CADMIUM – WHERE ARE WE AT? WHAT DO WE NEED? HOW DO WE GET THERE?

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Background

Cadmium (Cd) is a non-essential, naturally occurring heavy metal present as a natural impurity in phosphate rock used to produce phosphate fertilisers. With continuous fertiliser application cadmium may accumulate in soil.

Cadmium can cause detrimental effects to plants, animals and people and concerns about its gradual accumulation in soil exist. Further, other than smoking and industrial exposure, the major route of cadmium intake in people is through food or water (FAO/WHO, 1989).

A brief history of cadmium management in New Zealand agriculture

Figure 1 shows a timeline of notable events in the history of managing cadmium in New Zealand agriculture. Briefly, phosphate fertiliser was and continues to be a critical component of increasing productivity in New Zealand agriculture. Prior to the 1990's phosphate fertiliser manufactured with predominantly Nauru Island phosphate rock (high in Cd) fertiliser was used (MAF 2008). In 1991, as concerns around Cd in agriculture were raised, an offal discard policy was implemented in New Zealand. This policy required that kidneys from sheep with 6 erupted teeth, usually older than 30 months were discarded from the human food chain. This was followed by the introduction of voluntary limits on the level of cadmium in phosphate fertiliser – initially 340 mg Cd/kg P in July 1995, and stepping down to 280 mg Cd/kg P by Jan 1997. From 2001, independent audits on fertiliser cadmium content were included in the Fertmark scheme administered by the New Zealand Fertiliser Quality Council, and over 2001-2005, the average concentration was 175 mg Cd/kg P (MAF 2008).

In 2003 the *Guidelines for the safe application of biosolids to land in New Zealand* was released (NZWWA 2003). These guidelines included a soil limit for Cd of 1 mg Cd/kg for the application of biosolids to land. This was based on minimising Cd concentrations in animal and crop products and to avoid barriers to international trade. As the Biosolids Guidelines had quasi-regulatory status, the soil limit has subsequently been applied to other situations for assessing the potential impact of cadmium in New Zealand soils (e.g. Kim 2005, Taylor et al 2007).

There was renewed interest in cadmium in the mid-2000's with the release of a report on historical cadmium accumulation in the Waikato region, which included discussion on ways to prevent or manage further accumulation (Kim 2005). This led to the formation of the Cadmium Working Group, comprised of representatives from central and regional government, agricultural sectors and the fertiliser industry, in 2006. This group commissioned a review of cadmium concentrations in soil (Taylor et al. 2007), and undertook a risk assessment of cadmium in New Zealand agriculture (MAF 2008). This in turn led to the development of a National Cadmium Management Strategy that underwent international review, prior to being released in February 2011.

In parallel to the development of the strategy, the *National Environmental Standard for assessing and managing contaminants in soil to protect human health* was being developed and came into force on 1 January 2012. While this standard does not apply to production land (other than if soil near residential buildings or used for farmhouse gardens is disturbed), it does include a soil contaminant standard (SCS_{health}) for rural residential land-use of 0.8 mg Cd/kg (pH 5) that needs to be considered in the context of future land use flexibility.

