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Envirolink 73 – HBRC 9 – soil cadmium

Report prepared for Hawkes Bay Regional Council

August 2006

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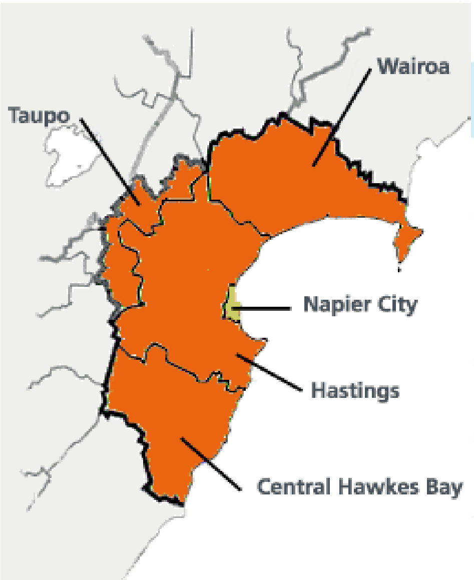

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1. Executive Summary

Cadmium (Cd) is a bio-toxic trace metal that is a naturally present element in all parts of the environment and its accumulation under farming practices in NZ has been of concern. Over the past 15 years much research has been conducted into understanding Cd in the soil-plant-animal cycle.
At present in NZ there are no specific regulations on permissible Cd concentrations in soils however there is an industry recommended guideline, with interested Government ministries endorsement, of a maximum permissible soil limit of 1 mg/kg.

This report reviews the data from the nationwide survey of Cd concentrations in soils and pastures under pastoral farming systems. In particular, data with relevance to the Hawkes Bay are identified and the results reported.

Results show that soil Cd concentrations in the Hawkes Bay soils countered those found in the nationwide survey. Where the Cd concentrations were higher for soil orders in the national survey (allophanic, pumice) the concentrations found in the Hawkes Bay were lower. Conversely, where the Cd concentrations were lower for soil orders in the national survey (alluvial, brown and pallic) the concentrations found in the Hawkes Bay were higher.

There were striking differences in regional distribution with the southern Hawkes Bay having mean Cd concentrations much higher than those of the central and northern regions. The reason for this anomaly is unclear but may be due to the generally lower fertiliser P inputs and higher liming inputs compared to other regions of NZ.

Overall, the Cd concentration found in the Hawkes Bay soils at 0-75mm depth were considerably lower with a mean (and median) of 0.30 mg/kg (range 0.04-0.63) compared to the mean of 0.44 mg/kg (range 0.4-1.53) found for pastoral soils throughout NZ.

Cadmium enrichment in pastoral soils has been found to be largely due to the use of phosphatic fertilisers. Approximately 5.6g Cd/ha/year is likely to be added to Hawkes Bay soils at a typical maintenance P fertiliser rate of 20 kg P/ha (assuming an industry standard concentration of 280 mg Cd/kg P in the fertiliser).

Predictions of Cd accumulation on a typical sheep/beef farm with maintenance fertiliser P inputs of 20 kg/ha were that it would take almost 300 years before the soil Cd limit of 1 mg/kg was reached. However, if 30 kg P/ha were routinely applied the soil Cd limit would be reached in 115 years.
Because of the higher initial soil Cd and the larger quantities of fertiliser P applied on dairy farms the accumulation of soil Cd is far quicker than under sheep/beef farming

systems. In fact, the longevity of dairy farming in the region is seriously questioned as at the lowest rate of maintenance P (35 kg/ha) the soil Cd limit of 1 mg/kg could be reached in 92 years. Applying higher maintenance fertiliser P rates (45 kg P/ha) would result in the timeframe before breaching the soil Cd limit decreasing to just 55 years.

Mitigating strategies for reducing the Cd loading should focus on either using low-Cd phosphatic fertilisers or investigating chemical processes that would reduce the Cd content of manufactured fertilisers. The greatest effect on mitigating Cd accumulation could be achieved through applying P fertilisers that have Cd concentrations of less than 85 mg Cd/kg P.

Other on-farm strategies could include: 1) ploughing the land when re-grassing to invert the top few cm of soil where the accumulated Cd is most likely to be concentrated thereby diluting the overall soil Cd concentrations; 2) growing a Cd accumulating crop, harvesting it and removing the crop from the farm for a non-food application; 3) intercepting the Cd cycle by feeding a larger proportion of the livestock diet on a feed pad thereby transferring greater quantities of manure where it could be treated to reduce Cd content before being returned back to the soil.

2. Background

Cadmium (Cd), a bio-toxic trace metal, is a naturally present element in all parts of the environment including both fresh and sea water, sediments, soils, and the air. As a result all food, whether of plant or animal origin, is exposed to and contains Cd. Although Cd was first identified as an element in 1817 it has only been in the past 15-20 years that there has been consideration given to its food contamination role. Interest in Cd gained serious attention in the late 1980s – early 1990s when random sampling of animal tissues at meatworks by MAF found higher than desirable Cd concentrations, particular in offal organs of stock. Since then there has been increasing interest directed at the progressive accumulation of Cd in biological systems. Continued exposure to small amounts of Cd leads to an accumulation in the liver and kidneys, of both humans and animals, and can result in damage and dysfunction of these organs.

The extent of Cd accumulation into the agricultural environment was investigated during the 1990s. Studies included a national review (Bramley, 1990); a nationwide survey in soils, plants and animals (Roberts et al., 1994); effect of phosphatic fertiliser type (Loganathan et al., 1996); understanding the soil-plant-animal link under hill country sheep farming (Roberts & Longhurst, 2002); atmospheric accessions (Gray et al, 2003a); and Cd leaching (Gray et al, 2003b). From these research findings a cadmium balance model was constructed for New Zealand soils for the NZ Fertiliser Manufacturer's Research Association in 1996 (updated 2005) by Roberts & Longhurst.

