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Review of Papers on the Impact of Land Use Changes on Pavement Wear

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INTRODUCTION

The RCA Forum have commissioned a study to quantify the impacts of changing land use patterns on pavement wear for the roads that they manage. The main purpose of this investigate is to help them to better predict future heavy vehicle traffic and the funding requirements for maintaining and upgrading their networks to cope with this traffic.

The findings of the study to date have been presented in two papers:

- The first is entitled "Land Use and Transport Demand Comparison" which looks at the road freight volumes associated with different land use activities.
- The second is entitled "The Impact of Heavy Vehicle Traffic on Road Pavements" and this considers the impacts of traffic loading from heavy vehicles on pavement wear and maintenance requirements

Both papers draw on a range of published material for basic data and information and then use this information to derive the findings and conclusions. Clearly the finding and conclusions of the papers depend on the quality and accuracy of the source data.

This report presents a peer review of these two papers. It considers the data sources used and assesses their validity in 2016 and going forward. It also determines whether there are alternative data sources available and whether these sources agree or disagree with the data that has been used. Finally in cases where there is evidence for alternate data values to be used, the implications of using these on the findings and conclusions are assessed.

The scope of this review is limited to verification of the data and how it has been applied in the models of transport demand generation and pavement wear modelling. There are more fundamental questions on the allocation of costs but these are outside of the scope of this review and are not addressed.

This report considers each of the two papers in turn and proceeds through them sequentially. For completeness, copies of the two papers are attached to this review as appendix I and appendix II. The pages numbers and section headings in these appendices are used for reference.

LAND USE AND TRANSPORT DEMAND COMPARISON

Background

The opening statement uses the government's "New Zealand Business Growth Agenda" to predict the growth in the freight task. The paper states that the goal is to double primary industry exports in real terms from $32 billion in June 2012 to $64 billion by 2025. They correctly point out that this requires an average annual growth rate of 5.5% in real terms. The paper then argues that as the value of primary industry exports is determined by international markets and there is no reason to foresee a doubling of value of these in real terms, the freight task supporting this growth must grow proportionately. This last assumption that the growth in the value of the exports will be generated primarily by a growth in volume is the author of the paper's opinion. It is not part of the business growth agenda. In my view this assumption is unrealistic because I don't believe that it is possible to achieve growth of this magnitude simply by increasing output. We would need a substantial increase in the amount of value added to our exports and this would not simply translate into a proportionate traffic growth. However, this is just my opinion and is not necessarily any more valid that the author's.

There are other problems with this analysis. The main one is that the Business Growth Agenda is an aspirational goal rather than a forecast. The first four years of the time period considered by the Agenda have already passed. From the Statistics New Zealand web-site[1], we see that primary production exports increased from $33.23b for the year ending June 2012 to $35.45b for the year ending June 2016. If we use the Statistics New Zealand Consumer Price Index (CPI) data to convert the data to 2012 values, the 2016 figure becomes $34.36b. Thus the increase in the real

[1] http://www.stats.govt.nz/infoshare/ViewTable.aspx?pxID=93f72a07-bbc2-4cdc-8ead-919511b49e23

value of exports over the four year period is 3.4% which is equal to 0.84% per annum. The Ministry for Primary Industries (MPI) regularly publishes forecasts of primary production and exports[2]. The 2015 edition contains data from 2012 onwards with forecasts up to 2019. Interestingly, although this data is similar to that published by Statistics New Zealand, it is not identical. For comparison both sets of data are shown.

Table 1. Value of Primary Product Exports.

Year – Jun 30th	Statistics New Zealand Data (2016)			MPI Data (2015)		
	Export Earnings $M	Inflation	Exports (2012$ M)	Export Earnings $M	Inflation	Exports (2012$ M)
2012	$33,231		$33,231	$32,300	2.2%	$32,300
2013	$32,541	0.68%	$32,320	$32,425	0.8%	$32,168
2014	$37,889	1.62%	$37,033	$38,305	1.5%	$37,439
2015[i]	$34,746	0.42%	$33,819	$35,201	0.5%	$34,234
2016[ii]	$35,450	0.42%	$34,362	$35,725	1%	$34,400
2017				$38,380	2.1%	$36,196
2018				$39,645	2.1%	$36,620
2019				$41,300	2.1%	$37,364

[i] MPI data for 2015 is an estimate
[ii] MPI data for 2016 onwards is a forecast.

[2] MPI (2015) Situation and Outlook for Primary Industries, Ministry for Primary Industries, Wellington.

The MPI data shows a 2% per annum growth in real earnings over the seven years but this value is boosted by higher growth in the forecast years than in the past years where there is actual data. Because the growth is compounding the difference between 5.5% annual growth and 2% annual over a 13-year time frame is substantial. The 5.5% annual leads to a 100% increase over 13 years while a 2% annual growth leads to a 29% increase over 13 years.

Historically road freight traffic growth has correlated reasonably well with the growth in real GDP (i.e. inflation-adjusted) but with freight traffic growing at a faster rate than GDP. However, in recent years the rate of growth in road freight traffic relative to GDP has slowed considerably. This is illustrated in Figure 1 which has been generated using the "Transport Indicators" data from the Ministry of Transport web-site[1]. All three datasets shown have been indexed to their 2001 values so that they are all on the same scale. The trend in tonne-km of freight moved matches the trend in in GDP reasonably well although the fluctuations are greater. Prior to 2009, the vehicle-kms travelled by heavy vehicles also matched this trend. However, since 2010, the vehicle-kms travelled has barely increased although the tonne-km has grown. This reflects the introduction of high productivity motor vehicles which have enable the freight task to grow without a matching growth in truck traffic. The 2014 VKT figure is approximately the same as the 2007 and 2008 figures.

Going forward it is likely that truck traffic will increase at a modest rate of possibly around 2% per annum nationally. This growth rate will not necessarily be uniform across the country and it is quite possible that some districts will experience significantly greater or smaller increases.

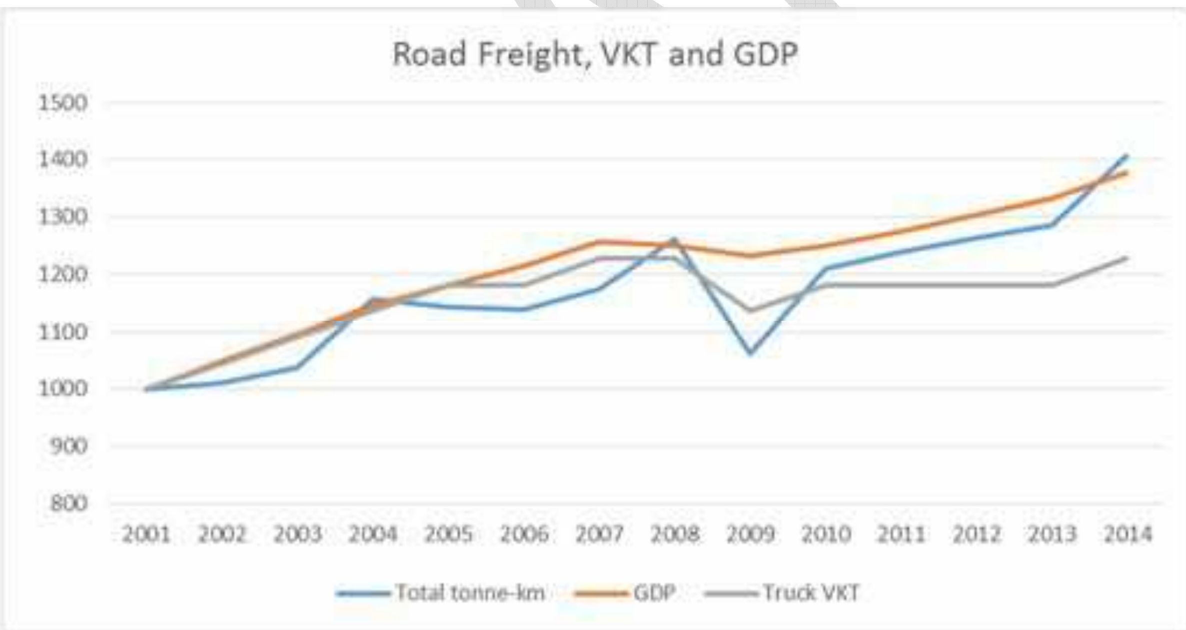

Figure 1. Road freight and GDP growth indexed to 2001 levels.

Primary Sector Trends

The first part of this section looks at the situation with forestry and considers the levels of planting and harvesting. Figure 1 in the paper shows the historical trend in annual new planting separated by government and private ownership. Although this highlights the spikes in private sector planting due to government incentives, it is less useful as a predictor of future harvesting volumes because it doesn't include re-planting of forests that have been harvested.

[1] http://www.transport.govt.nz/ourwork/tmif/

Figure 2 shows the harvesting volumes between 1990 and 2014. This shows two small peaks above the underlying trend in 2003 and 2013. These peaks align quite well with peaks new planting in 1975 and 1984 as shown in figure 1. The time intervals between the planting and harvesting peaks are 28 years and 27 years respectively which matches reasonably well with the normal harvesting cycle for radiata pine forests.

Figure 2 in the paper was extracted from the 2014 edition of National Exotic Forest Description (NEFD) published by MPI. The 2015 edition of this report is available and the equivalent figure from the 2015 report is reproduced below in Figure 2. This is interesting because both the new planting graph and the distribution of forest age classes shown in figure 3 in the paper would have predicted that the 2015 harvest would be less than the 2014 harvest. What this illustrates is that there is some flexibility in the age at which trees can be harvested. Forest owners will react to price and cost signals and may harvest earlier or later to maximise their returns. This effect is likely to smooth out the peak shown in figure 3 of the paper for 18 to 20 year old trees (as at 2014) by spreading the harvest over a longer period. This is also illustrated by Figure 3 below which shows the age classes of the forest estate in 2004 (this is an older version of figure 3 in the paper) and Figure 4 from the 2015 NEFD which shows the area harvested annually. If the average age at harvesting is 28 years, then the 2015 harvest would be centred on the 17-year age class in Figure 3 and for the five years prior to 2015 we would have expected about 60,000ha to have been harvested annually. However, the annual harvest over this period was significantly than this and the drop in volume expected in 2015 has not occurred.

This does not affect the total volume to be harvested. According to the 2015 NEFD, the net stocked area at 1st April 2015 was 1,717,715ha and 90% of this is radiata pine. The average age of radiata pine at harvesting in 2015 was 28.4 years. Assuming that this average age of harvest does not change, then the average area to be harvested per annum over the next 28 years is 60,483ha. The area harvested in 2015 was 49,896ha. Thus the average area per annum to be harvested is about 21% higher than current levels but the variation from year to year is not likely to be as great as suggested by the age profile of the trees.

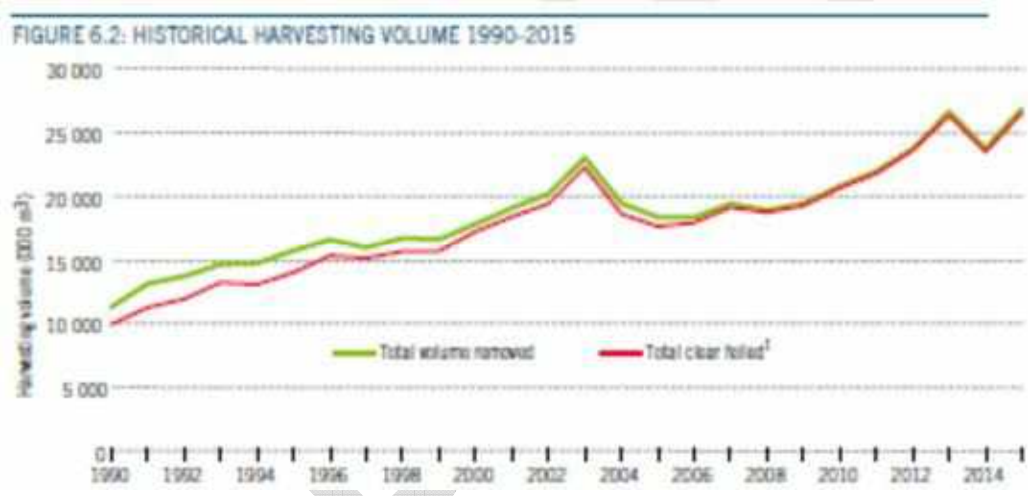

Figure 2. Annual harvest volume 1990-2015 (from NEFD 2015).

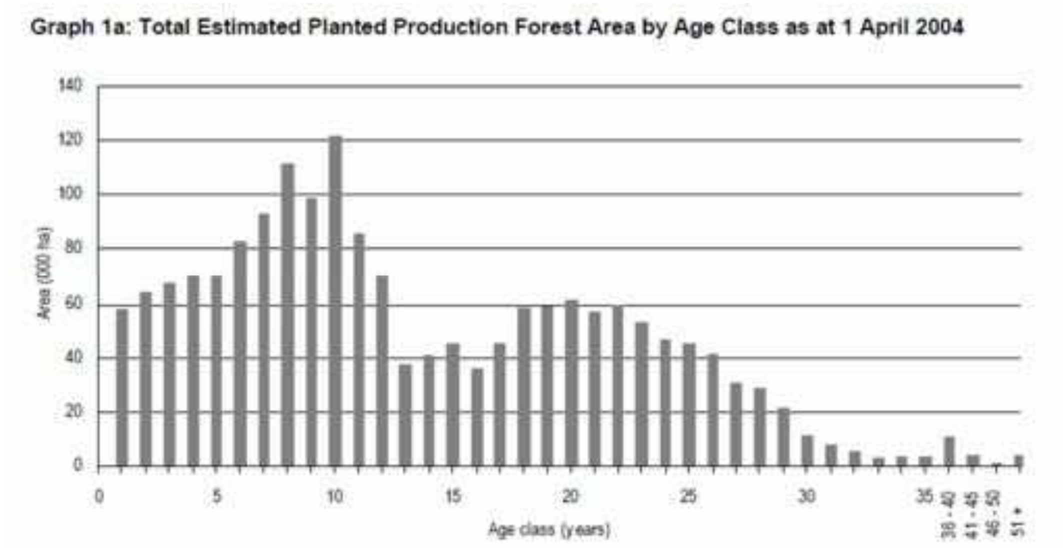

Figure 3. Production area by age class in 2004.

Figure 4. Annual area of plantation forest harvested.

The paper then considers the growth in dairy farming over the last 35 years. The figures quoted come from the DairyNZ publication "New Zealand Dairy Statistics 2014-15". This is the most recent version of this publication. The figures for land area, cow population and milk production have all been checked and are correct.

Figure 5 in the paper tracks the Fonterra milk price from 2002 to 2016. While these figures are correct they are a little misleading. The "New Zealand Dairy Statistics 2014-15" publication shows the payout figures for all dairy companies and also does an inflation adjustment. This is shown in our Figure 5 below. Using the inflation-adjusted figures, the average payout for the 10 years from 1995/96 to 2004/05 was $5.66/kg milk solids, while for the next 10-year period (2005/06 to 2014/15) it was $6.58/kg milk solids so in real terms the increase was 16%. However, coupled with this increase in average price there was also a significant increase in variability. The standard deviation for the first ten-year period is $0.78 while the standard deviation for the second ten-year period is $1.48.