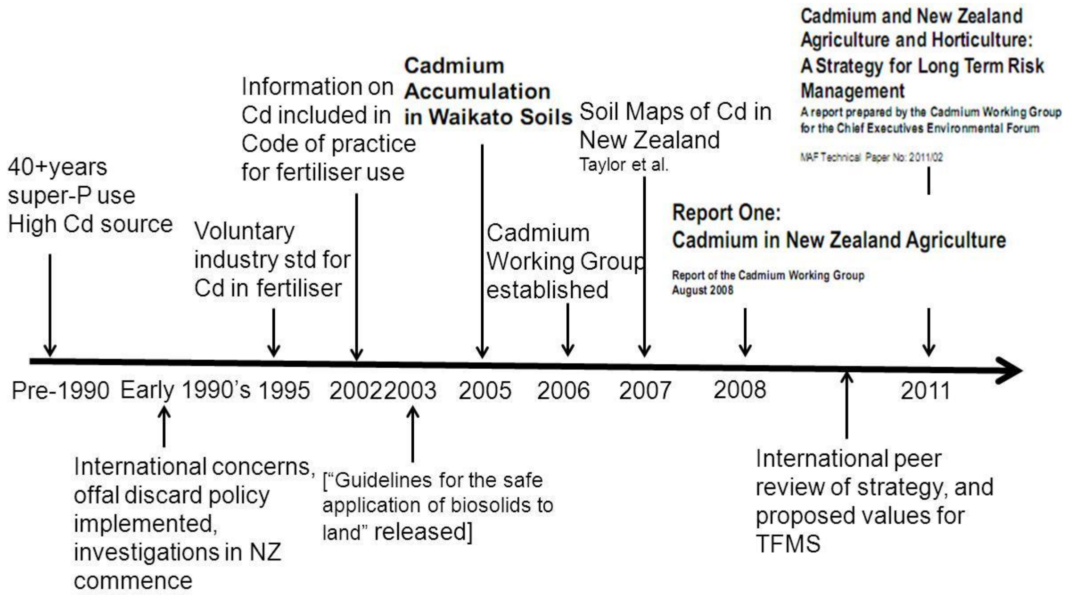

Figure 1 Timeline of notable events in history of management of fertiliser-derived cadmium in New Zealand.

Where are we at?

The National Cadmium Management Strategy

The *Cadmium and New Zealand Agriculture and Horticulture: A Strategy for Long Term Risk Management* (MAF 2011) provides a national approach for managing Cd in New Zealand agriculture. It is based on New Zealand research undertaken from the 1990's to the early 2000's, and underwent international review (Warne 2011).

The strategy has the objective:

> *To ensure that cadmium in rural production poses minimal risks to health, trade, land use flexibility and the environment over the next 100 years.*

This objective is intended to be achieved by managing the key risk areas of

- Protecting human health
- Maintaining trade access and a vibrant productive sector
- Maintaining flexibility in land use options
- Protecting the environment, particularly soil health and function, groundwater and natural ecosystems

The Tiered Fertiliser Management System (TFMS) is a central part of the strategy and aims to manage Cd accumulation in soil by imposing increasingly stringent phosphate fertiliser management practices as Cd concentrations increase. There are five tiers and four trigger values, based on increasing soil Cd concentrations, which result in different levels of action primarily related to phosphate fertiliser application (Table 1).

Table 1 Required management actions in relation to specified cadmium (Cd) concentrations trigger values, and the source of the trigger value

Tier	Management action	Cd concentration (mg/kg)	Trigger value (mg/kg)	Source of value
0	Five-yearly testing	0–0.6	0.6	99th percentile of natural background concentrations in Taylor et al. (2007)
1	Application is restricted to a set of products and application rates to minimise accumulation, and 5-yearly testing	>0.6–1.0	1.0	NZ Biosolids guidelines (NZWWA 2003)
2	Application rates are further managed by use of a cadmium balance programme to ensure that Cd does not exceed an acceptable threshold within the next 50 years	>1.0–1.4	1.4	Canadian SQG (human and ecological) for agricultural land use (CCME 1999)
3	Application rates are further managed by use of a Cd balance programme	>1.4–1.8	1.8	UK Soil Guideline value for allotments (Environment Agency 2009)
4	No further accumulation above the trigger value	>1.8		

To provide some context around the significance of these numbers, Taylor et al (2007), found that a number of soils in the Waikato and Taranaki regions exceeded 1 mg Cd/kg, while nationally concentrations ranged from 0.00 to 2.52 mg Cd/kg. Thus, there are sites in New Zealand that require management to reduce further Cd accumulation. Since the implementation of the strategy farmers are encouraged to include Cd in soil analyses when determining fertiliser requirements to enable application of the TFMS and initiate the specified 5-yearly testing regime.