At present in NZ there are no specific regulations on permissible Cd concentrations in soils however there is an industry guideline with interested Government ministries (MoH, MAF, MfE) endorsement (Nick Kim, Environment Waikato, pers. comm.). These guidelines recommend a maximum permissible soil Cd limit of 1 mg/kg. Information on the rationale behind this limit is attached in Appendix 1. Currently an environmental forum is discussing Cd on a three-pronged approach: 1) risk to NZ population from food ingestion, 2) risk to NZ trade, and 3) land use flexibility, e.g., effect of changing land use from pastoral activity to food crops/lifestyle blocks.

3. Scope of report

This report reviews the data from the nationwide survey of Cd concentrations in soils and pastures under pastoral farming systems. In particular, data with relevance to the Hawkes Bay are identified and results are reported.

4. Cadmium status on Hawkes Bay pastoral farms

4.1 Survey method

During 1990 soil and pasture samples were collected from pastoral farms in the Hawkes Bay as part of the NZ wide survey to provide benchmark data on the Cd status. In total, samples were collected from 28 farms comprising 26 sheep/beef farms and 2 dairy farms. The regional distribution throughout the Hawkes Bay was: Northern (14), Central (4), and Southern (10).

The soil samples were collected and analysed for Cd concentrations at two depths (0-25mm, 25-75mm). From these results an integrated 0-75mm depth could also be calculated. Pasture samples were collected from the same spot as the soil samples and dissected into their grass, legume and weed component and washed before being analysed for Cd.

4.2 Soil Cd status

The Hawkes Bay contains most of the major soil groups found in NZ. Detailed information on each of the soil orders found in the region is well described in 'Soils of Hawke's Bay' (www.hbrc.govt.nz). Soil samples were collected at two depths from 5 different soil orders in the region and results are reported in Table 1. The highest Cd concentrations were found in the Pumice soils and these levels were nearly twice that of the concentrations found in the Alluvial soils. These findings are similar to that found in the national survey which is discussed in the following section.

Table 1: Cadmium (mg/kg) status at different depths in pastoral soils of Hawkes Bay.

Soil order	No.	0-25mm	25-75mm
Alluvial	4	0.23	0.20
Allophanic	2	0.30	0.35
Brown	12	0.31	0.24
Pallic	6	0.29	0.32
Pumice	4	0.43	0.40

4.3 Comparison with national cadmium survey

The degree of Cd accumulation in the Hawkes Bay region can be gauged by comparing its concentrations to those found in the nation wide survey of pastoral soils (Roberts et al., 1994; Longhurst et al., 2004). Table 2 shows the comparison of Hawkes Bay soils to those of NZ pastoral soils for the integrated 0-75mm depth.

Table 2: Mean cadmium concentrations (mg/kg) for 0-75mm depth in Hawkes Bay soils compared to NZ pastoral soils.

Soil	Hawkes Bay soils		New Zealand soils	
order	No.	0-75mm	No	0-75mm
Alluvial	4	0.21	21	0.16
Allophanic	2	0.33	72	0.70
Brown	12	0.27	82	0.22
Pallic	6	0.31	71	0.12
Pumice	4	0.41	22	0.75

Results from Table 2 are interesting and show that Cd concentrations in the Hawkes Bay soils counter those found in the nationwide survey. Where the Cd concentrations were higher for soil orders in the national survey (allophanic, pumice) the concentrations found in the Hawkes Bay were lower. Conversely, where the Cd concentrations were lower for soil orders in the national survey (alluvial, brown and pallic) the concentrations found in the Hawkes Bay were higher.

Soil Cd data was broken down into a regional distribution within the Hawkes Bay and striking differences were identified (Table 3). The southern Hawkes Bay had concentrations much higher than those of the central and northern regions. Total P (phosphorus) concentrations are also provided in Table 3 as this gives an indication of the longer term phosphatic fertiliser history of the sites.

Table 3: Regional distribution in Hawkes Bay of soil Cd (mg/kg) and Total P (%) at the 0-75mm depth.

Region	No. sites	Mean Soil Cd	Standard error	Total P (%)
Northern	14	0.24	0.04	0.111
Central	4	0.29	0.02	0.121
Southern	10	0.42	0.06	0.088

In the nationwide survey a highly significant correlation (r = 0.62***, $P < 0.001$: n = 397) was found between Total P and soil Cd. What is strange is that the Hawkes Bay sites do not appear to follow the same pattern. For example, it would be expected that the southern sites would have had the highest Total P concentrations also but this is not the case, and in fact, the reverse has happened. The reason for this anomaly is unclear but may be due to the generally lower fertiliser P inputs and higher liming inputs in the Hawkes Bay compared to other regions of NZ.

Overall, the Cd concentration found in the Hawkes Bay soils were considerably lower with a mean (and median) of 0.30 mg/kg (range 0.04-0.63) compared to the mean of 0.44 mg/kg (range 0.4-1.53) found for pastoral soils throughout NZ. In comparison, Cd concentrations on non-farmed ("native") areas found in the national survey were 0.20 mg/kg (range 0.02-0.77).