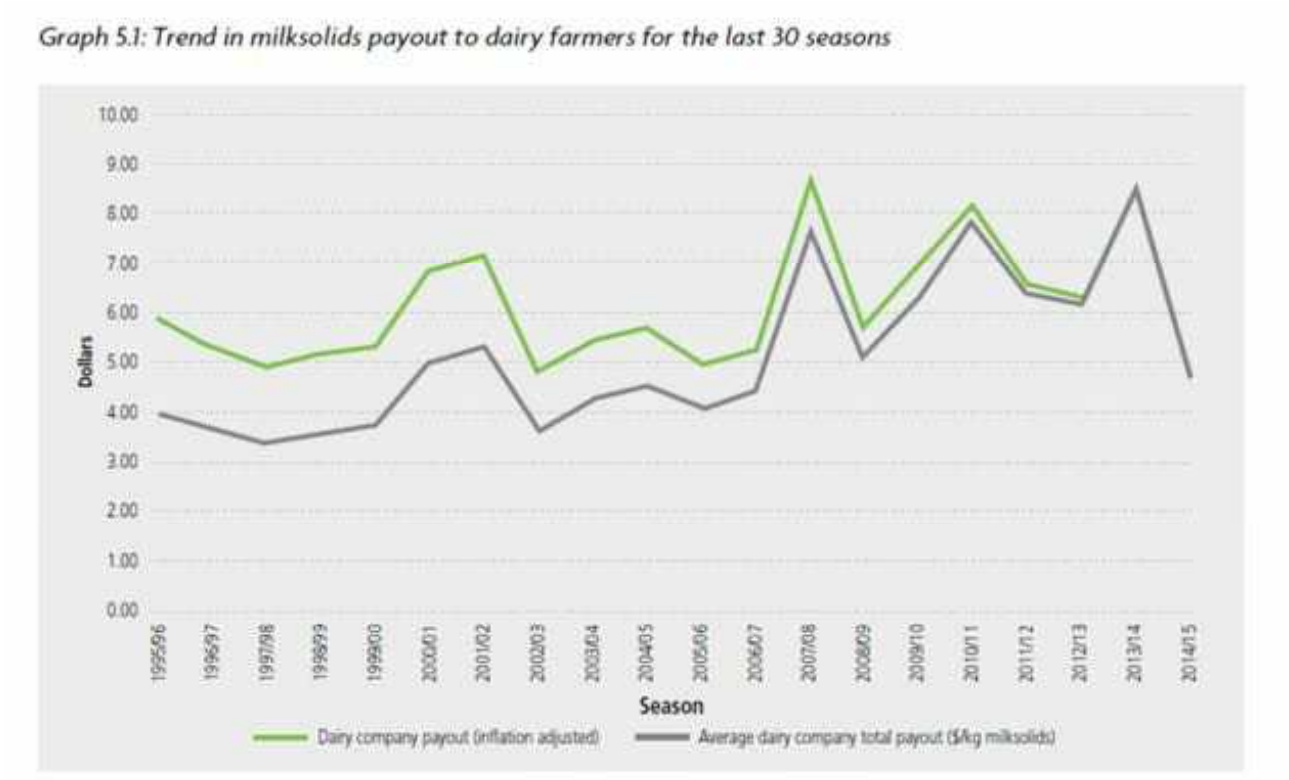

Figure 5. Average dairy company payout.

Land use correlation with heavy commercial vehicle traffic

The paper then uses a first principles approach to estimating the heavy vehicle traffic volumes generated by different land use activities. As part of this process it looks at a 30-year time period and converts farm outputs to truck trips per hectare. However, there are some inconsistencies in how this done particularly in relation to the payload capacity of the trucks. The analysis considers three main land use activities, dairy farming, sheep and beef farming and forestry and thus there are three main truck types involved; milk tankers, stock trucks and logging trucks. In addition to this there are other trucks for transporting fertiliser, supplementary feed, fuel etc. In recent years, the most popular truck configuration used for milk tankers, stock trucks and logging truck is the 4-axle truck towing a 4-axle full trailer with a gross combination weight limit of 44-tonnes. This 8-axle configuration has been more popular than the 7-axle alternatives (either a 3-axle truck and 4-axle trailer or a 4-axle truck and 3-axle trailer) because it incurred lower Road User Charges (RUCs) which offsets the loss of productivity from a higher tare weight. The new RUC system introduced in 2012 changed the relativities between the RUCs for 7 and 8 combinations making the 7-axle combinations more attractive. However, this effect was confounded to some extent by the 2010 amendment to the Vehicle Dimensions and Mass (VDAM) Rule which introduced high productivity motor vehicles (HPMVs). The 8-axle combinations are better suited to higher weight operations and so are more attractive as HPMVs. Developments in HPMVs have now led to a 9-axle combination (4-axle truck and 5-axle trailer) known as the 50MAX vehicle which has a gross combination weight limit of 50 tonnes. Complicating things further is the weighing tolerance which means that the operator of a 44-tonne combination cannot be prosecuted for being overweight unless its weight exceeds 45.5 tonnes (there are lower tolerances on axle group weight limits but these are not usually exceeded). In some sectors this weighing tolerance has been used as a de facto weight limit with 44-tonne vehicles routinely be operated at 45-46 tonnes. The VDAM Rule is currently being reviewed and it is proposed that the gross combination weight limit for 7-axle combinations will increase to 45 tonnes and 8-axle combinations will increase to 46 tonnes. These increases are in conjunction with a reduction of the weighing tolerance to 500kg. These changes are likely to make the 8-axle option more attractive although operators may prefer the 50MAX 9-axle alternative.

The payload capacities used in the analysis are 26.3 tonnes for milk tankers and 28.8 tonnes for stock trucks and logging trucks. If we assume that this is for a 44-tonne truck this implies a tare weight of 17.7 tonnes for a milk tanker and 15.2 tonnes for a stock truck or a logging truck. Some of these tare weights are unrealistic. For example, Fairfax Industries advertises a low tare weight 8-axle stock truck combination on their web-site[1] which has a tare weight of 22,580kg. I have obtained typical values for tare weights from a New Zealand trailer manufacturer[2] who produces all three vehicle types. They quoted a typical tare weight for an 8-axle logging combination at 16.9 tonnes, an 8-axle stock truck combination at 23-23.5 tonnes and a milk tanker at 19-19.5 tonnes. At 44-tonnes gross weight these values produce payload capacities of 27.1 tonnes for logs, 20.5-21 tonnes for livestock and 24.5 to 25 tonnes for milk. Fonterra's publicity material[3] states that their tankers can carry 25,500 litres of milk. The density of milk is 1.033 kg/l so this volume corresponds to a payload capacity of 26.34 tonnes.

Although there is some uncertainty as to the truck configurations and weights that will be used going forward, they are likely to be the same for the different land uses. It is therefore reasonable to compare the truck loads generated by each land use based on the current most common configuration which is the 44-tonne 8-axle truck and trailer. This gives us a standard basis for comparing the pavement wear implications which are investigated in the second paper. From the tare weight information that we have, it is reasonable to assume that dairy tankers have a payload capacity of 25,500 litres or 26.34 tonnes. Logging trucks have a capacity of 27.1 tonnes and stock trucks have a capacity of 21 tonnes. All of these assume a gross combination weight of 44 tonnes and no overloading. It is more appropriate to talk about truck loads rather than truck trips because in many instances a truck trip to a particular farm will not generate a full load from that farm but it will contribute to a full load. For example, a milk tanker will generally pick up from three of four farms in order to achieve a full load.

The paper says that it uses data from the 2014 DairyNZ statistics. In the previous section they used the 2015 statistics. The values for the various parameters that they have used are different in the 2015 statistics. The national average number of dairy cows per ha is given as 2.87. The average milk production per cow in the 2014/15 season is given as 4235 litres which then converts to 12,145 litres per ha. It should be noted that the 2014/15 season had the highest production per cow figure for more than 20 years (earlier data was not shown) so it was bumper season. Based on these figures, for a 30 –year period we get 14.29 outward tanker loads per hectare (2.87*4235*30÷25,500 = 14.288). This is quite similar to the figure in the paper even though the numbers used to generate it are different. Note also that this is based on a record year for production per cow and so the true figure may be a bit lower.

The paper refers to variations in stocking rates and milk production between districts and gives a likely range for outward tanker loads of between 10.7 and 16.3 per hectare over 30 years. In fact, in 2015, the milk production in litres per hectare varied from 8233 to 16479 between districts. Applying these values give a range of 9.7 to 19.4 outward tanker loads per hectare over 30 years.

The paper then notes that there are a wide range of activities included with the broad category of pastoral farming and describes the standard livestock unit (LSU) used for determining equivalencies across these various activities. It then proceeds to consider the outward truck traffic generated by some of these activities. However, there are major deficiencies in how this done.

The first case considered is a beef breeding unit where the cows give birth to calves which are then raised to the weaner stage and then sold for finishing elsewhere. The analysis assumes that a beef cow requires 9 LSU to raise a calf to weaning and the analysis is based on the land having a carrying capacity of 9 LSU's per hectare. However, the carrying capacity of land in New Zealand is based on the stock numbers at the 30 June. At the 30 June, there would be no calves except replacements on this type of farm. The LSUs associated with a breeding beef cow vary with weight

[1] http://www.fairfaxindustries.co.nz/stocktake
[2] Paul Goodman, TMC trailers, Personal communication by telephone, 4th November 2016.
[3] https://www.fonterra.com/wps/wcm/connect/5f8c1eed-d06e-4bc2-9412-0ceaec3eb1fe/Clandeboye+Fact+Sheet+2015.pdf?MOD=AJPERES&CACHEID=5f8c1eed-d06e-4bc2-9412-0ceaec3eb1fe

and calving percentages[1] ranging from 3.7 for 400kg cows with 68% calves weaned to 6.3 for 500kg cows with 90% calves weaned. A middle value is 5.3 for 450kg cows with 88% calves weaned.

Let us now consider a herd of 100 cows weighing an average of 450kg each at 30 June. Assuming 15% replacements, this herd will also have 15 weaner calves that have been retained and are approaching their first birthday. There will be a further 15 two year olds but they will have replaced 15 cows in the original herd and so are included in the 100. The 100 cows are equivalent to 530 LSU while the 15 calves are equivalent to 3.5 LSU each or 52.5 LSU. The 100 cows will produce 88 calves that survive to weaning and 15 of these will be retained as replacements so the output is 73 weaner calves. However, the 15 replacement calves that were kept from the previous year will replace 15 cows in the herd. Some of these 15 cows may have died and been disposed of on the farm but most will be sent for slaughter as cull animals and this is also an output. The total LSU for this herd is 582.5. If the average carrying capacity is 9 LSU per hectare, then 64.7 hectares are required to carry this herd. A well-performing beef unit will have a death rate for cows of 2-3%[2]. Thus the output of this herd would be 73 calves and 12 cull cows. If we assume that the calves weigh 200kg and the cull cows weigh 450 kg, the output per hectare over 30 years is (73 x 200 + 12 x 450) x 30 ÷ 64.7 = 9273.6 kg. With a stock truck payload capacity of 21 tonnes, this gives 0.44 outbound truck loads per hectare.

The second type of operation considered is finishing where the farmer acquires the weaner calves and carries them to finishing weight before they are slaughtered. This analysis assumes that it takes two years to bring the stock to finishing weight and assumes that each animal represents 5.5 LSU. However, there are two approaches to finishing beef. The fast approach which takes the animal through to finished weight in one year and the slow approach which takes two years. The fast growth approach is more profitable[3] because, with this approach, 54% of the feed goes to maintaining the animal and thus 46% of the feed goes into growth. With the slow growth approach, 70% of feed goes into maintenance. The fast growth approach requires a stocking rate 4.6-4.7 LSU per animal and achieves a slaughter weight of 500kg+ at 17-20 months of age, that is, within a year of weaning. The slow growth approach requires only 3.7 LSU per animal but can take up to two years after weaning to reach slaughter weight. Assuming 9 LSU per hectare, over a 30 year period the fast growth approach produces (9÷4.7) x 500 x 30 = 28723 kg per hectare. The slow growth approach will produce (9÷3.7) x 500 x (30 ÷ 2) = 18243 kg per hectare. With a stock truck payload capacity of 21 tonnes, these values are equivalent to 1.37 and 0.87 outbound truckloads per hectare respectively.

The third type of pastoral farming considered is sheep farming. The production rates per hectare per year shown for meat and wool are not supported by any references. The NZ Beef and Lamb web-site[4] shows a national average stocking rate of 6.4-6.6 stock units per hectare for all pastoral farms over the last three years so the 6.6 figure used in the analysis is reasonable although there are very large variations in this value around the country. Beef and Lamb NZ[5] gives an average lamb weight of 18.1kg and a value of 19.5kg lamb output per ewe. These are carcass weights and the live weight of the lambs will be more than double this so the 38.5kg per lamb value is reasonable. The per ewe value is higher than the per lamb value because the national average lambing rate is now over 100%. The compendium gives an average wool production rate of 5.2kg/head which is a little higher than the 4.9kg used in the analysis.

Allowing for the lambing percentage, the output of weight of lambs per ewe is 41.5 kg. At 6.6 LSU, the 30 year output of lamb meat per hectare is 8213 kg which is equivalent to 0.39 truckloads. The wool output is 1030kg per hectare. The truck for transporting the wool would have a lower tare weight and could potentially have a payload capacity of 28 tonnes. Thus the wool transport would potentially only require 0.04 truckloads per hectare. Note that, although

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[1] http://www.ruralfind.co.nz/about/rural-data-information/livestock-units/

[2] Steve Morris and Duncan Smeaton (2009). Profitable Farming of Beef Cows. NZ Beef Council.

[3] MPI and Beef and Lamb NZ. Growing cattle fast on pasture.
http://www.beeflambnz.com/Documents/Farm/Growing%20cattle%20fast%20on%20pasture.pdf?__cldee=dGFsbHlAdG90YXJhbnVpc3R1ZC5jby5ueg%3D%3D&urlid=12

[4] http://portal.beeflambnz.com/tools/benchmarking-tool

[5] Beef and Lamb NZ (2016). Compendium of New Zealand Farm Facts.
http://www.beeflambnz.com/Documents/Information/nz-farm-facts-compendium-2016%20Web.pdf

the national average stock carrying rate is 6.6 LSU per hectare, there are large variations in this. A 50% higher stock carrying rate is not unusual and this would generate 50% more truck traffic.

The paper then goes on to consider inbound truck traffic with such things as fuel, fertiliser and replacement stock. It notes that the weight of inward freight can equal or even exceed the weight of outward freight. This is a problematic issue for the RCAs because some of these items are carried on smaller trucks and smaller trucks generate far more pavement wear per unit of freight moved than large trucks. Consider a 44-tonne 8-axle truck and trailer combination with 8 tonnes on the twin-steer axles and 12 tonnes on each of the three tandem axle sets. Fully loaded this vehicle generates 2.31 ESA. As a livestock truck with 21000kg of payload, this vehicle transports 9.09 tonnes of payload per ESA or conversely applies 0.11ESA per tonne of payload.. Now consider a 3-axle rigid truck operating as a fuel tanker for farm deliveries. Fully loaded this vehicle can weigh 21 tonnes with 6 tonnes on the steer axle and 15 tonnes on the drive axles. In this configuration it generates 2.93 ESA. Typically it would have a payload capacity of about 9 tonnes. Thus it transports only 3.07 tonnes per ESA or conversely generates 0.326 ESA per tonne of payload. That is, it generates nearly three times as much pavement wear per unit of payload as the stock truck. Some of inward traffic such as livestock will be similar in character to the outward traffic but other traffic will not. There is no obvious way of breaking this down without an in-depth analysis.

