	*50 x 50*	*4450*	*185*

Table 4 : Formation Costs and Total Costs

Site	*Soil Type*	*Formation Cost ($ per m^3)*	*Total Cost ($ per m^3)*
K1	*Pumice*	*0.63*	*1.32*
K2	*Pumice*	*0.30*	*0.57*
K3	*Pumice*	*0.27*	*0.51*
K4	*Pumice*	*0.26*	*0.56*
K5	*Pumice*	*0.51*	*0.83*
W1	*Pumice/clay*	*0.24*	*0.45 (without mixing)*
W1	*Pumice/clay*	*0.46*	*0.66 (with mixing)*
T1	*Clay*	*0.58*	*1.17*
T2	*Clay/rock*	*0.89*	*1.20*
T3	*Clay*	*0.70*	*1.17*
T4	*Clay*	*0.57*	*0.75*

exception was site T4. This was an unusual site. It was cut out of a spur and this enabled spoil and stumps to be disposed of downhill on three sides of the landing. It was an ideal site for disposing of a large earthwork volume. This site would be an exception in Tairua.

The profiles showed that in general the width of a landing on a moderate sideslope had a 2/3 to 3/4 ratio between solid and fill. On the steeply sloped Tairua ridge top site only a limited amount of fill was used for the landing, due to the steepness of the side slope. This made retention of fill difficult without benches being formed and mechanical compaction used on the fill material. A simple guide to the volume of cut is :

$$V = \frac{0.5 * L * W * W * TAN\ S}{1 - 0.25 * TAN\ S}$$

Where -

V = Cut volume (m^3)
L = Length of formed landing (m)
W = 0.67 to 0.75 width of formed landing (m)
S = Slope angle (degrees)

When applied to a landing constructed on a moderate side slope, this formula gives a reasonable indication of cut volume. By applying this formula to selected landings in the study using the original side slope before construction, a reasonable indication of cost was obtained. An estimate within 10 or 15% of the actual cost can be expected.

For example, if the mixing is excluded from the Whaka site, this had an average slope angle (S) of 10 degrees, 75% of the landing width (0.75 x 37m) was in solid material, and the length of landing formed in the solid was 50 metres. This gives a cut volume of 3544 m^3 and an estimated cost of $2055. The actual volume and cost (excluding mixing) was 4020 m^3 and $1800.

The cut volume estimate is sensitive to the amount of solid cut as a percentage of the landing width. This should be carefully assessed from measurements of the ground slope, the landing location, and previous construction practice.