4.4 Sources of pastoral Cd contamination

Cadmium enrichment in pastoral soils has been found to be largely due to the use of phosphatic fertilisers. The high P fixation soils (allophonic, pumice) generally require larger amounts of P fertilisers for continued pasture production than other soil groups and the effect of this was seen in higher soil Cd concentrations in these soils (Roberts et al., 1994). Cadmium is naturally present in the phosphate rocks deposits found around the world. However, Cd concentrations in the phosphate rocks will vary depending on whether the deposit is of sedimentary, igneous (volcanic) or guano (seabird) origin. Historically in NZ, superphosphate fertiliser was manufactured from phosphate rock sourced from Nauru Island deposits which contain 90-100 mg/kg Cd. Since the Fertiliser Industry became aware of the problem the Cd concentrations of NZ fertilisers has been reduced by blending phosphate rocks from different sources to lower the overall concentration (Furness, 1996). Recently, a voluntary benchmark level of 26 mg/kg Cd (or 280 mg/kg P) for NZ manufactured superphosphate was adopted by member companies of Fert Research (NZFMRA, 2002). Table 4 gives an estimate of typical annual amount of Cd imported onto Hawkes Bay sheep/beef farms through typical maintenance fertiliser applications.

Phosphatic fertilisers are the main but not the only source of Cd imported onto pastoral farms. Trace amounts are likely to come with animal remedies plus larger quantities are also possible with ground limestone. Most NZ lime deposits contain approximately 5 mg/kg Cd. Most of the Hawkes Bay farmers use the high quality Hatuma lime. Assuming that 2.5 tonnes/ha of lime is used every 5 years and that the lime has a Cd concentration of 5 mg/kg then the quantities of Cd from this source are also significant on Hawkes Bay sheep/beef farms (Table 4). For this scenario a sheep/beef property carrying 13 SU/ha and requiring 20 kg P/ha as maintenance fertiliser was assumed (Morton & Roberts, 1999). As Table 4 illustrates the most likely contributor to Cd enrichment on pastoral farms is from the use phosphatic fertilisers.

Table 4: Estimates of annual Cadmium loading onto sheep/beef farms in Hawkes Bay.

Material applied	Cd in material (mg/kg)	Application rate (kg/ha)	Applied (mg Cd/ha)	Applied in 5 years (g Cd/ha)
Superphosphate	26	215 *	5,600	28
Lime	5	2,500	12,500	12.5

* 20 kg P/ha

Even those farmers following organic or bio-dynamic practices and using reactive phosphate rocks (RPR) are inadvertently importing Cd onto their properties as reactive RPRs suitable for direct application, such as Sechura RPR and North Carolina RPR, contain 11-12 and 40-50 mg Cd/kg, respectively.

4.5 Cadmium status of pastures

On all 28 pastoral sites in the Hawkes Bay there were sufficient grasses and legumes present for samples to be collected and be analysed for Cd. Weeds were present at 24 of these sites. A summary of the Cd concentrations found in Hawkes Bay pastures is given (Table 5), for comparison, the results from the national survey (Roberts et al., 1994) are also included.

Table 5: Cadmium concentrations (mg/kg DM) in Hawkes Bay pastures.

Measurement	Grasses	Legumes	Weeds
Hawkes Bay - mean Cd	0.19	0.11	0.26
Standard error	0.02	0.02	0.03
Range	0.06-0.41	0.01-0.36	0.12-0.59
NZ survey – mean Cd	0.10	0.06	0.28

Results from Table 5 show that the Hawkes Bay sites had much higher Cd concentrations in both grasses and legumes than for the NZ survey while concentrations in the weeds were similar to those found throughout the country. The most likely reason for higher Cd concentrations found in the grasses and legumes is that the species present on sheep/beef farms contain a higher percentage of lower fertility species, with higher Cd concentrations, than those found on dairy farms. For example, at the Whatawhata site when a single sub-sampling of pasture occurred, it was found that browntop grass contained higher Cd concentrations than ryegrass, likewise, lotus and subterranean clover had higher concentrations than white clover.

4.6 Relationship between cadmium in soils and pastures

The national Cd survey (Roberts et al., 1994) identified that there were significant correlations between soil Cd at 0-75mm depth and grasses, likewise for weeds ($P < 0.05$). The same correlations for the soil Cd and pasture Cd were not as clear for the Hawkes Bay sites.

In a North island hill country study on sheep grazed pastures Roberts & Longhurst (2002) found that the distribution of soil Cd and pasture Cd differed markedly depending on the rate of P fertiliser and spatial variability within the paddocks (camp sites, easy slopes, sheep tracks and steep slopes). The study was superimposed on an existing 15-year old trial looking at increasing rates of fertiliser P and so allowed the effect of Cd accumulation to be quickly identified. Historically, the fertilisers used contained either 30 mg Cd/kg (superphosphate) or 35 mg Cd/kg (triple superphosphate).

Some key findings from this 4-year study that have relevance to the Hawkes Bay are illustrated in the following figures. Figure 1 shows the accumulation of Cd in soils and pastures at increasing rates of fertiliser P. Total soil Cd (at 0-75mm depth) increased significantly ($P < 0.003$) with increasing rate of fertiliser P above 30 kg/ha. Fertiliser P applications above maintenance rates will raise the Olsen P status in the soil. At the Whatawhata hill country site the initial Olsen P status was 9, 10, 14, 36, and 55 for the 10, 20, 30, 50, and 100 kg P/ha rates, respectively. As there is a highly significant correlation between soil Olsen P and soil Cd concentrations it would therefore be prudent to maintain Olsen P levels at optimum levels. The target Olsen P values for ash and sedimentary soils for near maximum pasture production are 20 and 22 for sedimentary and ash soils respectively (Morton and Roberts, 1999).

The effect of paddock position on Cd concentrations in soils varied greatly. Stock campsites contained the highest Cd concentrations (mean 0.49 mg/kg) and the steep slopes had the lowest concentrations (mean 0.25 mg/kg). Both tracks and easy slopes had intermediate Cd concentrations (mean 0.32 mg/kg). Cadmium enrichment of campsites is caused through heavy deposition of stock faeces (can be equivalent to 12 tonnes/ha/year) which contains appreciable amounts of Cd (measured mean 0.75 mg/kg). Also campsites tend to be flat and therefore faeces and fertiliser particles are less likely to be washed off. In contrast, on steep slopes less fertiliser or faeces is likely to remain *in situ*, especially after heavy rainfall events.