The paper quotes fertiliser application rates of between 0.26 tonnes/hectare and 0.36 tonnes per hectare for various sheep and beef farming configurations. These values are drawn from Statistics New Zealand and are from 2012. I have checked the Statistics New Zealand data and although it is not entirely clear how these values were derived it appears that they took the total weight of fertiliser and lime applied to the particular category of farm and divided this by the number of hectares in grassland or crops on these farms. The problem with this is that for specialised sheep farms, this land area represents a little over half of the total area for these farms. For mixed sheep and beef farms. It is 62% of total land and for specialised beef it is 74% of the total. For dairy farming it is 90% of the total. This raises the question of what “area” are we talking about when we consider the area of the farm for calculating production outputs or fertiliser requirements. If we mean total area, which is the easiest to deal with, then the quoted fertiliser application rates are too high particularly for sheep and beef farming.

The paper then uses data from six farms in one district to estimate the average inward and outward freight flow per hectare. This data is reproduced from a paper by Gribble which is referenced. It states that this is a random sample but strictly speaking this is not the case. It also appears that this data is for a single year and does not necessarily reflect long term averages. The outward traffic is 0.254 tonnes per hectare per annum which gives 7.62 tonnes per hectare over 30 years. This is significantly less than the values calculated for any of three types of pastoral farming above. The key point is that the inward freight volume is nearly as large as the outward freight volume. The largest component of the inward traffic is fertiliser. The number of trucks and the pavement wear implications of fertiliser traffic are highly dependent on the scale of the batches of fertilizer being applied. If we look at the web-site of one the ground-spreading companies[1] we see that 5-tonne batches can be delivered and applied by a 2-axle truck, 7-tonnes batches can be delivered and applied by a 3-axle truck, 10 axle batches can be delivered and applied by a truck and trailer combination while larger quantities can be delivered to a farm-based stockpile using 44-tonne truck and trailer combinations and then spread from there. The 2-axle truck will have a gross mass of between 14.2 and 15.4 tonnes depending on the type of steer axle tyres. Assuming standard tyres and 14.2 tonnes, the vehicle generates 2.52 ESA. Its payload is 5 tonnes and so it generates 0.504 ESA per tonne. This is over 4.5 times as much as a loaded stock truck. The 3-axle truck generates 2.93 ESA and carries 7 tonnes so it generates 0.42 ESA per tonne of payload. Bulk delivery using 44-tonne truck and trailer combinations is much better. The typical combination used is a 7-axle tipper vehicle (3-axle truck and 4-axle trailer) which generates 3.56 ESA. This vehicle would typically have a payload capacity of about 27-28 tonnes which results in 0.127-0.132 ESA per tonne of payload. However, in this case, the fertiliser spreading machinery also has to be driven to the farm and this also generates heavy vehicle traffic.

It is rather odd that they have used the data from six arbitrarily selected farms in one district to determine the baseline freight movements for sheep and beef farms especially as these figures do not align well with their earlier calculations for generic sheep and beef farming operations.

[1] http://www.wealleans.co.nz/gs/groundspreading/

The paper then considers the inward traffic for dairy farming. It quotes a fertiliser application rate of 0.76 tonnes/hectare. The issue of what area this is based on has already been discussed above. If it is total area the figure is too high and should be 0.68 tonnes/hectare. The paper then quotes average rates of supplementary feed purchases at 1.36 tonnes/hectare nationally with regional variations ranging from 0.82 tonnes/hectare to 1.86 tonnes/hectare. This data is referenced as coming from DairyNZ (2014). There are no further details on the source of the data and I have not been able to find this specific data source on DairyNZ's web-site even though this does contain an extensive set of statistical data for the industry.

The paper then states that roughly 20% of dairy farm expenditure is on replacement or winter grazing and feed. This figure is said to come from DairyNZ's 2015 Farm expenditure price index. In fact, the 2013 value is nearly 31%[1] but the cost is irrelevant to this discussion. The paper then goes to say that "In several regions dairy herds are moved to alternative, often distant, pastures for a period of approximately 16 weeks over winter and return in-calf." It then goes on to calculate the traffic associated with this movement and attributes it to all dairy farms. The author of the paper appears to have misunderstood the practice of "wintering off" by dairy farmers. "Wintering off" is strategy used primarily in Southland other colder area as well as in some high rainfall areas. In these areas the grass growth over the winter months is minimal and leaving the cows on the pasture at this time can cause damage to the pasture which affects production when the weather warms up again. Similar pasture damage can occur in high rainfall areas Once the cows have been "dried off", usually in mid-May, some or all of the herd may be moved to alternative grazing. They will normally come back to the milking farm in late July to have their calves on the main milking platform in early August.

DairyNZ describes five production systems for dairy farming with varying level of intensiveness. They range from system 1 where all of the cows are carried on the milking platform and all supplementary feed is grown on the platform to system 5 where over 30% of the feed requirements are bought in. The farms that use "wintering off" are some system 2 farms which are defined as those that purchase 4-14% of total feed. This is considered a low input production system. Thus "wintering off" is associated with low levels of imported feed as well as colder or wetter climates. Only a small proportion of farms use this approach. Farms that use high input production systems with high levels of imported feed do not transport their herds to off-farm grazing.

The calculation of the truck movements generated by dairy farms assume average levels of feed input and "wintering off". This is not realistic.

The paper then goes on to consider the heavy vehicle traffic generated by forestry. It considers both forestry blocks on farms where forestry is not the main activity and standalone forestry blocks. It then says that:

> *"Forestry analysts adopted a representative figure of 660 tonnes per hectare as an average for forestry production in 2003. This appears to adopt a weight of 1.46 tonnes per cubic metre of harvested exotic timber, based on an average harvest of 450 m3/Ha, which is in keeping with internationally accepted conversion factors for green softwood logs."*

These figures are extraordinary. The 660 tonnes/hectare is derived from a report by Frame Group which quoted an average annual production of 22 tonnes/hectare. This would give 660 tonnes over 30 years but it is very unlikely that the tree harvests shown in Table 2 were 30 year-old trees. Certainly a density value of 1.46 tonnes per cubic metre is completely unrealistic for radiata pine. The density of water is 1 tonne per cubic metre. Measurements of radiata pine logs undertaken at Tokoroa in the late 1950s[2] found a density of almost exactly 1 tonne per cubic metre for both saw logs and pulp logs.

The data in Table 2 shows that on 2007, the harvested volume was 449 m^3/hectare while in 2012 it was 523 m^3/hectare. The paper interprets this as showing that the annual harvest per hectare is increasing significantly. Although this may be true these numbers do not of themselves show this. The amount harvested per hectare

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[1] DairyNZ 2014. DairyNZ Economic Survey 2012-13. http://www.dairynz.co.nz/media/566864/economic_survey_2012-13.pdf

[2] F.A. Coulter (1959) Density of Pinus Radiata Logs, New Zealand Journal of Forestry, V8 No 1 pp143-147.

depends on the age of the trees that are harvested and this changes from year to year in response to market conditions. The NEFD gives annual figures for the area harvested, the volume of logs extracted and the average age of the trees at harvesting. From these numbers we can easily calculate the yield of forestry in cubic metres per hectare per annum. Each edition of the NEFD contains harvest data for the current year and the previous year. Table 2 below shows data from the 2009 and 2015 editions of the NEFD. This data does suggest that the yield per hectare has been gradually increasing.

Table 2. Yield data for radiata pine from NEFD.

Year	Area clearfelled (ha)	Volume cleafelled (000 m^3)	Average age (years)	Average yield (m^3/ha/year)
2008	38500	17753	27.9	16.53
2009	37700	18095	28.3	16.96
2014	42896	22331	28.9	18.01
2015	46045	25036	28.4	19.15

The current level is 19.15 m^3 per hectare per annum. Over 30 years this results in 574.5 m^3 per hectare which equals 574.5 tonnes per hectare. This is substantially less that the 769 tonnes per hectare in the paper. Using 44-tonne trucks with a payload of 27.1 tonnes, this represents 21.2 truckloads per hectare over 30 years.

Comparing HCV Traffic Generation

The next section of the paper uses the previous discussion to compare the heavy vehicle traffic associated with pastoral farming to that associated with dairying and forestry. This analysis is flawed. Apart from the issues associated with re-using the incorrect values from the previous section it makes a number of other assumptions which are potentially distorting when considering the pavement wear implications of the traffic generated.

For pastoral farming it uses the truck movement data from the arbitrary set of six farms from one district as the basis for the calculation even though their own analysis of various pastoral farming activities generated significantly higher levels of traffic. Their trip numbers are based on an unrealistic tare weight for stock trucks and thus the payload capacity is significantly less and the number of trips is significantly higher. They then add the weight of the vehicle for the empty trip in the opposite direction to the vehicle weight for loaded trip to give a total traffic loading for the 30-year period in terms of weight per hectare. In the justification for this, they say the "Normal pavement design is based on the heaviest loading in one direction only; taking the total traffic loading is for the comparison of land use demand on the road network between different activities." This is not correct. Normal pavement design is based on the number of equivalent standard axle loads (ESA) that the pavement is expected to be subjected to. This is quite different to gross weight. As shown earlier a 44-tonne 8-axle truck and trailer combination generates about 2.31 ESA. The same combination with a tare weight of 17.5 tonnes generates about 0.27 ESA. These ESA will vary a little depending on the axle group weight distribution assumptions but this effect is quite small. Clearly the pavement wear impact of the empty vehicle is less than 1/8th of that of the loaded vehicle. However adding its weight in to the total traffic implies that its contribution is about 40% of that of the loaded vehicle. The argument applies to all of the land use options not just the pastoral farming.

It is also important to consider the impact of smaller loads. For stock movements, the analysis assumes that these are all undertaken with 44-tonne truck and trailer combinations. As we have shown, a 44-tonnes truck and trailer generates 2.31 ESA and can carry about 21 tonnes of stock. Thus it generates 0.11ESA per tonne of payload when it is loaded. Suppose that the farmer wishes to move a smaller amount of stock and so only the truck is required. A 4-axle stock truck has a gross weight capacity of 25.8 tonnes. The tare of this truck will be 13.5-14 tonnes. Let us assume 13.8 tonnes so that we have a 12 tonne payload capacity. Fully loaded, this vehicle generates 2.69 ESA, i.e. more than 44-tonne truck and trailer combination. With a 12-tonne payload it generates 0.22ESA per tonne of payload. Thus in this example, the pavement wear generated by moving the stock in smaller batches in smaller trucks is double that of using the large trucks to move large batches.

For milk collection, the paper rather strangely calculates the outbound dairy tanker traffic on the basis of full truck loads while it assumes that the inbound tankers are already half full. This is effectively attributing the milk collected from other farms to the freight generated by the farm under consideration. Although milk tankers do undertake some partially laden travel, the distance travelled in this state should be relatively small compared to the distance travelled empty and the distance travelled full. Fonterra uses a sophisticated software system to schedule its milk tanker runs so as to maximise the utilisation of the vehicles. From the DairyNZ statistics we know that the average herd size is 419 cows and that the average cow produces an average of 18.61 litres of milk per day. Thus the average herd produces 7798 litres per day. In the peak of the season the daily production is 27% higher than this while at the end of the season it is 34% lower. With daily milk collection, it only takes 3-4 average herds to fill a milk tanker. The optimum strategy for an individual tanker is to go first to the farm that is furthest away and then to pick up from the other two or three farms on the return journey. To maximise the vehicle utilisation these subsequent farms should be as close as possible to the first farm collected from. Some variation from this “close as possible” strategy may be needed in order to achieve a total tanker load that is as close to the maximum as possible. Furthermore the scheduling system is designed to achieve the best result for the fleet as a whole which may mean that some individual tankers do not have an optimal schedule. Nevertheless, the basic principle is that the tankers will scheduled so as to achieve loads that are as close to the maximum as possible and so that their utilisation is as close to 50% as possible. For practical purposes it is reasonable to estimate the traffic impacts of milk tankers on the basis of an empty inbound trip and a full outbound trip.

The other traffic associated with dairy farming is based on the stock truck movements associated with “wintering off” and these are significant. This practice is only undertaken by a small proportion of dairy farms in particular regions and farmers undertaking this practice generally have lower requirements for bought-in feed. This is not taken into account.

For forestry the main issue with the calculations is the over-estimation of the harvest volume. The analysis indicates 26.7 truckloads where our calculations show 21.2 truckloads. The other issues already raised are around adding together the full and empty truck weights to give a total traffic weight apply to forestry as well as to pastoral farming and dairy farming.

This section finishes with a table comparing the traffic loading generated by the various land uses over 30 years in tonnes per hectare. These figures are gross vehicle tonnes and are meaningless in term of pavement wear. The figures themselves are highly debatable as has already been discussed but the approach is not meaningful either. The final comment says: “It is clear, however, that traditional pastoral farming will generate something like only 1/50th of the total vehicle loading generated by modern dairy farming.” This is far from clear. The heavy vehicle traffic generated by traditional pastoral farming seems to have been substantially under-estimated and the heavy vehicle traffic generated by dairying and forestry has been substantially over-estimated.

In my view we need to establish agreed values of ESA per payload tonne for each important transport activity. These activities would include:

- Stock transport
- Milk collection
- Feed transport
- Fertiliser transport and application
- Fuel transport
- Wool and general freight

Then for each land use activity we can determine the 30-year transport requirements for both outbound and inboard movements in tonnes per hectare. It is then very straightforward to convert these freight requirements into ESA per hectare which is a surrogate for pavement wear.

Determining HCV Traffic Generation from Land Use

The final section describes a process for identifying the HCV traffic generated by a particular land use. Broadly this process is logical and sensible. The main thing that I would add is that, for item 4, I would convert the traffic volume information into ESA rather than gross weights as has been done in the paper.

The other element that is missing from this analysis is distance. A farm that is 1 km from a state highway imposes far less pavement wear cost on the local RCA than an identical farm which is 20 km from the state highway. Differentiating between these two farms in terms of rates or other charges is likely to be very difficult.

The final comment in the paper is:

> *"For most districts the figures adopted for HCV capacities and weights in the preceding sections will be appropriate. The variation from national average figures will be sufficiently minor in some districts to allow the national average figure to be adopted without modification, but this should be done only after establishing the deviation from the average."*

I disagree with this statement. Most of the figures for HCV capacities and weights are demonstrably wrong. It is true that there is relatively little variation from district to district although there is some.

THE IMPACT OF HEAVY VEHICLE TRAFFIC ON ROAD PAVEMENTS

The second paper to be reviewed considers the impact of heavy vehicle on pavements particularly those managed by local road-controlling authorities. Again we will consider this paper section by section.

Background

This section gives an overview of the roading network in New Zealand. There are only two points in this section that require comment. The first is the statement that "Predictions are for HCV traffic on roads to double in the next 10 years". Growth rates of this magnitude were predicted some years ago but over the last 8 years or so the growth rate has been much slower. This is shown in Figure 1 of this report. Currently we are seeing an annual growth rate of about 2% per annum. Over 10 years this would see traffic volumes rise by about 22%. However, this is not necessarily uniform across the country and some districts may well see higher rates of growth.

The second point relates to the comment on High Productivity Motor Vehicles (HPMVs) which is a little misleading. The HPMV legislation has increased the allowable axle group weights for HPMVs but to operate at these weights, the vehicles need a route-specific permit from the RCA involved. Thus local authorities have control over whether or not they allow HPMVs to operate on their roads. The 50MAX HPMVs, which have a wider level of access, do not have increased axle loadings and it can be shown that these generate less pavement wear than the alternative 44 –tonne vehicle.