Research

Studies on Cd in New Zealand have largely focussed on establishing Cd concentrations in soils, which has sometime been used to determine accumulation, and studies investigating plant uptake or phytoavailability (measures of the plant available Cd typically determined by the use of various extractants) (Figure 2). As can be seen from this figure, the majority of research in New Zealand on Cd has been conducted prior to 2006 (and in reality mainly prior to 2000). This research has largely been summarised in MAF (2008) and Cavanagh et al (2013) and is not discussed further here suffice to mention that studies on plant uptake have been conducted on a limited number of species, and variation between cultivars has only been examined for wheat (Gray et al. 2001). Of the post-2006 studies, some have been specifically on Cd, including its accumulation in soil (Schipper et al. 2011a, b; McDowell 2012, McDowell et al 2013) while for others, Cd is one of several metals being examined (Black et al. 2012 a,b; Gaw et al. 2012). These recent publications also include the only assessment of potential offsite movement of Cd through surface run-off from agricultural fields (McDowell 2010).

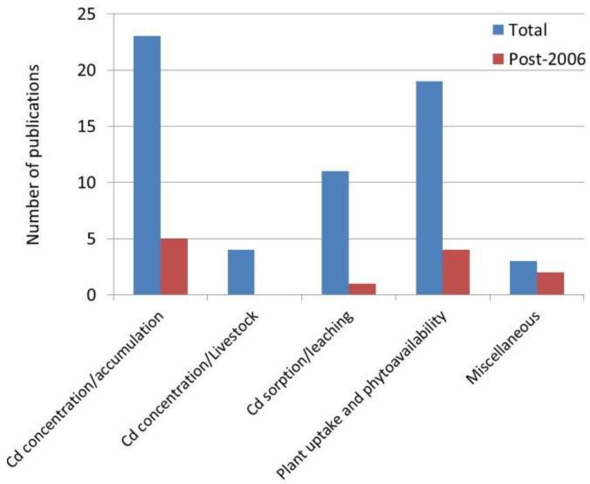

Figure 2 New Zealand publications (scientific papers and reports) on cadmium (Cd) in soil, grouped in general topic areas. * phytoavailablity studies refers to those that use chemical means to assess plant-available cadmium.

In addition to these recent publications, some research is currently being conducted at Lincoln University and Landcare Research. Research at Lincoln University is investigating options to reduce plant uptake of Cd, primarily through the addition of lignite and compost. This includes pot trials and soil lysimeters. Landcare Research is using soil lysimeters to investigate the leaching of Cd derived from fertiliser, and dairy shed effluent, through a stony soil that has been identified as a soil particularly vulnerable to leaching.

This research starts to address some of the identified research gaps (see below) although many gaps remain.

What do we need?

The National Cadmium Strategy is based on international research along with the New Zealand research which was largely undertaken from the 1990s to the early 2000s. It acknowledges a lack of New Zealand specific information is constraining management of Cd risks. As such, research priorities were identified within the strategy with:

- Immediate priorities determined as the knowledge required to improve the management of Cd
- Medium-term priorities were those related to information required to review the strategy and;
- Long-term priorities were those focussed in areas leading to no long-term net accumulation of Cd in soils

The specific priorities under each category are shown in Table 2. It should be acknowledged that the relative importance of these priorities may differ between stakeholders. For example, remediation approaches and potential productivity impacts are of more interest to fertiliser companies while environmental and ecological impacts are of more interest to regional councils.

Table 2 Research priorities identified in the National Cadmium Management Strategy (from MAF 2011)

Immediate	**Medium term**	**Long term**
• Information about soil Cd concentrations • Pathways and transport mechanisms within soil and the soil-plant-animal systems in a New Zealand context, particularly in the context of identified exceedances. • Soil management techniques to minimise Cd uptake. • Varietal variation in Cd uptake with a view to exploiting genetic variation in uptake	• Understanding of Cd levels suitable for different land uses and animal classes. • Environmental and ecological impacts of Cd both *in situ* (soil organisms) and in the wider ecosystem. • Risks from Cd in groundwater in relation to drinking water standards. • Cost-benefit analysis of the Cd management strategies and alternative actions. • Soil Cd balances and appropriate tools.	• Alternative sources of low Cd phosphate. • Remediation approaches where this may be necessary. • Understanding of the costs and benefits of a strategy of no net accumulation. • Increasing the efficiency of phosphate use.