The bioavailability of Cd was also investigated with extractable Cd measured along with Total Cd. Total Cd increased with the increase in rate of P applied but the proportion of extractable Cd to Total Cd remained relatively constant (35-41%). However, paddock position had a greater effect on the plant availability of Cd. The proportion of extractable Cd relative to Total Cd was lower on the campsites (29%) compared to the steep slopes (41%). The lower extractability of Cd from campsites was believed to have been due to the significantly higher ($P < 0.001$) organic carbon content (10%) found on campsites. In comparison, steep slopes contained only 7% organic carbon. Therefore the organic matter content of a soil may be an important soil factor in determining the availability of Cd for plant uptake.

The mean Cd concentrations in pastures generally increased with increasing rates of fertiliser P (Figure 1). However, the greatest effect of the bioavailability of Cd to pasture was clearly seen in the opposite trends to soils found when paddock position was considered (Figure 2).

Figure 1: Effect of fertiliser P on cadmium concentrations (mg/kg) in soils and pastures.

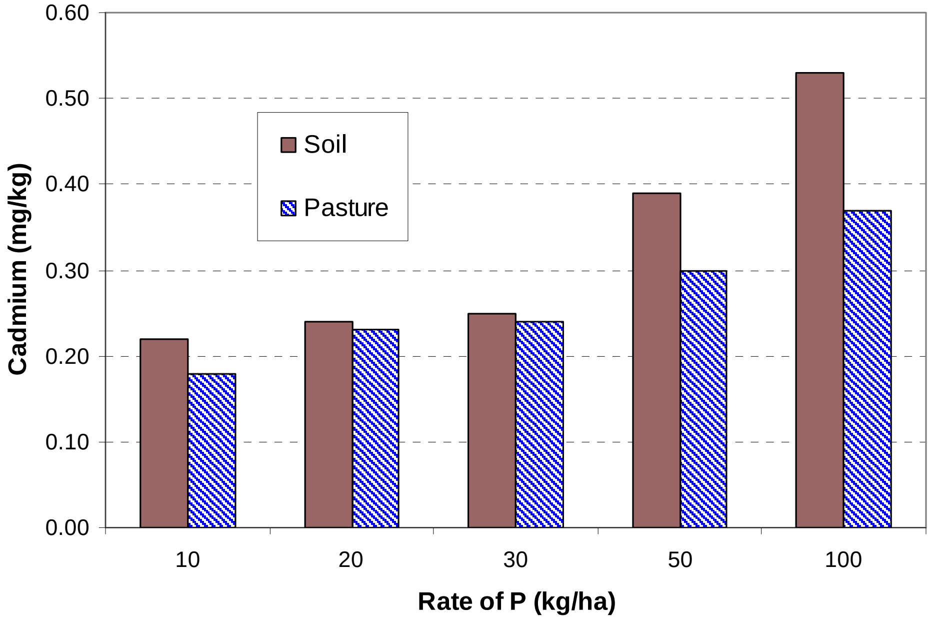
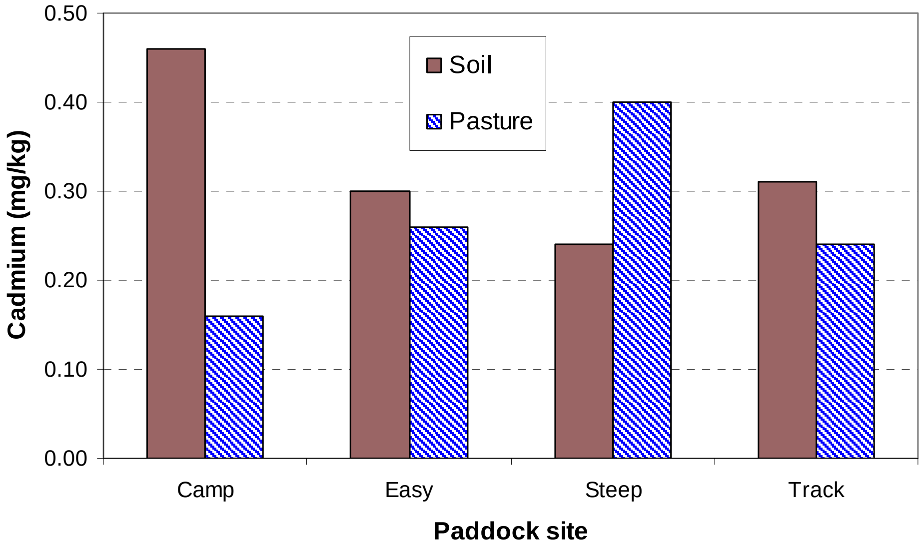


Figure 2: Soil and pasture cadmium concentration (mg/kg) as influenced by paddock site.



Whereas campsites contained the highest soil Cd concentrations they had the lowest pasture Cd concentrations and, conversely, the steep slopes had the lowest soil Cd concentrations but the highest pasture Cd concentrations. This seemingly paradoxical situation may be attributed to the proportion of extractable Cd on campsites relative to steep slopes, although the absolute amounts were similar. Other factors likely to contribute to the effect are: 1) differences in annual pasture yields (e.g., campsites: 11-12 t DM/ha; steep slopes 5-6 t DM/ha) causing a "dilution effect" in the case of campsites, and 2) pasture composition. The herbage on campsites tends to contain higher fertility pasture species (ryegrass) with a lower weed content while on steep slopes lower fertility species dominant (browntop) and more weeds are present. As weeds accumulate higher concentrations of Cd pasture concentrations are higher on the steeper slopes. The easy slopes and sheep tracks tend to have intermediate Cd concentrations to the two extremes.