Consider the 44-tonne 8-axle stock truck example that we have used earlier in this report. It carries 21 tonnes of stock and generates 2.31 ESA. If we convert this to a 50MAX vehicle, the trailer will have 5 axles instead of 4 and the combination will be 23m long instead 20m. The tare weight will increase by about 1.5 tonnes and so at 50 tonnes gross weight it will have a payload capacity of 25.5 tonnes. If we assume that the truck is unchanged and so all the additional weight is in the trailer, then this vehicle will generate 2.64 ESA which is 0.10 ESA per tonne of payload. This compares with 0.11 ESA per tonne for the 44-tonne 8-axle combination. Thus 50MAX trucks reduce the number of truck trips needed to move a given amount of freight and reduce the amount of pavement wear generated. Note that this only works because of the extra axle on the 50MAX truck. Using instead an 8-axle truck operating at 50 tonnes would reduce the amount of truck traffic but it would increase the amount of pavement wear.

The function of road pavements

No comments.

Characteristics of New Zealand roads

In the fourth paragraph of this section there is a comment that "Pavement wear caused by the passage of HCV traffic depends not only on the gross of the vehicle but also on the distribution…" In fact the pavement wear does not directly depend on the gross weight of the vehicle at all. It depends only on the axle loads, axle configurations and tyres as described.

In paragraph 6 it says:

> *"Anecdotal evidence also indicates that the rate of pavement deterioration and the road maintenance costs increase with increased repetitions of axle loads on a road pavement and increased axle loads imposed by HCV traffic."*

This comment is referenced to an Austroads report AP-T216-13. However, it misquotes it. The Austroads report does not say that the rate of pavement deterioration increases with increased repetitions of axle loads. It does say that it increases with increased axle loads. This is an important distinction. This analysis is based on increased traffic volumes not increased axle loads.

Road pavement design

This section describes the design approach for pavements and the concept of Equivalent Standard Axles (ESA) for quantifying the impact of different truck axle configurations. It then tabulates the ESA for various commodities in New Zealand as reported in Transfund NZ Research Report 185, Methods to Establish Design Traffic Loading" (RR185), which was written by Bartley Consultants and published in 2000. The main method used by Bartley consultants was to analyse the data records from four Weigh-in-Motion (WIM) sites operated by Transit New Zealand (now the New Zealand Transport Agency). Video recording o the vehicles passed the WIM stations were used to identify the freight types. For cross-checking a further survey was undertaken at the Plimmerton weigh station. This found lower ESA values than the WIM-based survey.

It appears from the gross weight data shown in RR185 that there was a considerable level of overloading occurring at this time, or that the WIM systems were reading high. For logs, it is particularly notable that the Tokoroa site had significantly higher readings than the other three sites for both laden and unladen vehicles. The laden vehicles could be explained by a culture more overloading occurring in that district but this does not explain the higher values for the empty vehicles.

The apparently high ESA value for logs compared to other commodities can be largely explained by the fact that the logging trucks operate either fully laden or empty and the analysis was able to separate the two cases. For other commodities all load states were combined into one overall average. If we combine the laden and empty ESA values for logs and take an average we get 3.29. This is a little higher than milk which is 2.65 but not excessively so. However, the overall ESA values, as averages for all states of load, are high for both logs and milk. The livestock value on the other hand is surprisingly low. The axle data in RR185 shows that the most logging trucks (60%) were 7-axle combinations and this will go some way to explaining the higher ESA level. No axle data is given for milk trucks or stock trucks because the numbers of these vehicles were much smaller. Note that this study was undertaken over 16 years ago and there have been some changes to the vehicle configurations used since. Certainly in logging 8-axle combinations have become more prevalent.

Road pavement wear effects of heavy vehicle traffic

No comments.

Determining the impact of heavy vehicle traffic alternative loadings

Asset management is outside of my area of expertise. It seems to me that using a 5% increase in ESA as a trigger for a pavement impact assessment is very conservative. I would be very surprised in their forecasting tools were accurate to anything like 5% but I am not qualified to comment.

Assessing the Impacts of HCV Traffic Loading on Road Pavements

Again the procedure described this section seems reasonable but asset management is not something that I have any real experience of. Again the 5% increase in ESA is used as trigger which seems quite low to me. In general the ESA applied to a pavement is not known to 5% accuracy. There are traffic counts which can identify how much truck traffic occurs on the road but the axle loadings and weights are usually not known and average values based on WIM sites elsewhere are used to infer these. The WIM measurements themselves are only expected to be accurate to 5% and the associated error in ESA is then over 20%.

Pavement Wear Calculations

Again this is outside of my area of expertise.

SUMMARY

This review has considered two papers prepared for the RCA forum. The first paper entitled ”Land use and transport demand comparison” considers the heavy vehicle traffic generated in rural areas by different land uses; in particular, pastoral agriculture, dairy farming and forestry.

The fundamental approach which is reiterated in section 1.5 of the paper is logical and makes sense. There are, however, a number of issues with how the methodology has been applied in the paper. The most fundamental one is that the paper quantifies heavy vehicle traffic on the basis of gross vehicle weight per hectare. The primary reason for attempting to quantify the heavy vehicle traffic associated with different land uses is to determine the pavement wear implications and hence the future roading costs. However, pavement wear does not directly depend on gross vehicle weight, it depends on the axle loadings and configurations. Thus in my view the heavy vehicle traffic for different land uses should be quantified in terms of ESA per hectare rather than gross tonnes per hectare.

At the detail level there are a number of other issues with this paper. The vehicle tare weights and hence payload capacity of the vehicles considered for different transport tasks are not realistic. This is particularly true for stock trucks but the log truck and dairy tanker values are also not correct. For pastoral farming, the paper quotes some national average values for output and input data which it then ignores in favour of some data from six farms in one district which appear to have relatively low freight demands compared to the national average figures. For dairying it uses a mixture of production models which have higher transport demands than are typical and for forestry it uses unrealistically high output values. The overall effect is that it exaggerates the difference in heavy vehicle traffic generated by the different land uses although there is no doubt that dairying and forestry generate more heavy vehicle traffic than sheep and beef farming.

A variation of the methodology would work to determine the traffic loading impacts of different land uses in a transparent way. In my view we need to determine a set of universally agreed values for ESA per tonne of payload for different freight tasks. Thus, there would be values for:

- milk collection by tanker
- log harvesting
- large scale stock transport
- small scale stock transport
- large scale fertiliser application
- small scale fertiliser application
- Stock feed delivery, etc.

Then applying the methodology described in section 1.5 of the paper, local values for inputs and output in tonnes per hectare would be determined and these can then be converted to ESA per hectare using the factors above.

The second paper was entitled “The impact of heavy vehicle traffic on road pavements”. The first part of this paper is a basic overview of pavement design theory and practice in New Zealand. The one area where there may be some contention is Table 2 which shows ESA values for some freight commodities. This data comes from a study undertaken by Bartley Consultants in the late 1990s which used data from four WIM stations operated by Transit New Zealand (now the New Zealand Transport Agency). The WIM data did show a significant level of overloading and, rather interestingly, some quite large differences between WIM sites for some commodities. There have been some changes to the mix of vehicle configurations used for some of these freight tasks since the study was done which would have an effect. More importantly for many of the commodities we don’t know how much payload the vehicles were carrying and so we can’t determine ESA per tonne of payload from this data.

The rest of the paper considers asset management techniques for determining the impact of changes in traffic loading and the future cost of these. This is outside of my area of expertise and I have little comment to make. The one point that I found surprising was the 5% increase in ESA as a trigger level for needing a review. Because ESA is based on the fourth power of weight a 1.2% increase in weight will generate a 5% increase in ESA. On a 44-tonne truck this is only

540kg. The gross vehicle weight changes proposed in the VDAM Rule review are likely to have an effect of this order of magnitude. In my view, the actual level of ESA applied currently by the heavy vehicle fleet is not known to within 5% accuracy. The variability in pavement materials and construction quality is also greater than 5%. In section 1.4 the author notes that pavements are typically designed with a 25 year life. A 5% variation on this is just over 1 year. There are many pavements around the country that are considerably more than 25 years old and have experienced far more traffic loading than they were designed for. They have, of course, needed maintenance but they have not failed. The 5% value originates from a Queensland Government Department of Transport and Main Roads document entitled “Guidelines for the Assessment of Road Impacts of Developments.” I have checked this source and it is correct.

APPENDIX I

1. LAND USE AND TRANSPORT DEMAND COMPARISON

1.1 Background

The New Zealand Business Growth Agenda includes six policy areas that the Government considers will make a significant impact on national business performance: export markets, innovation, skilled and safe workplaces, resources, infrastructure and capital markets.

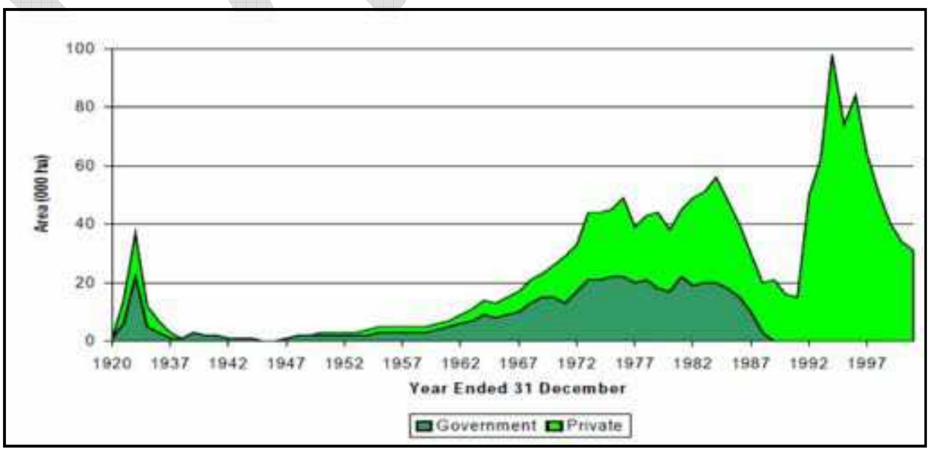
Government policy seeks to increase the ratio of exports to GDP to 40 per cent by 2025. The primary industries currently earn 71 cents in every dollar of merchandise export earnings. The goal is to double primary industry exports in real terms from $32 billion in June 2012 to $64 billion by 2025. To achieve this, New Zealand's primary industries must sustain an average growth rate of 5.5% a year through to 2025. As the value of primary industry exports is determined by the international markets, and there is no reason to foresee a doubling of value for these in real terms by 2025, it is reasonable to expect that the freight task supporting this growth in exports must grow proportionately.

1.2 Primary Sector trends

An example of the changing freight task is the onset of significant forest harvest of the North Island woodlot. These plantations coming to harvest in the next decade were planted in response to Government economic policies and financial assistance regimes in the 1990's

Figure 1 shows annual new planting of exotic forest by government and private landowners over the period from 1920 to 1997 and clearly shows the spike in planting between 1992 and 1997. These trees will be due for harvest over the next decade.

Figure 1 Annual Government and Private New Planting of Exotic Forest (1920-1997)[1]



[1] After MAF 2002, Discussion Paper No. 45, Development of Plantation Forest Resources in New Zealand

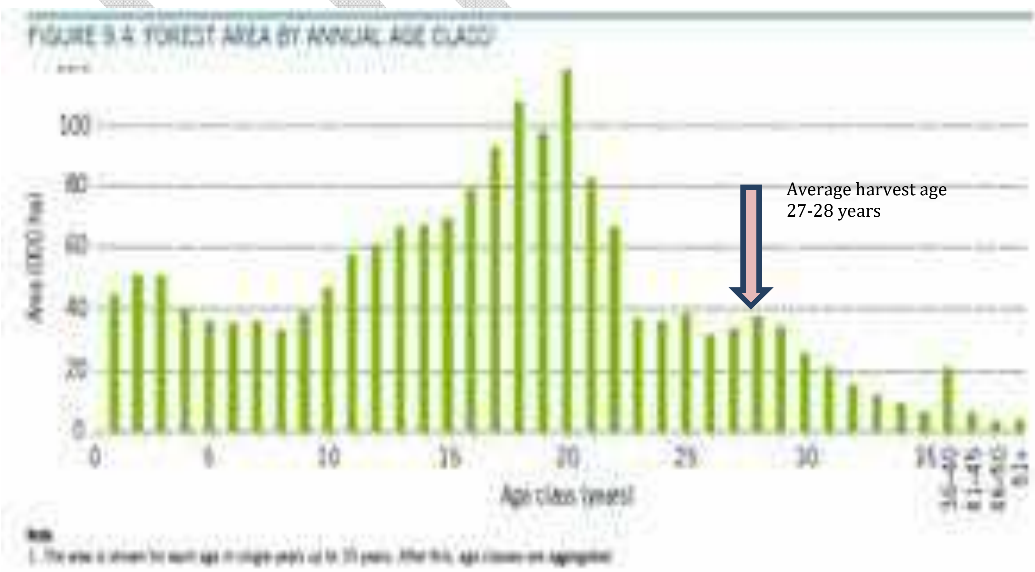
The majority of new planting through the 1990s was undertaken by a variety of small-scale investors, rather than the government or major forestry companies. Today, 91 percent of the plantation forest resource is in private ownership and the plantation forest estate contributes 99.7 percent of New Zealand's total wood harvest.[2]

The National Exotic Forest Description[1] shows that there has already been a 145% increase in forestry harvesting over the quarter century since 1990. This can be seen in Figure 2.

Figure 2 Forest Harvest Volumes (1990-2014)

Very little of the forest planted since 1991 will have yet been harvested. The average age at harvest is 27 or 28 years. The published age class data for New Zealand forestry indicates that the volume of wood available for harvest will increase almost exponentially from less than 40,000 Ha in 2020 to almost 120,000 Ha in 2023, before declining steadily to return to current levels by 2035. This is shown in Figure 3.

Figure 3 Exotic Forest Area by Annual Age Class (2014)



[1] h National Exotic Forest Description as at 1 April 2014, MPIps://www.mpi.govt.nz/document-vault/4948

Timber companies will harvest at different ages and vary their plans according to the state of the market and their capacity to harvest, process or export the rapidly increasing supply of product. Wood availability forecasts explore a number of scenarios for harvesting.

Some forests have been planted with harvesting transport needs in mind, close to state highways or in ways that limit the impact on local roads. Other blocks are located in relatively isolated areas and in steep hill country with road access suitable only for light vehicles. Upgrading of these roads will be needed to cater for the weight and size of logging trucks.