As noted above, the TFMS is an integral part of the National Cadmium Management Strategy. The soil Cd concentrations currently used as trigger values in the TFMS were agreed to by the Cadmium Working Group (CWG), following international review and recommendations (Warne 2010), at a meeting in September 2010 (MAF 2011) and are from a variety of sources (Table 1). The CWG agreed that these trigger values will be reviewed after 5–7 years and compared to New Zealand-specific values (MAF 2011).

A report commissioned by MPI in 2012 (MPI 2012) provided recommendations on the research required to develop New Zealand-specific soil guideline values for use in the Tiered Fertiliser Management System. This report considered the protection of four endpoints: Food safety, human health, ecological receptors (e.g. microbial processes, soil invertebrates, plants) and groundwater. The report included a summary of available soil guideline values derived to protect these different endpoints (Table 3), and provides context for the report recommendations.

Table 3 A summary of soil guideline values derived to protect different endpoints (from MPI 2012)

Endpoint	Range of values for derived soil guideline values (SGV)	Source
Food safety	0.2–2.3 mg/kg (pH 4.5–7.5, wheat) 0.7–1.0 mg/kg (pH 5–6, offal (kidney))	Warne 2011 Rodrigues et al. 2012
Ecological receptors Microbial processes Soil species Secondary poisoning	 1.5–86 mg/kg 1–140 mg/kg 0.6–0.9 mg/kg	Various
Human health	0.8 mg/kg (rural residential) (pH 5) 3 mg/kg (residential) (pH 5)	NES for soil contaminants
Groundwater	unknown	

As can be seen from Table 3, SGVs derived to ensure food safety standards are met can be quite low, and lower than some of the values in the TFMS. However, relevant values for New Zealand need to take into account crop species, and soil types present in New Zealand. SGVs for the protection of ecological receptors cover a wide range of concentrations – the reason for this variation includes the data used, and more significantly, the methodology used. While these values tend to be higher than SGVs for protection of food standards, the European risk assessment report for cadmium (EU 2007) indicates that nitrogen fixation by *Rhizobium,* which is an important part of New Zealand agriculture, is the most sensitive microbial process – this in turn may have an impact on pasture productivity at environmentally relevant Cd concentrations. SGVs for the protection of human health in New Zealand are provided by the *National Environmental Standard for assessing and managing contaminants in soil to protect human health,* and as indicated above are primarily applicable in the context of future land-use flexibility. No SGVs to protect groundwater were found, however it is more relevant to consider this on a site-specific basis, and thus this endpoint isn't suitable for inclusion in the TFMS.

The recommendations arising from the report, in order of priority, were that:

- Further research is undertaken to better understand the pathway of Cd accumulation in animal agricultural systems in New Zealand.
- Further research is undertaken to establish the relationship between plant uptake and species, cultivar, and soil properties for relevant species. This research requires industry input to determine what species and cultivars are most economically important and widely grown, and should include crop species that are high and low in Cd accumulating ability.
- The methodology for deriving SGVs for ecological receptors proposed in the report is used to generate preliminary SGVs using currently available toxicity data. New Zealand data on the toxicity of Cd under New Zealand conditions (species, soils) are generated to determine whether the preliminary SGVs are sufficiently protective.
- Further research is required to better establish the risk of leaching to groundwater, in particular for vulnerable soils, such as stony soils

These recommendations highlight that exceedance of food standards, and the associated trade risk (from the actual exceedance or damage to our clean green image) is likely to occur at the concentrations lower than that associated with ecological impacts. However, greater knowledge of Cd uptake by economically important crop species and cultivars, factors influencing this uptake (e.g soil properties), is required to better quantify the risk, as well as providing knowledge to enable more effective management of the risk (e.g. by growing low-Cd accumulating cultivars on soils with higher Cd concentrations). Similarly, better understanding of the routes of exposure for livestock, leading to exceedances in offal, is required to better quantify the risk, as well as providing knowledge to enable more effective management of the risk.