4.7 Source of cadmium intake by stock

Originally it was believed that Cd accumulation in livestock was due to soil ingestion however research by Roberts and Longhurst (2002) identified that soil ingestion was only about 5% of the diet under hill country sheep farming. Soil ingestion does indeed occur, for example Healey (1967) reported that ewes can ingest 400 g of soil/day and annual intakes of 23 kg or more are possible. However the bulk of the soil ingestion occurs during the winter period when soil Cd concentrations tend to be lower. Under normal farm management practices used on NZ hill country farms the greatest contribution of Cd intake comes from grazing perennial pastures. In these situations weeds may typically comprise 20% of the pastures with the remaining 80% made up of grasses and legumes. As the contribution of pasture to the diet is considerably more than soil ingestion, Cd is accumulating in livestock via plants. Table 6 presents estimates of the Cd burden to sheep under two grazing regimes from soil and pastures from the Waikato hill country study (Roberts and Longhurst, 2002).

Table 6: Estimates of the annual Cd intake by sheep from soil and herbage.

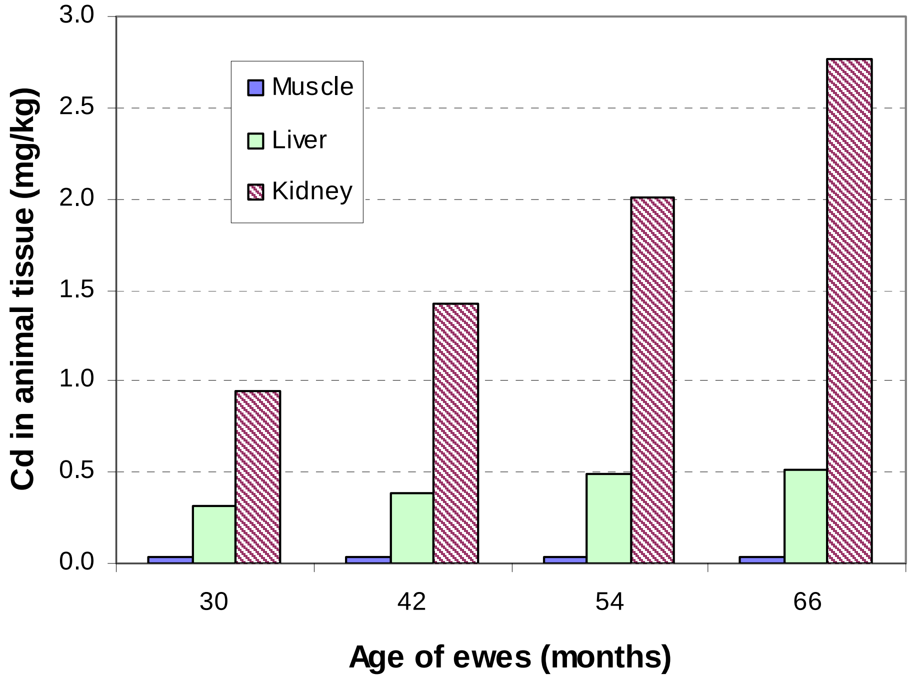
Parameter	Lax grazed	Hard Grazed
Stocking rate (ewes/ha)	10.7	16.4
Liveweight (kg)	53	46
Soil		
Soil ingestion (kg/ewe)	12	22
Cd in soil (mg/kg)	0.36	0.36
Cd intake (mg/ewe)	4.3	7.9
Pasture		
Feed intake (kg DM/ewe)	508	423
Cd in pasture (mg/kg)	0.28	0.28
Cd intake (mg/ewe)	142.2	118.4
Total Cd intake (mg/ewe)	**146.5**	**126.3**

4.8 Cadmium accumulation in stock

Approximately 97 and 99% of the total feed intake for sheep and cattle respectively is excreted in the faeces (Bramley, 1990). Cadmium can accumulate in wool and during the hill country trial this was analysed and found to average 0.09 $\pm$ 0.02 mg//kg (n = 27). Typically, ewes average 4.5 kg wool per year so a small amount (about 0.40 mg Cd/ewe) would be exported off the farm.

Following Cd ingestion by livestock the amount of Cd retained can accumulate in some animal tissues. Continued exposure to small amounts of Cd leads to progressive accumulation. For example, in the hill country study the Cd accumulation rate in lamb kidneys showed a 22% increase per month from 3-months following weaning to 15 months of age (Roberts and Longhurst (2002). In the same study when the two-tooth sheep were introduced to the hill country site (with a mean Cd concentration in kidneys of 0.90 mg/kg) there was a significant increase in kidney Cd concentrations (Figure 3). The Cd accumulation rate, based on final slaughter information, was calculated at 43% per year for kidney tissues and by age 2.5 years the average kidney Cd content of the sheep had exceeded the MRL of 1 mg Cd/kg. In comparison, the accumulation of Cd in liver tissues averaged 19% per year while accumulation in muscle tissue was negligible.

Figure 3: Cadmium accumulation in sheep tissues.



5. Cadmium balance

5.1 Cadmium inputs

A cadmium balance can be constructed for NZ pastoral soils from the research already undertaken. Information can be obtained on soil groups, soil depth, bulk density, typical pasture yields, as well as atmospheric accessions and leaching losses. From this information the estimated Cd accumulation over time and the number of years taken to reach a specific soil Cd target can be determined. Annual atmospheric deposition rates for Cd were measured over two years and averaged 0.36 g/ha (range 0.28-0.43) for the Hawkes Bay (Gray et al., 2003a). Little data is available in NZ on leaching losses under pastoral farming systems. In a lysimeter study of various NZ soils (Gray et al., 2003b) found that the average amount of Cd leached from pallic soils was 270 mg/ha/year. Losses of soil Cd can occur from pastoral farms due to surface runoff of fine soil particles. The finer particles contain higher Cd concentrations than the bulk soil and losses are accentuated under heavy rainfall events and increased land slope. As can be imagined annual sediment losses are highly variable. Hicks (1994) measured sediment losses between 250-900 kg/ha from pasture land throughout NZ. Under Hawkes Bay hill country sheep/beef farming a value of 500 mg Cd/kg has been used for estimating sediment losses from pastures.