The other significant change in the primary sector over the same period that has had implications for rural road controlling authorities has been the conversion of pastoral farms to dairying. Between 1985 and 2015 some 737,964 Ha of pastoral farm land was converted to dairying and the national dairy herd increased 116% from 2,321,012 cows to 5,018,333 cows. Figure 4 shows the increase in milk production from 5,868 million litres in 1980/81 to 21,253 million litres in 2014/15.[1]

Figure 4 New Zealand Milk Production (1980-2015)

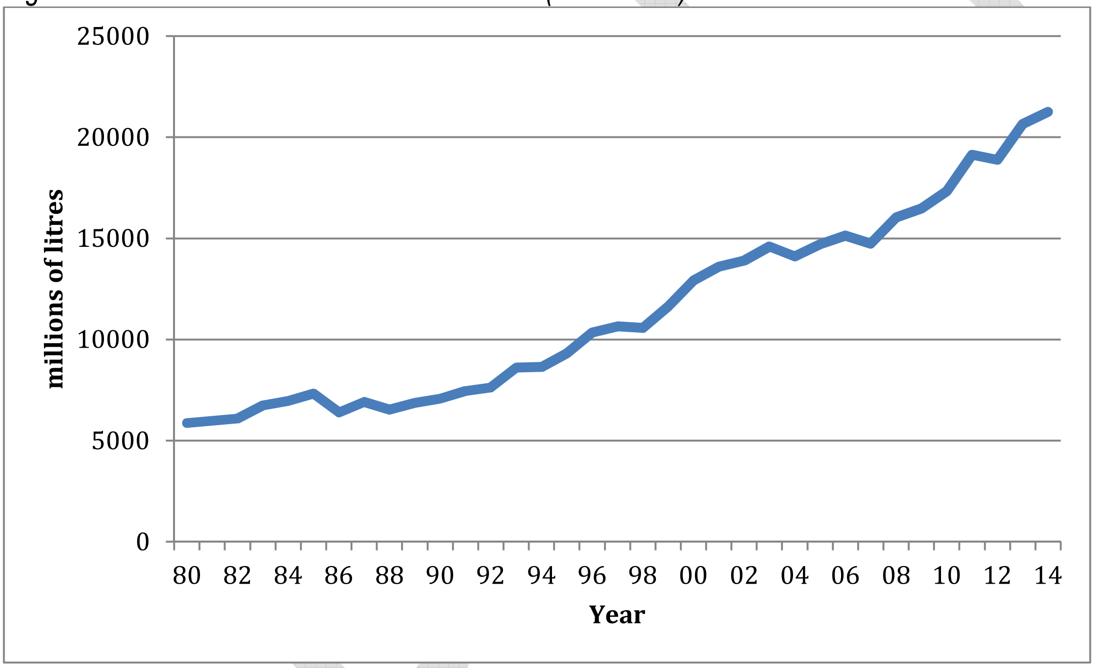


Figure 5 shows the dramatic increase in the price paid for milk solids in the 2007 year and the sustained historically high prices paid over the next six years.

[1] New Zealand Dairy Statistics 2014-15 Table 2.1 and Table 2.2

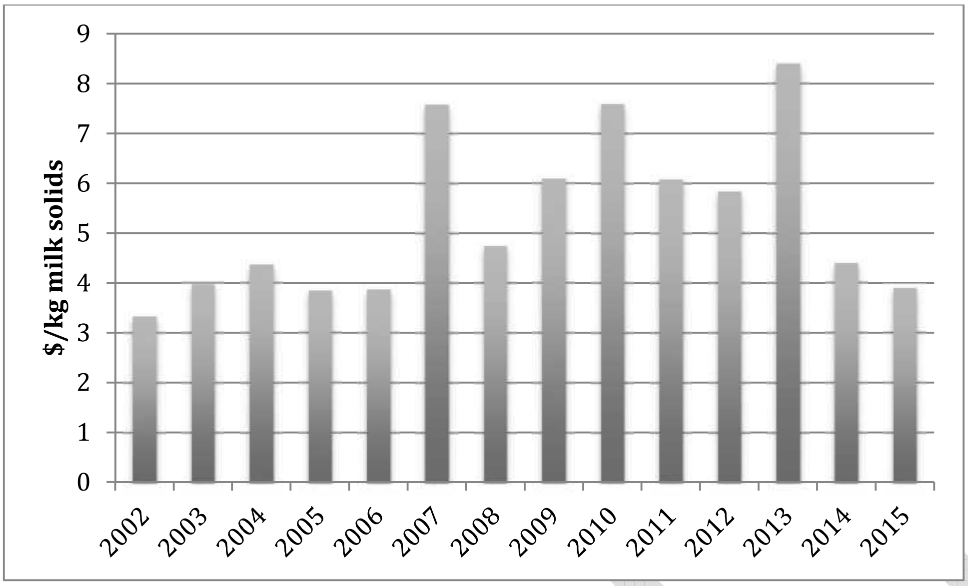


Figure 5 Fonterra Milk Price (2002-16)

1.3 Land use correlation with heavy commercial vehicle traffic

The productivity per hectare from rural land uses and the associated pavement loading from heavy vehicles varies significantly between sectors, and varies between regions. The productivity per hectare can be determined for different farming sectors. For example, New Zealand Dairy Statistics suggest a national average number of dairy cows per hectare is 3.2 and the average milk production is 3930 litres per cow per year.[1] Some regions will have lower carrying rates and lower productivity; others will have higher rates.[2] For this national average, production of approximately 12.576 tonnes per hectare per year is expected. Each tanker can carry a maximum of 26,300 litres of milk, or 26.3 tonnes. Based on these numbers, for a 30 year period, 14.35 outward tanker trips are generated per hectare by dairy production:

3.2 × 3930 × 30 ÷ 26300 = 14.345.

Variations in stocking rates and milk production between regions and districts will affect the number of outward tanker trips on local roads, with a likely range between 10.7 and 16.3 outward tanker trips per hectare over a 30 year period.

Pastoral farming can involve a wide range of activities: sheep, mixed sheep and beef, beef for finishing and for store livestock, deer and other exotics. A means of expressing the carrying capacity of a farm in a unit with a standard value across all of these potential activities was developed between 1965 and 1994. Most countries now use live-stock units per hectare (or acre) to express pastoral productivity. These units vary in basis and equivalent weight between countries. In New Zealand the live-stock unit is the ewe equivalent system. It expresses the annual feed requirements required for one ewe rearing a single lamb. The base assumption is that a ewe weighing 55 kg at mating and raising a single lamb to weaning at 25 kg will require approximately 520 kg of good quality pasture dry matter per year. This is 1.0 LSU.

If a district has a stocking rate on average of 9 LSU per hectare, it produces in an average year sufficient good quality pasture dry matter for nine 55 kg ewes to each rear a single lamb to weaning. Over a period of 30 years

[1] DairyNZ 2014: average for all North Island is 3.05; for upper South Island, 3.48; and lower South Island, 3.28.

[2] Central North Island average is 2.53 cows per Ha and average production of 3710L per cow p.a.

a hectare with an average stocking rate of 9 LSU would produce about 140.4 tonnes of pasture dry matter, which may be expressed as equivalent to 270 LSU.

Complex tables of equivalency have been developed for differing breeds, types, ages and weights. A weaner beef heifer is 3.5 LSU and a weaner steer is 4.5 LSU.

Assuming one beef cow requires nine live-stock units to raise a calf to weaning, a hectare with an average productivity of 9 LSU would carry 1.0 cow with calf. Over 30 years 270 LSU could support 30 cows raising 30 calves to weaning weight (135 - 270 kg) within that period. If 15 percent of the weaners were retained as replacements[1] and the rest were sold at an average weight of 200 kg, that hectare would generate about 5 tonnes of produce over 30 years:

$$30 - (0.15 \times 30) \times 200 = 5100$$

If those weaners were placed on pasture with a similar stocking rate for finishing, a hectare with an average productivity of 9 LSU would carry 1.636 cattle to finishing weight. Assuming a two year finishing period and sale weights of 450 kg, over a 30 year period about 11 tonnes of finished beef would be sent to the freezing works per hectare: $1.636 \times (30 \div 2) \times 450 = 11045$

Assuming a full stock truck and trailer carries 28.8 tonnes, the hectare in the first example generates 0.18 outward truck movements over 30 years. The hectare in the second example generates 0.38 outward truck movements over 30 years.

Stocking rates vary for sheep farming, but average rates between 150 kg and 260 kg of liveweight per hectare per year and 28 kg to 36 kg of wool clip per hectare per year can be adopted. Assuming an average live weight of 38.5 kg for each lamb and 4.9 kg for each fleece implies that one hectare with an average stocking-rate of 6.6 live-stock units per hectare produces 254.1 kg of live weight lamb per year as well as 32.3 kg of wool.

Over 30 years one hectare with a relatively high stocking-rate for sheep farming would produce 7.6 tonnes of lamb live weight and 970 kg of wool, and generate 0.3 outward truck movements: $6.6 \times (38.5 + 4.9) \times 30 \div 28800 = 0.298$.

In addition to their outward production, however, farms have inwards movements of fuel, fertiliser, and replacement or finishing stock. This traffic can equal or exceed the outwards freight weight in some instances.

The carrying rate of the land, mix of stock carried and individual farming practices can cause significant variations in the freight load generated by farms even within the same sector. This can include variables such as the rates at which fertiliser is applied.

Nationally, mixed sheep and beef farming applies fertiliser and lime at an average rate of 0.26 T/Ha, while specialised sheep or beef farms apply fertiliser at rates of 0.33 T/Ha and 0.36 T/Ha respectively.[2] Even within the same farming activities, however, the rates of application can vary dramatically. In the small sample shown in Table 2 the rates of application range between 0.06 T/Ha and 0.233 T/Ha within the same district.

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[1] Replacements in beef herds average 14 to 16 percent; in dairy herds 24 to 26 percent. Waikato Regional Council.

[2] Statistics NZ, *Fertiliser and lime applied by farm type; Agricultural areas in hectares by farm type; Year to 31.03.2012*

A random sample of farm production data from mixed sheep and beef farms implies these inwards freight movements contribute significantly to the total movement of mass per hectare per year for such farms.[1]

An analysis of the reported productivity of the six mixed sheep and beef farms in one district used in the sample is reproduced in Table 1.

Table 1 Reported farm productivity values for six combined sheep and beef farms

Farm	1	2	3	4	5	6
Land area (Ha)	1800	650	400	1470	1500	1200
Outwards (tonnes)						
Wool	43.00	21.00	18.00	51.75	51.00	22.32
Cattle	52.50		2.20	1.45	122.00	111.40
Sheep	221.00	103.25	127.92	342.00	270.00	133.60
Total outwards (T)	*316.50*	*124.25*	*148.12*	*395.20*	*443.00*	*267.32*
Total outwards /Ha (T)	*0.176*	*0.191*	*0.370*	*0.269*	*0.295*	*0.223*
Total out /Ha in 30 yrs (T)	*5.28*	*5.73*	*11.10*	*8.07*	*8.85*	*6.69*
Inwards (tonnes)						
Live-stock	85.00	108.00	36.04	64.80	69.00	2.08
Fertiliser	380.00	40.00	58.00	342.00	220.00	120.00
Fuel	6.00	3.60	6.00			10.10
Total inwards (T)	*471.00*	*151.60*	*100.04*	*406.80*	*289.00*	*132.18*
Total inwards /Ha (T)	*0.262*	*0.233*	*0.251*	*0.277*	*0.193*	*0.110*
Total in /Ha in 30 yrs (T)	*7.86*	*6.99*	*7.53*	*8.31*	*5.79*	*3.30*
Total in and out (T)	787.50	275.85	248.16	802.00	732.00	399.50
Inwards as % of Total	59.81	54.96	40.31	50.72	39.48	33.09
Total /Ha (T)	0.438	0.424	0.620	0.546	0.488	0.333
Total /Ha in 30 years (T)	13.14	12.72	18.60	16.38	14.64	9.99

Adopting a figure of 0.254 tonnes per hectare per annum for outwards freight and 0.221 tonnes per hectare for inwards freight, traditional sheep and beef pastoral farming would yield a total inwards and outwards freight productivity over a 30 year period of 14.25 tonnes per hectare, which equates to 0.5 truck movements: *(0.254 + 0.221) × 30 ÷ 28.8 = 0.49*.

By comparison with sheep and beef farming, dairying is a significantly more intensive land use. Stocking rates are higher and other inputs tend to be proportionately higher as a result. The national average application rate for lime and fertiliser on dairy farms, for example, is 0.76 T/Ha.[2] Dairy farms also tend to buy in supplementary feed, such as silage or palm kernels. Bought feed averages 1.36 T/Ha nationally, ranging between 0.82 T/Ha in the lower North Island and 1.86 T/Ha in the upper South Island.[3] Over a 30 year period the average input for fertiliser, lime and supplementary feed on a dairy farm amounts to 63.6 tonnes:

(0.76 + 1.36) × 30 = 63.6.

A significant difference between dairying and other pastoral farming is that roughly 20% of dairy farm expenditure is on replacement or winter grazing and feed.[4] Providing replacement and winter grazing can represent more

[1] After Gribble, M. *Logging trucks on local roads – is forestry really having an unreasonable impact? (2011)*

[2] Statistics NZ, *Fertiliser and lime applied by farm type; Agricultural areas in hectares by farm type; Year to 31.03.2012*

[3] DairyNZ 2014: averages: upper North Is, 1.66; lower North Is, 0.82; upper South Is, 1.86; lower South Is, 1.10.

[4] DairyNZ 2015: *Farm expenditure price index 2009-2012*

than 80% of this expense.[1] In several regions dairy herds are moved to alternative, often distant, pastures for a period of approximately 16 weeks over winter and return in-calf.

Using the average dairy stocking rate of 3.2 cows per hectare and assuming the average cow going onto winter grazing weighs about 450 kg, the outward movement to winter grazing represents 1.44 T/Ha. Assuming the average cow returning from winter grazing weighs about 475 kg, the return movement from winter grazing represents 1.52 T/Ha. The annual movement to and from winter grazing adds 2.96 T/Ha to the impact of dairying on local roads. Over a 30 year period this amounts to 88.8 tonnes: *3.2 × (0.450 + 0.475) × 30 = 88.8*.

So a dairy farm with milk production of approximately 12.576 tonnes per hectare per year, and generating 14.35 outward tanker trips per hectare over a 30 year period, will also generate another 3.64 tonnes per hectare per year of inward freight movements and 1.44 tonnes of outward freight movements. Over a 30 year period this amounts to 152.4 tonnes per hectare or 5.3 truck movements: *(0.76 + 1.36 + 1.44 + 1.52) × 30 ÷ 28.8 = 5.29*.

Sheep, beef and dairy farms also harvest significant volumes of exotic forestry. In the year ending 31 March 2007, 1,380,565 m^3 was harvested from farmland and this rose to 1,671,566 m^3 in the year ending 31 March 2012.[2] Details of this production are shown in Table 2.

Table 2 Forestry production by farm type[3]

	Year to 31 March 2007			Year to 31 March 2012		
Land use	*Ha*	*Harvest m^3*	*m^3/Ha*	*Ha*	*Harvest m^3*	*m^3/Ha*
Sheep	629	275200	437.52	1126	536392	476.37
Beef	706	310551	439.87	628	275887	439.31
Sheep/beef	866	361356	417.27	932	475998	510.73
Dairy	1079	433458	401.72	822	383289	466.29
Forestry	37239	16798052	451.09	44376	23369522	526.63
See Note 1	40519	18178617	448.84	47884	25041088	523.36

Note 1: For *Ha* and *Harvest (m^3)* the total is the sum of the individual land use figures; for *m^3/Ha* the weighted average is based on the percentile contribution of each land use to the total harvest.

Forestry analysts adopted a representative figure of 660 tonnes per hectare as an average for forestry production in 2003.[4] This appears to adopt a weight of 1.46' tonnes per cubic metre of harvested exotic timber, based on an average harvest of 450 m^3/Ha, which is in keeping with internationally accepted conversion factors for green softwood logs. Assuming a 30 year harvest period and that each truck carries 28.8 tonnes, one hectare of exotic forestry over 30 years would therefore generate 22.9 truck movements: *660 ÷ 28.8 = 22.92*.

As Table 2 indicates, however, the average harvest per hectare has increased substantially. The forestry production statistics indicate a significant improvement in the harvest per hectare for all land uses, except from specialist beef farms. The weighted average harvest has increased by 74.52 m^3/Ha. This suggests that the harvest in tonnes has increased by 109.29 tonnes between 2007 and 2012: *74.52 × 1.4666 = 109.291*.

On the basis of the updated national data, a representative figure for average forestry production in 2012 was 769 tonnes per hectare. Assuming a 30 year harvest period and that each truck carries 28.8 tonnes, one hectare of exotic forest harvested now should generate 26.7 outward truck movements: *(660 + 109.29) ÷ 28.8 = 26.71*.