The research priorities identified above largely relate to a better fundamental understanding of the movement and effect of cadmium in New Zealand soil-plant-animal systems. This information could then be applied in several contexts: better quantification of the potential risks associated with Cd – in particular, uptake into food products; flexibility of land use within agricultural systems; potential environmental and productivity impacts – and options to mitigate or manage the risks, including on a site-specific basis (Figure 3). Included within the management options is a cadmium balance programme, which is identified as a critical element of managing cadmium (through its inclusion in the TFMS). A cadmium balance model (Cadbal) has previously been developed and used (e.g. McDowell 2012), and could provide the basis for such a programme, however further research to refine default parameters and for model validation is required to ensure that the model is robust for New Zealand circumstances, as well as being able to be used readily.

Complementing this research is specific research on risk mitigation options – this could include plant breeding, the use of amendments or other technological approaches – and the continued development of policy or strategic approaches to managing cadmium in agricultural systems.

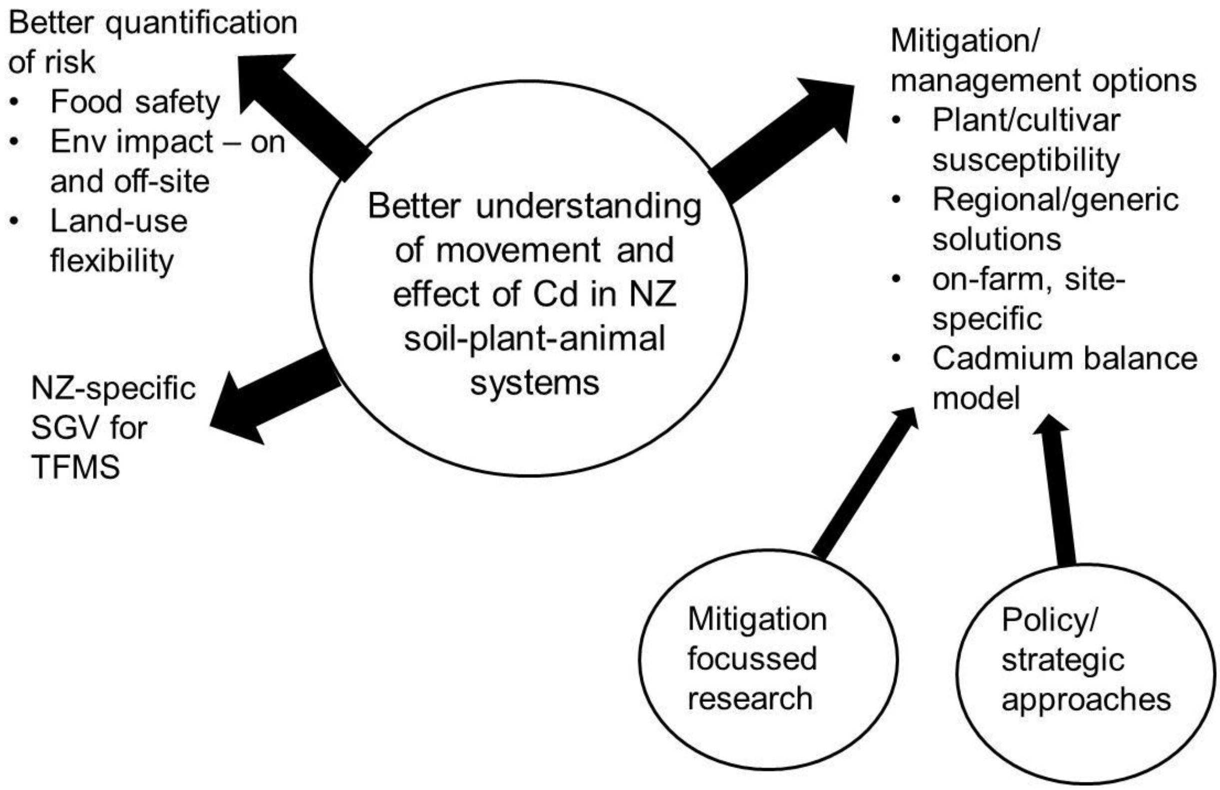

Figure 3. Diagrammatic representation of the research required to progress cadmium management in New Zealand.