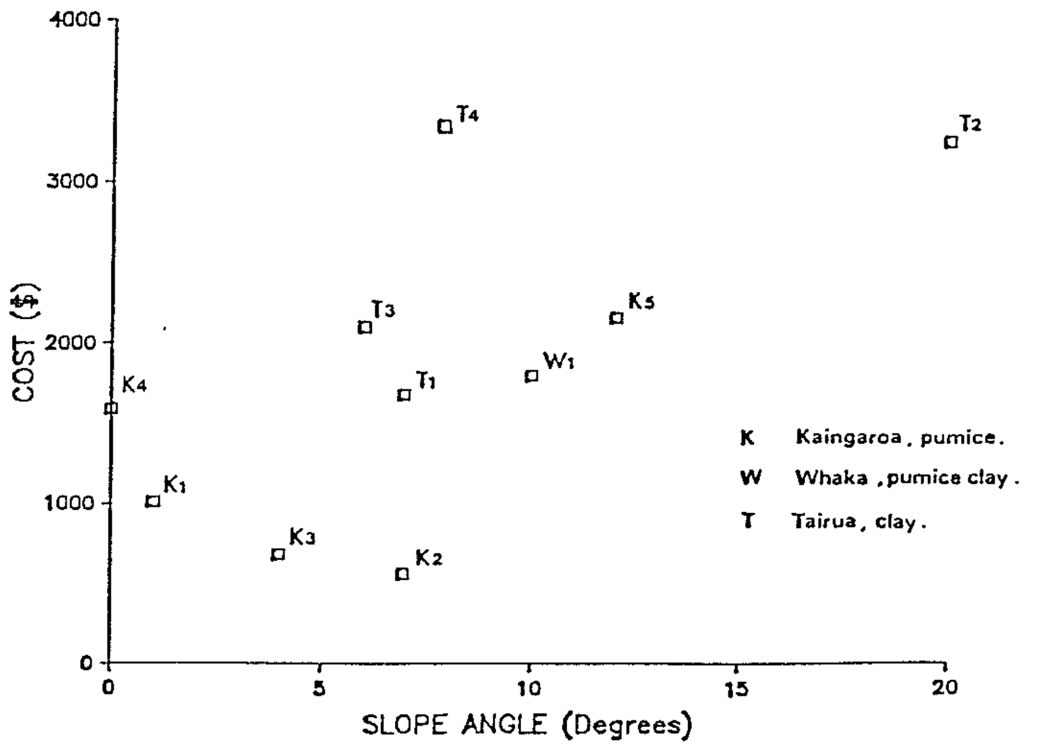

Figure 3 : Landing Construction Costs versus Slope

COST VERSUS SLOPE ANGLE

From such a limited survey it is difficult to accurately demonstrate the effect of slope angle on cost. However the survey did show that landing cost is least on 2 and 8° slopes, whereas on flat sites (0 to 1°) and steep sites (9° and over) costs are higher. With flat sites the disposal of stumps and the need to provide adequate drainage presents a problem and the machine ends up doing a lot more pushing than on a sloping site. On steeper slopes the sheer volume of soil to be removed adds to the cost, although the cost becomes less on a per cubic metre rate.

Site T1 at Tairua had a similar slope angle to site K2 (pumice) as shown on Figure 3, but cost considerably more to construct. However no definite conclusions can be drawn without more data on clay soil landing costs and slope angle.

COST VERSUS SOIL TYPE

The formation cost of landings in pumice soil, in this study, ranged from as little as $600 to as much as $2500. Cost versus soil type can best be compared on a $ per cubic metre and cubic metre per hour basis. On the pumice soils an average total cost of $0.58 per cubic metre applied. On the Tairua clay, costs varied from $0.75 to $1.20 per cubic metre. In a limited survey such as this the actual costs are not as important as the overall trend, which indicates that on a unit rate basis costs are approximately double for clay soils.

Tairua soils tend to be highly variable, even within a small area. This was particularly evident at landing T1 where rock outcrops were a feature of the ridge on which the landing was formed. The rock requires ripping but is rarely suitable for basecourse. It could provide a useful subbase