[1] South Island Dairy Development Centre, Lincoln University, *Financials to year end March 2015*

[2] Statistics NZ, *Forestry production and planting by farm type, Year to 31.03.2007 and Year to 31.03.2012*

[3] Statistics NZ, *Forestry production and planting by farm type, Year to 31.03.2007 and Year to 31.03.2012*

[4] Frame Group, 2003, 22 T/Ha for averaged annual production

In Table 3 the forestry production for the land uses listed in Table 2 has been extended to give the estimated tonnage per hectare and number of trucks required.

Table 3 *Forestry production by farm type*[1]

	Year to 31 March 2012				
Land use	*Ha*	*Harvest m^3*	*m^3/Ha*	*T/Ha*	*Trucks*
Sheep	1126	536392	476.37	698.64	24.26
Beef	628	275887	439.31	644.29	22.37
Sheep/beef	932	475998	510.73	749.04	26.01
Dairy	822	383289	466.29	683.86	23.75
Forestry	44376	23369522	526.63	772.36	26.82
See Note 1	47884	25041088	523.36	767.56	26.65

Note 1: For *Ha* and *Harvest (m^3)* the total is the sum of the individual land use figures; for *m^3/Ha* the weighted average is based on the percentile contribution of each land use to the total harvest; for *T/Ha* the total is the weighted average *m^3/Ha* multiplied by the conversion factor of 1.46'.

1.4 Comparing HCV Traffic Generation

It is possible to compare the land use traffic loading associated with pastoral farming activities over a 30 year cycle with the traffic loading from dairying or forestry. Sheep and beef farms generate 0.5 truck movements per hectare. Assuming a full truck weighs 44 tonnes and an empty stock truck weighs 17.5 tonnes, the total traffic loading over a 30 year period would be 29.2 tonnes per hectare:[2] *0.254 × (44 + 17.5) + 0.221 × (44 + 17.5) = 29.21*.

For dairying, a dairy tanker will fill progressively as it travels out from, and returns to, the milk factory, so the applied load will vary between 17.7 tonnes for an empty tanker and potentially 40 tonnes for one almost full. If a dairy farm sends out 14.35 full tankers per hectare, the outward traffic loading over a 30 year period would be 631.4 tonnes per hectare. Adopting an average weight of 28 tonnes for an incoming tanker, the inward traffic loading over a 30 year period would be 401.8 tonnes per hectare.

Assuming an empty weight of 17.5 tonnes for stock trucks and 15.5 tonnes for empty stock feed and fertiliser trucks, rotating stock to and from winter grazing and bringing in feed and fertiliser generates additional traffic loading of 338 tonnes per hectare over 30 years:

(0.76 + 1.36) × 30 ÷ 28.8 = 2.21	*2.21 × (44 + 15.5) = 131.50*
1.73 × 30 ÷ 28.8 = 1.80	*1.80 × (44 + 17.5) = 110.70*
1.50 × 30 ÷ 28.8 = 1.56	*1.56 × (44 + 17.5) = 95.94*
	338.14

For forestry, if an inwards traffic loading of 17.5 tonnes for an empty logging truck carrying jinkers is adopted, the total traffic loading over a 30 year harvest cycle would be 1642 tonnes per hectare, based on 26.7 outward loads of 44 tonnes and 26.7 inward loads of 17.5 tonnes.

[1] Statistics NZ, *Forestry production and planting by farm type, Year to 31.03.2007 and Year to 31.03.2012*

[2] Normal pavement design is based on the heaviest loading in one direction only; taking the total traffic loading is for the comparison of land use demand on the road network between different activities.

The different traffic loadings from these different uses of rural land over 30 years (equivalent to one forest harvest cycle) are summarised in Table 4.

Table 4 Traffic loading generated by various rural land uses over 30 years (T per Ha)

Land use	Outwards	Inwards	Totals
Pastoral	15.6	13.6	29.2
Dairy	876.4	494.9	1371.3
Forestry	1174.8	467.25	1642.1

The actual district production values need to be used to calculate the contribution of each industry to the vehicle loading on the road. It cannot be simply assumed that forestry yield is twenty percent greater than that of dairy, therefore the damage generated is only twenty percent greater. It is clear, however, that traditional pastoral farming will generate something like only 1/50th of the total vehicle loading generated by modern dairy farming.

1.5 Determining HCV Traffic Generation from Land Use

The following steps outline the process described in the previous sections for identifying the HCV traffic generated by a particular land use:

1. Identify the Land Use or Activity ie forestry, quarrying, dairying, dry-stock beef farming, stock finishing, sheep, etc.

2. Determine the average productivity per hectare for that land use.
   - Regional or local stocking rates
   - Local milk production statistics
   - Local beef, sheep, wool production statistics
   - Local forest harvest statistics or quarry statistics

3. Determine the average farm input values per hectare.
   - Regional or local fertiliser or lime application rates
   - Regional or local statistics for restocking rates
   - Regional or local statistics for feed supplement use
   - Regional or local statistics for fuel, fencing, etc

4. Determine the HCV traffic generated by the established land uses.
   - List the types and number of HCV traffic generated by land uses.

5. Determine the comparison period to be used to compare the HCV traffic generated by differing land uses.
   - One forest harvest cycle is recommended.

For most districts the figures adopted for HCV capacities and weights in the preceding sections will be appropriate. The variation from national average figures will be sufficiently minor in some districts to allow the national average figure to be adopted without modification, but this should be done only after establishing the deviation from the average.

APPENDIXII

1 THE IMPACT OF HEAVY VEHICLE TRAFFIC ON ROAD PAVEMENTS

1.1 Background

The road network in NZ compromises approximately 95,100 km of roads. About 12.5 % or 11,900 km of these roads are State Highways managed by NZTA. State highways generally carry higher traffic volumes and are constructed and maintained to higher design standards.

The remaining 83,200 km of roads are managed by Local Authorities. These roads carry lower volumes of traffic and accordingly they are designed to lower design standards.

New Zealand and Australia have led the world for many years in the design and management of low cost road pavements. This has allowed sealed road access to areas which would otherwise be serviced by unsealed gravel roads. Nevertheless, approximately 40 % or 38,000 km of roads are unsealed gravel roads In New Zealand. The majority of these are local roads.

One of the largest challenges facing Local Authorities is the rapidly growing amount of heavy commercial vehicle (HCV) traffic being carried on the roads which were not designed to carry this increase in traffic. Predictions are for HCV traffic on roads to double in the next 10 years. This is a result of increased heavy traffic-generating activities, such as forestry, quarries, landfills or dairy farming.

Additionally there has been an increase in the allowable weight that HCV can carry with the introduction of High Productivity Motor Vehicles (HPMV). This has in turn resulted in increased axle loadings on the road pavements.

Road Controlling Authorities are being faced with the need to make predictions of the impact of increased HCV traffic on their road networks and the funding required to maintain and upgrade the road networks to cope with this increasing demand.

1.2 The Function of Road Pavements

The road pavement must serve two basic functions: it must perform structurally and at the same time meet functional and operational requirements.

In terms of structural performance, it must be strong enough to support the axle loading from the heaviest vehicles (HCV traffic) using the road and the cumulative effects of the passage of these vehicles on the road. The surface must also be capable of resisting stresses imposed by axle loading in order to maintain its structural integrity. If a road surface is damaged and cracked by heavy axle loads, water can enter the underlying pavement layers, which weakens the pavement and can result in premature failure.

In terms of functional and operational performance, the road pavement must be wide enough and of suitable geometry to permit all vehicles to safely operate at an acceptable speed. The pavement must have a surface which has adequate strength, drainage, skid resistance, and visual delineation to ensure safe travel.

1.3 Characteristics of New Zealand Roads

The majority of New Zealand roads comprise either granular pavement layers with a thin chip seal or asphalt surface or unsealed gravel roads which have been built up over time. These have been designed and maintained to carry the loading imposed by the historically forecast traffic.

Chipseal surfaces are not considered to contribute structurally to pavement strength; however, an intact chipseal surface prevents the ingress of water into a pavement, with water having a negative impact on pavement performance, particularly the subgrade.

Research since the 1960's by AASHTO, ARRB, Austroads and the NZ Transport Agency has shown that pavement deterioration of granular pavements is a function of the axle load applied to the pavement, the number of axle loads applied (expressed as Cycles) and the strength of the road pavement.[1]

This relationship between the load and the pavement structure is the key determinant of the rate of pavement wear. Pavement wear caused by the passage of HCV traffic depends not only on the gross weight of the vehicle but also on the distribution of the vehicle weight onto the pavement. In particular it depends on:

- The number of axles on the vehicle
- The manner in which these axles and their wheels are configured into axle groups
- The loading applied to the pavement through each of these axle groups – the axle group load and the contact stress (governed by tyre size and pressure).

Figure 1 below shows the dispersion of the wheel load from a vehicle axle onto the underlying pavement and the imposed stress on the pavement layers.

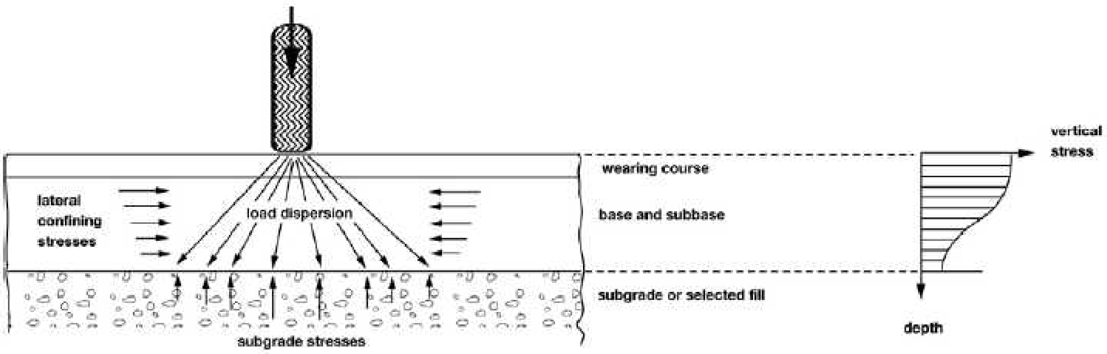


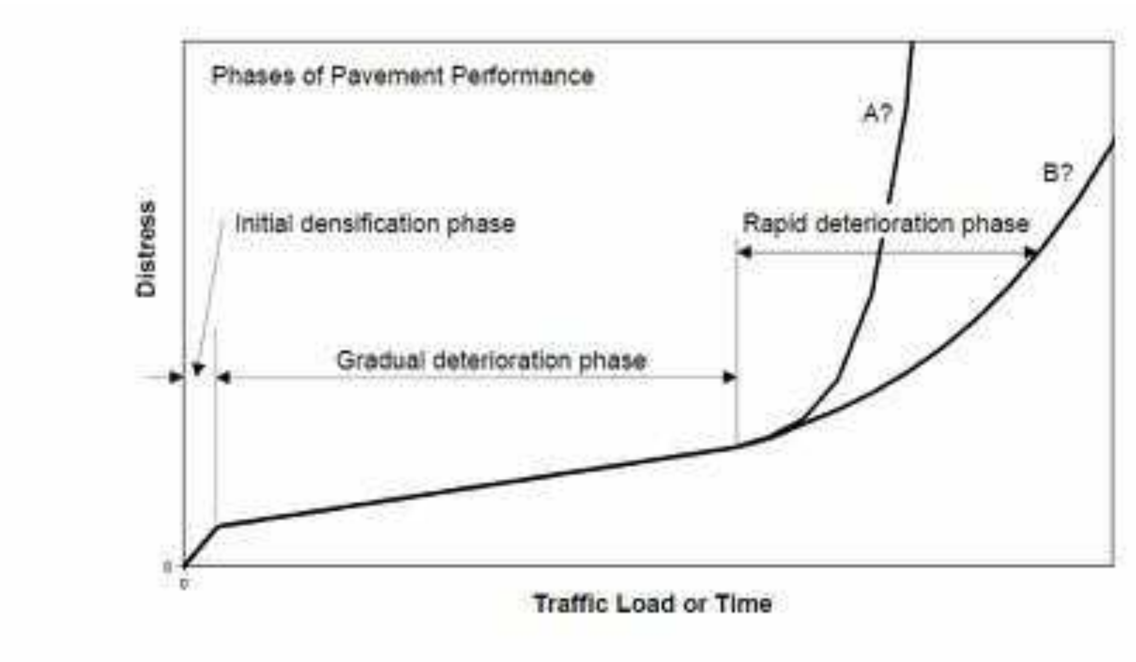
Figure 1: Stresses within a pavement under loading

Anecdotal evidence also indicates that the rate of pavement deterioration and the road maintenance costs increase with increased repetitions of axle loads on a road pavement and increased axle loads imposed by HCV traffic.[2]

Figure 2 below shows the typical road pavement performance over time.

[1] Austroads Technical Report AP-T104/08 *Relative Pavement Wear of an Unbound Granular Pavement due to Dual Tyres and Single Tyres*

[2] Austroads Research Report AP-T216-13 *Estimating Accelerated Road Wear Costs Due To Increased Axle Mass Limits*



Over time, the road pavement slowly deteriorates during the gradual deterioration phase due to the wear caused by axle loadings imposed by HCV traffic. During this phase maintenance work carried out by RCA's will maintain the road in an acceptable condition. At some point in the life of the road pavement, the road condition reaches a point when rapid deterioration occurs due to structural failure of the road pavement. At this point the road pavement is no longer able to a carry the loads imposed by HCV axle loading and accelerated wear of the pavement occurs. This is shown as the rapid deterioration stage on Fig 2. At this stage the pavement has reached its terminal condition and the road pavement will require reconstruction or rehabilitation to restore the road pavement structural capacity.

Road pavements are designed to carry the forecast HCV traffic and to operate in the gradual deterioration phase. If the pavement loading increases due to increased HCV loading, this will shorten the gradual deterioration phase, which in turn brings forward the rapid deterioration phase of the pavement. The result is a corresponding decrease in the pavement life. As a result, the amount of maintenance required to maintain the road in acceptable condition will increase substantially, and the pavement will require reconstruction or rehabilitation to strengthen it to carry the additional loading earlier in the life of the pavement.

As outlined above, the axle loading applied to road pavements due to HCV vehicles contributes disproportionately to the pavement wear. Unless the affected road pavements are designed to carry the extra loading, the pavement will suffer accelerated deterioration which will result in the need to reconstruct or rehabilitate the road pavement, rather than maintaining the pavement with periodic resurfacing and maintenance. The increase in pavement maintenance and reduction of the pavement life is directly proportional to the pavement deterioration, which in turn is proportional to the HCV loading on the pavement.

Where the axle loading due to HCV movements on a road increases, the road's structural wear will generally increase in proportion with the increasing numbers (cycles) of axle loads on the road pavement. A substantial increase in axle loading from HCV traffic on a road that is not designed to carry the additional axle-loading will result in multiple adverse effects in the form of:

- increased routine maintenance and resurfacing
- reduction in the level of service (road quality) as the road pavement deteriorates
- reduction in the pavement life

- increased reconstruction and or rehabilitation costs due to the increase in required structural capacity
- increased lateral instability and damage along roads due to heavy wheel loads tracking close the edge of the road
- added traffic effects and cost of control measures (eg lower speed limits, signage, turning lanes, lane widening, islands, pedestrian paths or cycleways, removal of spillage or detritus to maintain safety and restore traffic flow

1.4 Road pavement design

Design of road pavements in New Zealand generally adheres to the guides produced by Austroads (2012) and the New Zealand Transport Agency's Supplements to Austroads (Transit 2007 for new pavement design, Transit 1999 for rehabilitation). These documents identify the methods by which the design traffic and the pavement structure are determined.