Before any estimate of Cd accumulation in Hawkes Bay soils can be undertaken some parameters are required to be defined. The following assumptions have been used based on the best available information (Table 7).

Table 7: Parameters used for assessing soil Cd accumulation.

Input parameter	Unit used	Value used
Fertiliser Cd	mg/kg	26
Soil depth	cm	7.5
Fertiliser rate	kg/ha	215
Bulk density	t/m^3	1.07
Atmospheric	g/ha	0.36
Leached	mg/kg	270
Initial soil Cd	mg/kg	0.34 *
Pasture DM yield **	kg/ha	10,000
Sediment yield	mg/kg	500

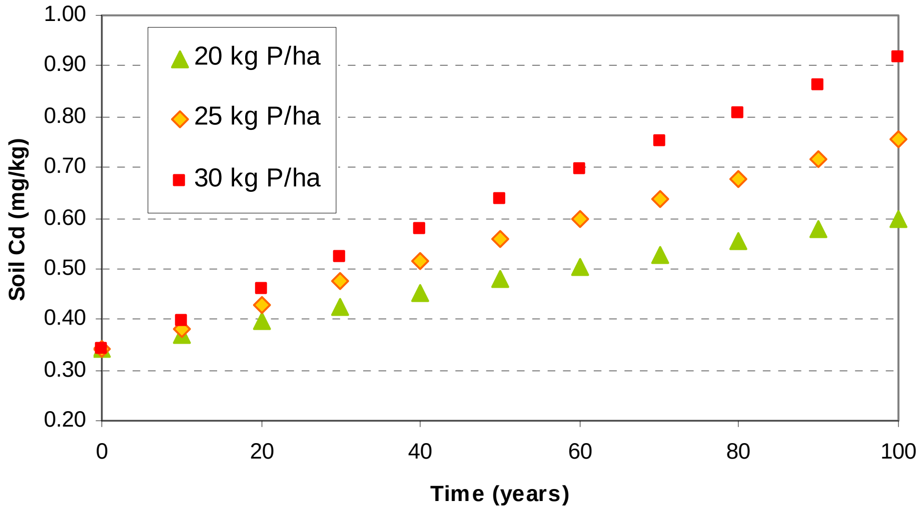
- * The soil Cd concentration of 0.34 mg/kg is used to account for estimated accumulation over 15 years since 1990 survey findings of mean soil Cd of 0.30 mg/kg.
- ** The effect of Cd removal in animal product and transfer to non-productive areas of the farm are incorporated in the model.

5.2 Calculated increase of cadmium in Hawkes Bay soils

5.2.1 Sheep/beef farms

Based on a typical sheep/beef farm in the Hawkes Bay the following scenarios are presented in Figure 4 showing the effect of applying three different rates of maintenance fertiliser (20, 25, and 30 kg P/ha). Applying the maintenance rate of P fertiliser for these soils shows a slow accumulation over time. At this rate of P fertiliser it would take almost 300 years before the soil Cd limit of 1 mg/kg was reached. However, if 30 kg P/ha were routinely applied then the soil Cd limit would be reached in 115 years. Based on the Fertiliser Industry standard of 280 mg Cd/per kg P in fertilisers to achieve a steady state level in soil Cd the application rate would need to be reduced to 11 kg P/ha. At this P fertiliser rate there would be serious deterioration in pasture yields and quality, therefore a better strategy would be to target further reductions in the Cd content in fertilisers.

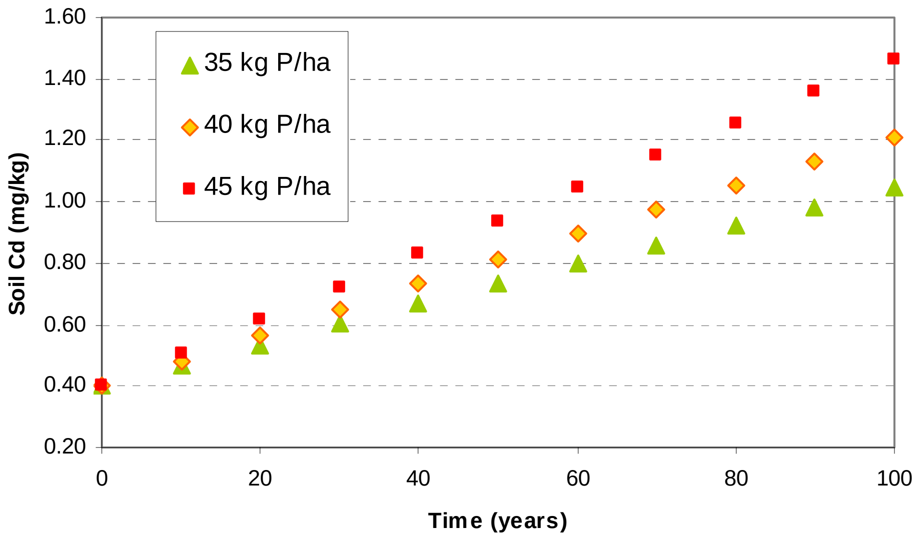
Figure 4: Cadmium accumulation in pallic soils under three fertiliser P regimes on sheep/beef farms.