Figure 4

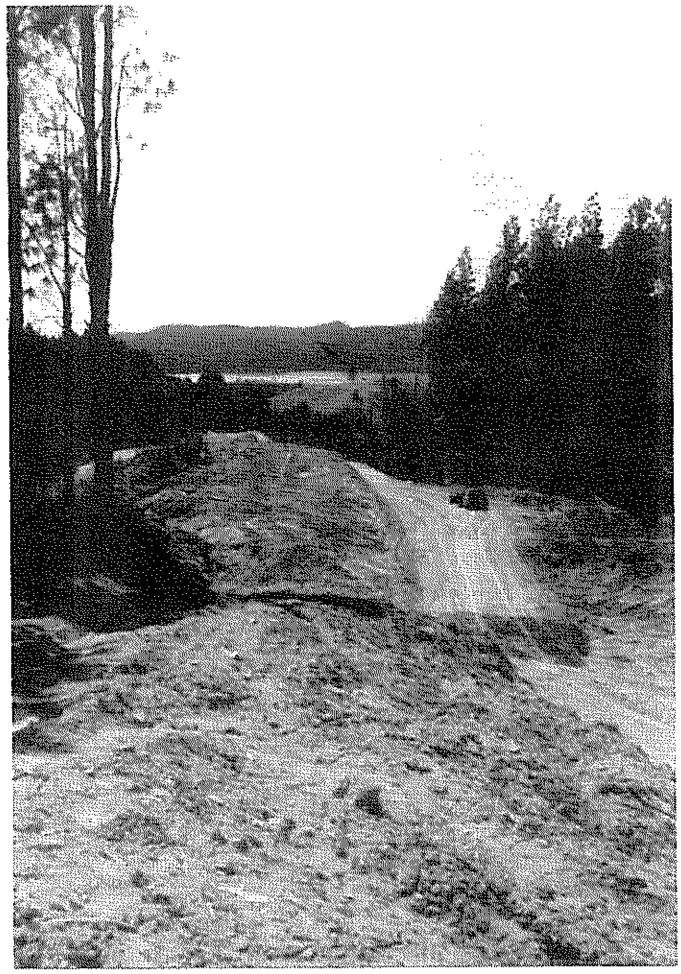

Figure 5

Tairua skid T2 before and after formation. Steep side slopes and bedrock made this an expensive skid.

if well compacted with a grid roller. It is standard practice to put aggregate on landings on clay soils, but the use of compacted on-site material could help lower these costs by reducing the depth of aggregate required.

The Kaingaroa practice of using a landing almost immediately after formation proved very effective in providing a well compacted base. This is probably because the pumice is closest to its optimum moisture content for maximum compaction at this time. If the exposed surface is left for a period then moisture content will become too low during dry periods, or too high for optimum compaction during wet spells.

Soil mixing, combined with mechanical compaction, can be applied to clay soil landings. In clay soils this can best be achieved by making several runs across the landing using the bulldozer's ripper tines. Mechanical compaction using a sheepsfoot roller or a grid roller will form a dense relatively impervious layer. The depth of this layer will depend on the ripping depth and the degree of compaction used. The bearing capacity of the compacted clay is likely to be significantly greater than the uncompacted material. Aggregate surfacing will still be necessary for both summer and winter use landings, but the low additional cost of the mixing and compaction will be compensated by greater savings in the cost of aggregate.

If the landing is left for a period to consolidate, the moisture content of the clay soil will increase beyond the optimum point for maximum compaction. The surface will become sunbaked and hard, but beneath this thin layer the bearing capacity of the soil will be very low. It is the low bearing capacity of the underlying material that determines the amount of aggregate surfacing required.

SUMMARY

Stumping productivity varied between 3.5 and 7.0 hours in the Kaingaroa pumice soil sites. At Tairua there was difficulty in distinguishing between stumping and formation. Average stumping time was estimated at 8 hours per landing at Tairua. The main factor influencing stumping time is the disposal of stumps. At Tairua there are few flat landing sites, so disposal is rarely a problem, except on steep sites where benching is required. On flat pumice sites disposal costs are higher than for sites where slopes are moderate.

In pumice soils formation costs can vary considerably depending on the slope angle and soil properties. The cheapest landings occurred on coarse-grained pumice soil sites with slope angles between 2 and 8°. A cost as low as $600 was achieved at Kaingaroa, whereas some sites in the northern area of the forest where the terrain is more broken cost about $2500. This represents a range of over 400% and the survey illustrates the need to carefully consider those factors, particularly soil properties and slope angle, when estimating landing formation costs. These costs are of course time dependent and it is realistic to expect that they will increase in line with the general increase in construction costs.

The mixing of small pockets of inferior material in pumice soil by tumbling action from a dozer blade, is an effective technique for improving soil strength. It requires careful identification of soil types and properties. The technique also has application in clay soils when combined with mechanical compaction of the subgrade.

Pumice is a light, free-draining material. The unit cost of shifting a cubic metre of pumice was approximately half the cost of clay material. A comparison between a large and a small dozer showed that in pumice the large machine was no cheaper per cubic metre shifted than a smaller machine. On steep sideslopes most of the landing must be on solid ground, which adds to the cost. On a moderate sideslope only 2/3 to 3/4 of the landing needs to be on solid ground.

Due to the free-draining nature of pumice and consequent lack of permanent water courses, the environmental impact caused by landing formation in Kaingaroa Forest is low. The placement of stumps at the toe of a fill, immediate use of landings and disposal of slash over the end of the fill, all help to slow the migration of fines down the slope into watercourses.

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