The design life of a pavement is typically chosen as 25 years, based on the period over which the expected traffic is calculated. The total design traffic loading may be applied earlier than 25 years if the design assumptions are not met and thus the theoretical life of the pavement will be less. Conversely, the pavement may not be subjected to the design traffic in the design period and the achieved life may theoretically be greater.

The design traffic is the product of a number of factors: typically the average daily traffic (averaged over a year as the annual average daily traffic), the percentage of heavy vehicles, the axle load per heavy vehicle, and the growth rate. Other factors, including the design period, the average number of axle groups per heavy vehicle, lane distribution and the direction factor, need to be considered in calculating the design traffic.

Design traffic is calculated by quantifying all the loading from heavy vehicles into Equivalent Standard Axles (ESA). This is achieved by determining the allowable Standard Axle Repetitions (SAR) before expected failure, based on the ratio of the load on an axle group to the standard load for an axle group to the power of an exponent. This is expressed in the equation: $SAR=(L/SL)^m$ where L is the load on the axle group, SL is the standard load on the axle group, and ^{m} is the load damage exponent (specified by NZTA to be equal to 4 for general pavement wear to granular pavements with thin bituminous surfacings).

The load applied by a single axle with dual tyres subjected to a load of 80 kN with an individual tyre contact area of 0.0267 square metres is 1 ESA. With a load damage exponent of 4, a doubling of axle load has a sixteen-fold increase on the pavement wear induced by the axle.

The standard loads for various axle groups that cause the same pavement wear as a single standard axle are reproduced from Austroads (2010) in Table 1 below. Austroads assumes that roads with the same surface deflection will suffer the same pavement wear, after the SAR value for the relevant case is taken into account.

Table 1 Axle group loads

Axle group type	Load (kN)
Single axle with single tyres	53
Single axle with dual tyres	80
Tandem axle with single tyres	90
Tandem axle with dual tyres	135
Tri-axle with dual tyres	181
Quad-axle with dual tyres	221

A recognised method to establish design traffic loading involves establishing the commodities being carried on a road and applying the appropriate ESA load factor for the commodity for each heavy vehicle.[1] The load factors for commodities commonly encountered on rural local roads are listed in Table 2.

Table 2 Mean Load factors for common primary industry commodities[2]

Commodity	*ESA4*	*ESA7*
Aggregates	*2.90*	*3.77*
Livestock	1.49	1.92
Logging truck carrying jinkers	1.40	1.93
Logs	5.18	11.04
Milk	2.65	3.56
Powders (lime, fertiliser)	1.97	2.91
Stock food	1.62	1.69
Wool, hides	1.13	.77

1.5 Road pavement wear effects of heavy vehicle traffic

Where the number of vehicle movements on a road increases, the structural wear will generally increase in proportion with the increasing movements if the axle loads remain constant. By contrast, the load-wear-cost relationship results in an exponential function that means even small increases in individual axle loadings induce disproportionately large decreases in road pavement structural life.

The anticipated pavement damage caused by different axle configurations and axle weights can be determined by converting the axle loading to an equivalent number of passes of the standard axle using the fourth power relationship. As a result of extensive full-scale road testing[3] in the USA in the late 1950s on heavy-duty structural asphaltic pavements, the pavement damage caused by an axle passing over any form of flexible pavement has traditionally been considered proportional to the fourth power of its weight relative to a standard axle.[4]

Rural roads usually have narrow traffic lanes and a surface water channel on each side of the road. This road construction is adequate for low levels of heavy commercial traffic. With increased pavement loading, however, the additional loading often over-stresses the pavement edge, resulting in loss of edge support followed shortly thereafter by edge break and shear failure, with associated substantial impacts on maintenance costs. Lane widening may be necessary, as truck and trailer units tend to track along a wider traffic path on corners than normal traffic, thus requiring a wider traffic lane than lighter traffic and placing greater stresses on the road edges.

[1] Transfund NZ, (RR185), 2000, 5.2.6
[2] From Transfund NZ, (RR185), 2000, Appendix B, Table B1
[3] AASHO Interim Guide for the Design of Flexible Pavement Structures. AASHO Committee on Design, Oct. 12, 1961
[4] A standard axle has been defined as a twin-tyred single axle loaded to 80kN or approximately 8.2 tonnes.

1.6 Determining the impact of heavy vehicle traffic alternative loadings

A pavement impact assessment should be undertaken where a proposed increase in heavy vehicle traffic equals or exceeds 5% of the existing ESA loading on the road. A design horizon of at least twenty years should be adopted for the pavement life assessment. The 30-year Long Term Plan horizon is likely to be appropriate, and a longer horizon can be appropriate in some circumstances. In practice it is very straightforward to allow modelling to be projected out to 50 years or more in order to carry out a sensitivity analysis for the impact of any given cut-off date on the associated net present value calculation of future life-cycle costs. Where only a small number of roads is being considered, a long evaluation period is often necessary because of the irregular (markedly stepped) profile of the cumulative cost curve as the date for each life-cycle renewal expenditure is reached.

A pavement impact assessment should consider the surface condition and structural capacity of the pavement, and the effect on the forward works programme. Surface condition should be assessed preferably from high speed data surveys as well as visually and recorded with detailed location data. Structural capacity can be assessed readily with measurement of pavement deflection. Increased deflection before and after a temporary increase in loading of the pavement can be used to quantify any evidence of pavement deterioration.

Measured change requires falling weight deflection structural evaluation for the affected road prior to the increase in heavy vehicle traffic, as well as subsequent to that increase. Comparison of the change in deflection, considering any increase in pavement deflection and allowing for any seasonal variation in moisture content, allows the post trafficking remaining pavement life to be recalculated. Hence the cost of the additional trafficking can be determined from the difference in net present value between the respective forward work programmes.

While it has been widely recognised that routes carrying increased traffic loadings will incur additional road pavement wear and associated additional costs, quantification of such wear has, until very recently, been contentious and uncertain. Advances in pavement asset management technology and more comprehensive databases available for many authorities' pavement networks, now enable relatively reliable quantification of pavement structural wear and the marginal cost of increased loading. Once the current and proposed future axle loadings are defined it is possible to consider both the (i) "*bring forward" costs of the added wear* and (ii)*consumption of existing assets* to calculate equitable apportioning of those marginal costs.

Pavement wear and associated costs can be calculated, once the distress mode and relevant critical layer are identified and the relevant load damage exponent determined, where the region has a suitable database of pavement structural information (FWD data).

For many low volume roads, however, such a database may be unavailable and this procedure could be disproportionately costly for the levels of service and likely maintenance costs if the length of the affected route is short. (For larger studies costs can be brought down to less than $100/lane km.) The methods adopted to determine the cost of the impact of heavy vehicle traffic on low volume road pavements need to be appropriate to the use and requirements of the road.

Assessing impacts on the Forward Works Programme involves a comparison of the nature and timing of roadworks required with and without the extra heavy vehicle traffic, based on predicted ESA loads. Forecasting required pavement works requires a sound knowledge of the issues involved, solid data and good professional judgement. RAMM condition data is not sufficient on its own, for this purpose.

Works to provide heavy vehicle access, such as widening, corner radius smoothing or pavement strengthening, can be identified separately from the load related damage. Routine resurfacing and maintenance costs need to be allocated with appropriate consideration of potential damage caused by all other road users.

1.7 Assessing the Impacts of HCV Traffic Loading on Road Pavements

Calculation of the remaining life of the road pavement can be conducted as a desk top analysis from records of the existing pavement design, current pavement loading (ESA), pavement age, and past traffic The remaining life (in ESA's) is the difference between the pavement design life (in ESA's) and the cumulative past traffic. The calculation of pavement life can be further refined using Falling Weight Deflectometer (FWD) testing to determine the existing pavement strength and to calculate the remaining life.

New developments or land use activities can generate increases in heavy commercial vehicle traffic which may have adverse impacts on road pavements. Typical impacts resulting from an increase in the number and /or weight of vehicles using the road include:

- a need for extra pavement width
- a change is in surfacing type or pavement thickness
- an increase in maintenance, and
- a reduction in the pavement life, requiring road pavement upgrading, which may include strengthening works or reconstruction of the pavement.

The pavement assessment needs to consider the impact of the additional HCV traffic loading pavement on the road pavement and to determine the extent, timing and costs of:

- pavement upgrading such as road widening
- additional maintenance
- pavement strengthening and or reconstruction.

The procedures for assessing the impacts of HCV traffic on road pavements are outlined in the Queensland Government Department of Transport and Main Roads "Guidelines for the Assessment of Road Impacts of Developments." These guidelines are consistent with the road pavement design and maintenance principles adopted throughout NZ including:

- NZTA Economic Evaluation Manual (EEM)
- NZTA's Supplement to Austroads Pavement Design Procedures
- Austroads Guide AGP-T01-09 Pavement Technology Part 1 Introduction to Pavement Technology
- Austroads Guide AGP-T02-12 Pavement Technology Part 2 Pavement Structural Design
- Austroads Guide to Traffic Management AGTM12-09 Traffic Impacts of Developments

The following steps outline the process described in the Queensland Guideline to assess the road pavement impacts due to increased HCV traffic generated by a development or land use activity:

Identify the Land Use	1. Such as forestry, quarrying, dairy farming, dry stock beef raising, stock finishing, sheep farming, horticulture, viticulture, arable, etc.

Determine the traffic loading

2. Determine the current road network affected by the proposed activity, and existing HCV traffic and pavement axle loading (ESA).

> Austroads Guide AGP-T02-12 Pavement Technology Part 2 Pavement Structural Design; NZTA Supplement to Austroads Pavement Design Procedures

Calculate remaining pavement life

3. Determine the condition of the existing road network and estimated remaining pavement life from road asset information held. Use RAMM data, maintenance records, as-builts, distress test results, condition data, deflection tests and unit rates for renewals.

Determine new HCV traffic

4. Determine the HCV traffic and pavement axle loading (ESA) generated by the proposed activity. List the types and number of HCV and calculate the total ESA generated.

Compare existing and new HCV traffic

5. Carry out a 'with" and "without" proposed activity HCV assessment for the pavement design period, based on likely traffic growth rates in both cases within the design period.
R

> Austroads Guide AGP-T02-12 Pavement Technology Part 2 Pavement Structural Design; NZTA's Supplement to Austroads Pavement Design Procedures

Determine remaining pavement life

6. Determine the remaining life of the pavement based on information held or from FWD testing of the road pavement. If the axle loading (ESA) is increased by more than 5 % above the existing loading, the increase will result in a reduction in the pavement life.

Estimate new works schedule

7. Predict when the road pavement will require upgrading and/or strengthening due to the increased axle loading (ESA) on the pavement.

Calculate new works programme costs

8. Predict the cost of pavement upgrading and/or strengthening due to the increased loading generated by the development /activity. Establish if there is a change in the vehicle mix using the road that may require widening of the pavement or surfacing, and estimate the cost of the upgrading works and the associated maintenance and resurfacing throughout the design period.

> Austroads / NZTA State Highway Geometric design requirements, for the appropriate traffic volume.

Calculate the added cost from new HCV traffic

9. Predict the total cost of routine and programmed maintenance in each year within the design period, with the current traffic (ESA), and with the current traffic plus the additional traffic (ESA) generated by the development / activity. Discount to determine net present value.

The above analysis should determine the extent to which any additional pavement upgrading works are required to accommodate the additional HCV traffic generated by a development /activity.

In some cases the pavement may have reached the end of its design life, but it may continue to operate satisfactorily with the current traffic volume. However, an increase in the pavement axle loading due to HCV traffic generated by a development or activity might not be able to be sustained by the pavement. In such cases a full pavement evaluation using FWD testing is recommended to assess what pavement upgrading and strengthening is required to carry the additional pavement loading from the additional HCV traffic generated by the development or activity.

The results of the pavement impact assessment give an indication of the road upgrading or strengthening works and maintenance requirements, (including resurfacing) required as a result of the increased pavement loading from HCV traffic generated by the development or activity.

The timing of the upgrading works depends on the residual strength of the existing road pavements and the increased axle loading on the pavement. In some cases the upgrading works need to be undertaken prior to commencement of the development or activity. However if the existing road has sufficient strength to carry the additional axle loading, the upgrading works may be deferred. In these cases it is recommended that monitoring of the road pavement is carried and the upgrading works are implemented before the road pavement reaches its terminal condition.

The impacts on bridge and other structures within the road corridor also need to be considered in cases where the additional axle loading imposed by HCV traffic generated by developments and changes in land use activities exceed the capacity of existing infrastructure.

1.8 Pavement Wear Calculations

Simplified vs Detailed Approaches

The spreadsheet calculation example in Appendix A demonstrates the calculation procedure using the Austroads Simplified Approach, as well as establishing a template for application elsewhere.

Simplified methods may suffice for specific instances of activities affecting pavement wear. However the nature of pavements in practice presents a need for due consideration of the level of detail warranted. A pavement is an assemblage of particulate materials that will vary in localised particle size distribution. As a result the pavement will have variations in stiffness within any constituent layer that can vary by an order of magnitude. The pavement will contain multiple layers with variations in stiffness and thickness.

The result will be variations in the pavement life in terms of ESA along any one road where the traffic is constant that can be several orders of magnitude. The cumulative distributions of pavement life highlight the importance of identification of valid structural treatment lengths. Homogenous sub-sections within each road will act in a similar fashion and will require a similar thickness of treatment for rehabilitation.

Effective sub-section identification for each road can reduce the variation in pavement life from two or three orders of magnitude to a typical variation of about one order of magnitude. A lesser variation should not be expected within a normal practical treatment length, which will encompass at least 100 m of pavement and usually more.

The consequence is that rehabilitation triggers are set based on a specified percentage of a given treatment length reaching a terminal condition. In practice the allowable percentage in terminal condition becomes a criterion beside maintenance cost in the selection of pavements for rehabilitation. The allowable percentage in terminal condition is, therefore, a key parameter in the FWP calculation.

If the identification of valid structural treatment length sub-sections has not been done in accordance with best practice, the modeled life of a pavement sub-section can change by a factor of five, depending on the adopted percentile for testing. This can have a massive effect on the NPV calculation. Some of this uncertainty can be offset by ensuring consistency, using the same assumptions and approaches for both original and altered activity calculations, but for equitable apportionment where costs are significant, detailed best-practice structural evaluation, rather than simplified approaches, should be considered.

1.9 REFERENCES

Yeo et al, (2006) Investigation of the Load Damage Exponent of Unbound Granular Materials under Accelerated Loading.

AUSTROADS Research Report Ap-T216-13 Estimating Accerated Road Wear Costs Due To Increased Axle Mass Limits.

AUSTROADS Research Report Ap-R486-15 The Influence Of Multi Axle Group Loads On Flexible Pavement Design.

AUSTROADS Technical Report AP-T104/08 Relative Pavement Wear of an Unbound Granular Pavement due to Dual Tyres and Single Tyres.

AUSTROADS Research Report Ap-R486-15 The Influence Of Multi Axle Group Loads On Flexible Pavement Design.