5.2.2 Dairy farms

With the intensification occurring within the dairy industry more dairy farms could be expected in the Hawkes Bay. A similar scenario as that used for the sheep/beef farms has been followed except that for the initial soil Cd a higher figure of 0.40 mg/kg has been used because of the higher fertiliser P inputs used on dairy farms and an annual pasture yield of 12 t DM/ha. Maintenance fertiliser P inputs increase with stocking rates, for example, 27-36 and 34-45 kg P/ha are recommended for 2.5 and 3.0 cows/ha, respectively (Roberts and Morton, 1999). Soil Cd accumulation on dairy farms is presented in Figure 5. Because of the higher initial soil Cd and the larger quantities of fertiliser P applied on dairy farms the accumulation of soil Cd is far quicker than under sheep/beef farming systems. In fact, the longevity of dairy farming in the region is seriously questioned as at the lowest rate of maintenance P (35 kg/ha) the soil Cd limit of 1 mg/kg would be reached in 92 years. As the maintenance fertiliser P rate is increased the timeframe before breaching the soil Cd limit decreases to just 55 years at the 45 kg P/ha rate. To achieve a steady state soil Cd concentration under the current Cd loadings in fertilisers then fertiliser P inputs would need to be reduced to 14 kg P/ha. Like the sheep/beef scenario, such fertiliser P input reductions are clearly impractical and instead targeting reductions in the fertiliser Cd concentrations would be more effective.

Figure 4: Cadmium accumulation in pallic soils under three fertiliser P regimes on dairy farms.



6. Mitigation strategies to minimise cadmium uptake

6.1 Fertiliser manufacture

As fertiliser P inputs is the main contributor to Cd enrichment of pastoral soils mitigation strategies targeting this area would be most effective. The Fertiliser Industry has been proactive over the past 10 years in reducing the Cd concentrations in fertilisers and has achieved a reduction from 420 mg Cd/kg P in 1995-1996 to 280 mg/kg P in 2002. Similar reductions have been achieved in Australia. However, when compared against the voluntary or limits in effect in Northern Europe (range 35 -200 mg Cd/kg P) the Australasian limits appear to have some room for downward movement.

There are possible chemical processes that could be used within the Fertiliser Industry such as volatilising most of the Cd by calcinations of the phosphate rocks (PRs) to reduce the Cd concentration. This is however an expensive process and the calcinations decrease the reactivity (and hence effectiveness) of the PRs. In some PRs, a significant quantity of Cd associated with the organic carbon content of this maybe able to be removed with caustic solvents removing the Cd without removal of P (Loganathan and Hedley, 1997).

6.2 Fertiliser source

As mentioned in section 3.4 the source of the PR deposit has the greatest influence on the Cd content in the manufactured phosphatic fertiliser. More consideration will need to be given in the future to sourcing PRs from igneous deposits. Many of these deposits come from the Middle East (Jordan, Israel) or Mediterranean region (Egypt, Tunisia, Morocco) and contain Cd concentrations as low as 10 mg/kg or less. The direct application of low-Cd RPRs, instead of superphosphate, is another possible option especially on farms that already have soil Olsen P values above optimum. For example taking the dairy situation in Figure 5 and using Sechura RPR which has a Cd concentration of 11 mg/kg (equivalent to 85mg Cd/kg P) means that 3.4 g Cd/ha would be applied at a maintenance rate of 40 kg P/ha. The result of using this RPR would be that it would take 593 years of Cd accumulation before the 1 mg/kg concentration in soil was reached. This is clearly a practical option for the sustainability of farming in the Hawkes Bay.

6.3 On-farm options

While there are several on-farm strategies for limiting Cd ingestion into livestock the options for mitigating Cd concentrations already present in the soil is more difficult. Increasing the soils' pH can decrease Cd availability but is unlikely to decrease its presence. Likewise the addition of organic matter can decrease the bioavailability of Cd. Maintaining higher fertility pasture species tend to have lower Cd concentrations.

Possible options for farmers of reducing the soils' total Cd content follow.

1) Applying low-Cd containing P fertilisers or direct application of RPRs would have the greatest effect.
2) If possible to plough the land when re-grassing and invert the top few cm of soil where the accumulated Cd is likely to be the most concentrated.
3) Growing a Cd accumulating crop and removing it from farm.
4) More than 99% of the animal's daily Cd intake is returned back to the soil in faeces, so feeding a larger proportion of the livestock diet on a feed pad could transfer greater quantise of manure where it could be treated to reduce Cd content before return back to soil.

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Appendix 1: Excerpted from ‘Guidelines for the safe application of Biosolids to land in New Zealand’, (2003) New Zealand Water and Wastes Association.

5 SOIL CONTAMINANT LIMITS

5.1 Introduction

This chapter provides the background to the soil metal limits given in these *Guidelines* (see section 7; and Volume 1, section 4). The recommended limits represent a further development from the Department of Health’s 1992 soil limits, which were in turn derived from limits used in the UK. These original limits have been revised using more up-to-date data. The recommended soil limits are based on our current state of knowledge, and it should be noted that more attention has been taken of research carried out with actual biosolids than of studies where metals have been added to soils in some different form (e.g., as simple metal salts). It is also important to realise that as the results of current and future research are reported, further changes to the soil limits may be required. In this regard, it should be noted that in the short to medium term, heavy metal accumulation in soils as a result of biosolids application is unlikely to be a significant issue. As long as biosolids are applied at agronomic rates (based on nitrogen application rates), the accumulation of metals will be very slow, and research should have answered the present uncertainties regarding permissible metal loadings in soils long before the current soil limits are reached.

5.1.1 Methodology

Three different methodologies are commonly used in setting soil limits:

- *analysis of pollutant pathways* – which involves an assessment of the effect of a particular metal on a particular target organism (this is the method used by the USEPA)

- *lowest observed adverse effect concentrations (LOAEC)* – where limits are set based on actual occurrences of effects due to metals (this is the method used in setting the UK and hence the Department of Health’s 1992 limits)

- *metals balance approach* – where metal limits are set based on losses of metals due to crop removal, soil erosion and leaching.