NZTA Research Report No 185 Design Trafic Loading

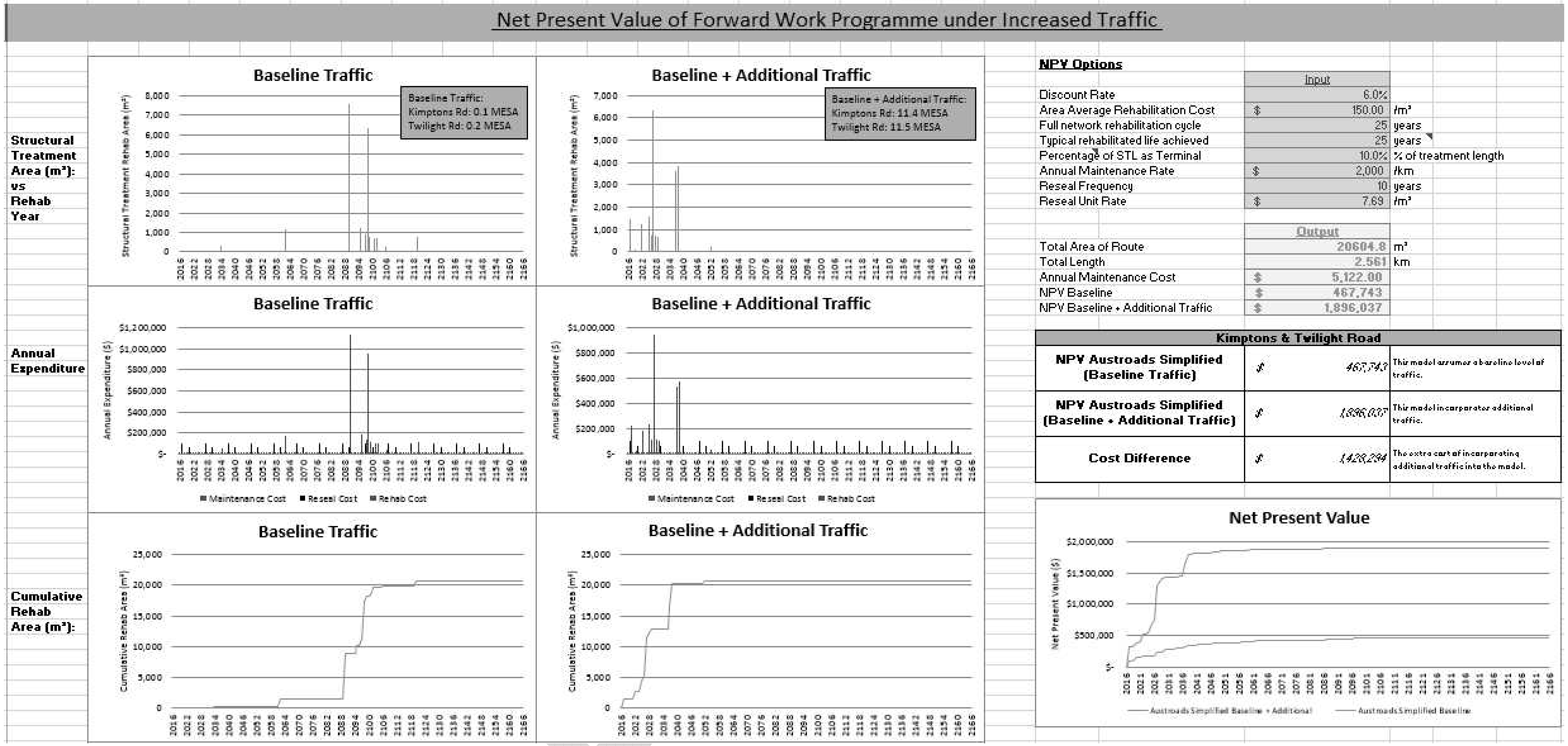
AUSTROADS TP-T195-12 Improving Cost Allocation By Road Type

AUSTROADS Pavement Technology Guide Part 1 And Part 2

AUSTROADS Guide To Traffic Management Part 12

APPENDIX A: SPREADSHEET CALCULATION – EXAMPLE

This example is the standard case where increased traffic loading is expected on a set of quarry roads, and the net present value resulting from the changed activity is to be quantified, using the Austroads Simplified Approach.



NPV Options

		Input	
Discount Rate		6.0%	
Area Average Rehabilitation Cost	$	150.00	/m²
Full network rehabilitation cycle		25	years
Typical rehabilitated life achieved		25	years
Percentage of STL as Terminal		10.0%	% of treatment length
Annual Maintenance Rate	$	2,000	/km
Reseal Frequency		10	years
Reseal Unit Rate	$	7.69	/m²

		Output	
Total Area of Route		20604.8	m²
Total Length		2.561	km
Annual Maintenance Cost	$	5,122.00	
NPV Baseline	$	467,743	
NPV Baseline + Additional Traffic	$	1,896,037	

Kimptons & Twilight Road			
NPV Austroads Simplified (Baseline Traffic)	$	467,743	This model assumes a baseline level of traffic.
NPV Austroads Simplified (Baseline + Additional Traffic)	$	1,896,037	This model incorporates additional traffic.
Cost Difference	$	1,428,294	The extra cost of incorporating additional traffic into the model.

APPENDIX B: TRAFFIC and SAFETY CONSIDERATIONS

AUSTROADS GUIDE TO TRAFFIC MANAGEMENT PART 12
TRAFFIC IMPACT OF DEVELOPMENT

2.1.3 Transport Considerations

During consideration of both an application and any appeal, access to arterial roads or traffic impacts on local areas are often contested issues. Issues typically focus on the impact on the adjacent road, the road network, or other modes (including modal split) created by:

- the type of development
- the scale, form or layout of the development
- the location and type of access onto the adjacent roads.

Transport issues considered during these processes typically include:

- the suitability of the development for its location, considering the transport options available for potential users
- compatibility of the development and its access requirements with the traffic function of the adjacent road
- the impact on the wider road network, both arterial and local
- the likely use of public transport, cycling and walking instead of using motor vehicles for access (modal split)
- trip generation (both people and goods), especially peak generation periods (development and background traffic)
- traffic volume generation and its distribution and accommodation, including traffic capacity issues
- impact on pavements where development involves significant haulage during the construction or operation phases
- the access and site layout needs of delivery and service vehicles, and public transport vehicles
- parking demands and where they are to be provided for
- traffic safety within the site, at the access points and on the approach roads for all likely groups of road users
- the accommodation of pedestrians and cyclists, including access to and location of pedestrian and cycling facilities
- noise assessment and mitigation
- air quality (transport emissions), for example, for a proposed childcare centre adjacent to a major road with high traffic volumes.

4.2.4 Other Assessments

A TIA may be just one of several assessments which are needed, to examine the impacts a development may have on a road network. Other assessments for consideration (discussed in Section 5) relate to:

- road infrastructure (including pavement) impacts
- road safety effects (potentiall for crashes and injuries)
- the utility for expected users (walkability, cycleability, availability of public transport)
- environment impacts and cultural or heritage issues.

The full assessment of the impact of a development will in many cases require consideration of other issues. These include:

- road infrastructure and pavement impacts
- road safety impacts
- environmental and other issues.

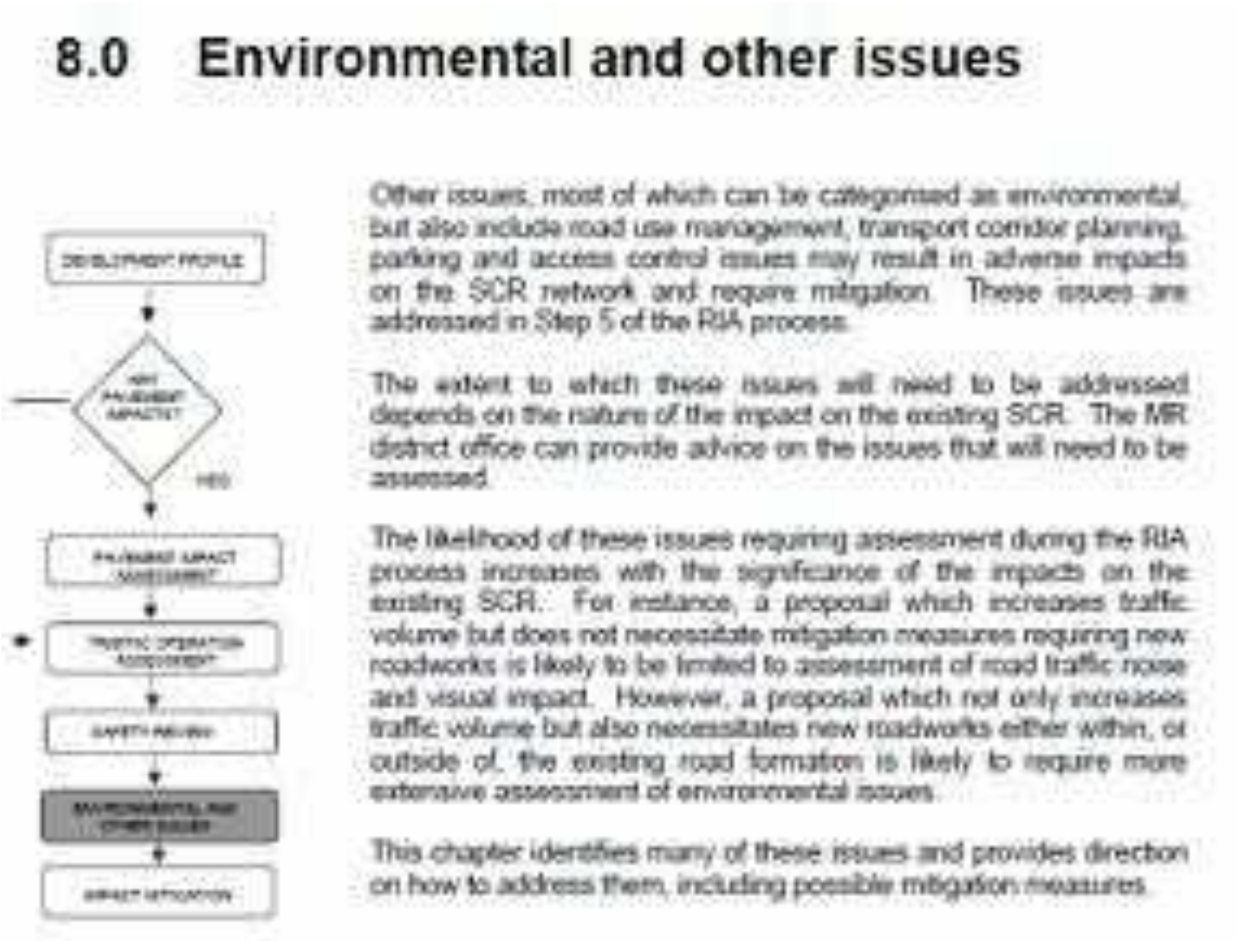
A TIA report should thus not be viewed as the only traffic-related development assessment report which should be considered. In particular, for developments of a size, scope or location as described in Section 5.3.2 a road safety audit report will be an essential part of any effective development assessment.

Rural roads

Aspects that may require consideration include the effect of additional traffic and access treatments on:

- overtaking opportunities
- dust nuisance and visibility impediment from unsealed shoulders
- speed differentials and reduction in LOS where significant heavy vehicle movement occurs
- noise for adjoining properties

APPENDIX C: ENVIRONMETAL CONSIDERATIONS



8.0 Environmental and other issues

Other issues, most of which can be categorised as environmental, but also include road use management, transport corridor planning, parking and access control issues may result in adverse impacts on the SCR network and require mitigation. These issues are addressed in Step 5 of the RIA process.

The extent to which these issues will need to be addressed depends on the nature of the impact on the existing SCR. The MR district office can provide advice on the issues that will need to be assessed.

The likelihood of these issues requiring assessment during the RIA process increases with the significance of the impacts on the existing SCR. For instance, a proposal which increases traffic volume but does not necessitate mitigation measures requiring new roadworks is likely to be limited to assessment of road traffic noise and visual impact. However, a proposal which not only increases traffic volume but also necessitates new roadworks either within, or outside of, the existing road formation is likely to require more extensive assessment of environmental issues.

This chapter identifies many of these issues and provides direction on how to address them, including possible mitigation measures.

RESOURCE MANAGEMENT ACT 1991

Under Section 17 of the RMA adverse effects need to be mitigated. A traffic impact assessment is carried out to determine the adverse effects.

17 Duty to avoid, remedy, or mitigate adverse effects

(1) Every person has a duty to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity carried on by or on behalf of the person, whether or not the activity is carried on in accordance with—

(a) any of sections 10, 10A, 10B, and 20A; or

(b) a national environmental standard, a rule, a resource consent, or a designation.

(2) The duty referred to in subsection (1) is not of itself enforceable against any person, and no person is liable to any other person for a breach of that duty.

(3) Notwithstanding subsection (2), an enforcement order or abatement notice may be made or served under Part 12 to—

(a) require a person to cease, or prohibit a person from commencing, anything that, in the opinion of the Environment Court or an enforcement officer, is or is likely to be noxious, dangerous, offensive, or objectionable to such an extent that it has or is likely to have an adverse effect on the environment; or

(b) require a person to do something that, in the opinion of the Environment Court or an enforcement officer, is necessary in order to avoid, remedy, or mitigate any actual or likely adverse effect on the environment caused by, or on behalf of, that person.

(4) Subsection (3) is subject to section 319(2) (which specifies when an Environment Court shall not make an enforcement order).

Comment

Section 17 of the RMA imposes a general duty to avoid adverse effects. Although Section 17 is not enforceable in and of itself, it can provide a basis for seeking an enforcement order.

As outlined by the Court in *Sayers v Western Bay of Plenty District Council (1992) AO98/92*, an enforcement order or abatement notice may require a person to cease, or prohibit a person commencing, anything that is or is likely to be : offensive, objectionable, dangerous or noxious enough to have an adverse effect on the environment. Alternatively, the order or abatement notice may require a person to do something that is necessary to avoid, remedy or mitigate adverse effects on the environment caused by, or on behalf of, that person.

Section 17(3), read together with s322, allows enforcement officers to enforce the s17 duty in a limited way. An abatement notice can require that an activity ceaseif it is having adverse effects and is noxious, dangerous, offensive, or objectionable (s322(1)(a)(ii)). Specific actions to cure the effects cannot be stipulated, unless a breach of a rule or consent also exists. An enforcement order provides a greater scope for action.

Importantly, the duty under section 17 applies whether or not the activity is in accordance with a national environmental standard, a rule, a resource consent, a designation, s10, s10A, s10B or s20A. In *Donkin v Board of Trustees of Sunnybrae Normal School [1997] C044/97*, the Environment Court made a declaration that an existing school building contravened s17 because it was too close to the boundary of a neighbouring residential property. The Court stated that the Board of Trustees of Sunnybrae Normal School and the Minister of Education had a duty to remedy or mitigate the adverse effects.

Gravel extraction resource management issues and effects

Gravel extraction can generate a number of on-site and off-site environmental effects through the excavation of material from riverbeds (or banks of rivers) and the associated, crushing, screening, stockpiling and transport of aggregate.

The degree and nature of effects caused by gravel extraction varies according to the scale of the operation, the methods used to extract the gravel, the surrounding land uses and the ecological and hydrological characteristics of the river environment.

Effects are either on site, on neighbouring properties or completely off site, such as the transportation of aggregate, or where fine sediments area transported downstream in the water column. The environmental effects of gravel extraction primarily include:

- the disturbance of land and vegetation
- the disturbance of river beds or coastal marine areas
- disruption of habitats for birds, freshwater and wildlife species
- dust
- vibration
- noise
- traffic
- visual effects
- impact on cultural and historic heritage values
- the discharge of contaminants into air, water, land and the coastal marine area.

The effects of gravel extraction need to be considered when developing appropriate objectives, policies and methods in District and Regional Plans. Although the effects of gravel extraction can often be mitigated, they cannot always be avoided.