Detailed risk assessment approaches, such as that used by the USEPA (1995), although appearing more sophisticated than the LOAEC approach, have their limitations. They can only ever be as good as the assumptions made in their development and the data used to estimate the various input parameters required (e.g., soil–plant transfer coefficients). In particular, the USEPA (1993) soil limits for biosolidstreated soils, estimated using a risk assessment process, have been the subject of considerable criticism. For several metals the derived soil limits are clearly much higher than those at which phytotoxicity has been observed, or would produce plant metal concentrations above current food maximum permissible concentrations (MPCs). In addition, different risk assessment procedures can result in vastly different soil metal limits. This raises questions regarding the use of this type of approach. For example, compare the soil copper limit estimated using the USEPA (1995) procedure (approximately 750 mg/kg) and that estimated using the Ministry for the Environment and Ministry of Health (MfE and MoH, 1997) procedure (40 mg/kg). In this case, these differences occur due to the use of different assumptions, exposure pathways and receptors in the risk model.

The metal balance approach to estimating soil metal limits essentially reflects a philosophy of allowing no metal accumulation in soils above background levels, irrespective of any evidence of their potential adverse effects. This approach effectively prevents recycling of biosolids to land.

Therefore, in keeping with the original New Zealand limits, the LOAEC approach has been retained in defining the current limits, which is thought to be appropriate given the effects-based approach of the Resource Management Act 1991.

5.2.2 Cadmium

Soil metal limit = 1 mg/kg dry weight

Mean background cadmium (Cd) concentrations for surface soils worldwide range from 0.06 to 1.1 mg/kg (Kabata-Pendias and Pendias, 2001). ANZECC (1992) guidelines for contaminated sites indicated typical background Cd concentrations in the range 0.04 to 2 mg/kg, and set an investigation level of 3 mg/kg (the level above which an environmental assessment would be necessary). A survey of 86 native (unmodified) soils in New Zealand determined an overall average background Cd concentration of 0.20 mg/kg, with a range of 0.02–0.77 mg/kg (Roberts et al., 1994). In the complementary survey of 312 pastoral soils, the average Cd concentration was 0.40 mg/kg, with a range of 0.04–1.53 mg/kg (Roberts et al., 1994). The elevation of Cd in pastoral soils was attributed to the long-term application of phosphate fertilisers. Several other New Zealand studies have confirmed the build-up of Cd in soils as a result of phosphate fertiliser use (e.g., Loganathan et al., 1995; Loganathan et al., 1997; Gray et al., 1999). Cd is regarded as one of the most bio-available of the heavy metals, and at relatively low concentrations in the soil can accumulate in the edible part of crop plants, while having no detrimental effects on crops themselves (Smith, 1996). Even with current New Zealand pasture soil Cd levels (mean 0.4 mg/kg), a substantial percentage of ovine and bovine kidneys exceed the maximum residue level of 1 mg/kg for the Cd content of meat and offal for human consumption.

As a result, the New Zealand meat industry now automatically condemns kidneys of slaughtered sheep over 2.5 years of age (Roberts et al., 1994). In addition, a survey of wheat crops in Mid Canterbury (Roberts et al., 1995) revealed that 15% of grain samples had Cd concentrations above the current maximum permissible concentration (MPC) of 0.1 mg/kg fresh weight (Australia New Zealand Food Authority Standards). A more recent investigation by Gray et al. (2001) found 10% of the wheat grain samples examined were non-compliant with the MPC. The Cd concentrations of the soils on which these wheat crops were grown were all below 0.45 mg/kg (Gray et al., 2001).

The soil limit of 1 mg Cd/kg soil is set primarily to minimise Cd concentrations in animal and crop products and to avoid barriers to international trade (failure to meet maximum residue levels and MPCs in food products set by importing countries). It should also be noted that although the current European Community maximum soil limit is 3 mg/kg (CEC, 1986), this value is under review (EC, 1999), and several European countries are already using much lower limits. The most recent European Community draft directive proposes cadmium levels between 0.5 and 1.5 mg/kg depending on soil pH (EC, 2000). It is seen as important that our limits for Cd, in particular, are not substantially higher than that of the European Community, which is an important export market for New Zealand produce. Using a risk assessment methodology, the UK has set a contaminated land guideline level for Cd in soil that is pH dependent (DEFRA, 2002b). For residential land where plants are grown for food and for garden allotments, the soil guideline values are 1 mg/kg dry weight (at pH 6), 2 mg (pH 7) and 8 mg (pH 8). The Canadians have a risk-based soil quality guideline of 1.4 mg/kg dry weight for agricultural and 10 mg/kg for residential land (CCME, 1999).

Setting a guideline level of 1 mg Cd/kg soil should also protect the microbial population of the soil (Chander et al., 1995), and should not result in significant leaching of Cd from the soil into groundwater. The Dutch soil quality objectives, which give consideration to leachability of soil contaminants set the target value for Cd in soil at 0.8 mg/kg (MHSPE, 2000). However, data on Cd leaching from field soils are scarce, and this is an area requiring further research. In the short term, adding biosolids-containing materials to soil may, as a result of increased organic matter levels, actually decrease Cd bio-availability to plants (e.g., McLaren and Gray, 1999; Bolan et al., 2001; Buchan, 2001). However, the long-term situation, as the organic matter decomposes, is unclear and requires further research. Some research does suggest that the bio-availability of added Cd may be permanently reduced over time as a result of interactions with inorganic soil components (e.g., Hamon et al., 1998; Gray et al., 1999; Li et al., 2001). Currently the evidence for this effect is far from conclusive so a precautionary approach has been taken in setting the soil Cd limit.

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