How do we get there?

Cadmium management is integrally related to fertiliser management. Thus the strategic extension of research programmes investigating the use (by plants e.g. nutritional requirements), efficiency (e.g. precision-agriculture), movement of fertilisers, in particular phosphate fertilisers, to include Cd as another parameter being measured can provide a cost-effective means to provide additional knowledge on Cd risks (in particular Cd movement), and mitigation options.

Further, farm management practices may also influence the potential risk associated with Cd – e.g. through the selection of crop cultivars, or choice of forage crops (for example, brassicas are a common winter forage crop and are known to often accumulate metals, including Cd – thus the choice of forage crops may influence the intake of Cd by livestock – additionally greater soil ingestion may occur during grazing on forage crops and represent additional intake). As such consideration should be given to the inclusion of Cd as an additional parameter to measure in studies examining different aspects of farm management.

Finally, there remains the need for Cd-specific research programmes to be undertaken – such as to investigate the influence of New Zealand crop species and cultivars on Cd uptake, the influence of soil properties on plant uptake; the potential impact of Cd on rhizobia in New Zealand soils and under New Zealand conditions; and to examine routes of Cd intake in animal systems.

Funding for the required research remains problematic in an environment where ‘innovation’ and ‘export growth’ are the primary focus for research investment and ‘defensive investment’ to protect and maintain the resources upon which our agricultural economy is based, is viewed less favourably. While the need for research on Cd is unlikely to be urgent, in the sense that significant exceedances of food standards or an ecological disaster are unlikely to be imminent (although there is some debate on this point e.g. Joy 2012); it remains an issue that isn’t going away. Effective management strategies have progressed as far as they can with the research undertaken to date. Undertaking further research sooner rather than later will ensure that a greater array of management and mitigation options are available for use at a lower cost, and potentially avoid currently unforeseen catastrophic events (e.g. rejection of high-value export products), as well providing a better perspective on the urgency for any specific further research.

In the same manner in which the Cd management strategy was developed, a joint partnership between government and industry may be a means to progress this research. Industry involvement ensures commitment, effective uptake of the research, and implementation of management strategies, while government involvement ensures additional transparency in the decision-making process.

References

Black A, McLaren RG, Reichman SM, Speir TW, Condron LM 2012a. Examining the integrity of soil metal bioavailability assays in the presence of organic amendments to metal-spiked soils. Soil Use and Management 28: 89-100.

Black A, McLaren RG, Reichman SM, Speir TW, Condron LM 2012b. Ryegrass (Lolium perenne L.) grown in soils treated with biosolids and metal salts. Soil Research 50(4): 304-311.

Cavanagh JE, Scott J, Stevenson B 2013. Status of research on Cd in New Zealand. Landcare Research Report Draft.

CCME (Canadian Council for Ministers for the Environment) 1999. Canadian Environmental Quality Guidelines. Cadmium. Canadian Council of Ministers of the Environment, Ottawa, Canada. 9p. Available at: http://www.ccme.ca/publications/can_guidelines.html

Environment Agency 2009. Soil guideline values for cadmium in soil. Science Report SC050021/Cadmium SGV. Available from: http://www.environment-agency.gov.uk/static/documents/Research/SCHO0709BQRO-e-e.pdf.

EU 2007. European Union risk assessment report: Cadmium oxide and cadmium metal Part 1- Environment. European Commission.

Gaw S, Northcott G, Kim, N et al.2012. Comparison of earthworm and chemical assays of the bioavailability of aged 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene, 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane, and heavy metals in orchard soils. Environmental Toxicology and Chemistry 31(6): 1306-1316.

Gray CW, McLaren RG, Roberts AHC 2001. Cadmium concentrations in some New Zealand wheat grain. New Zealand Journal of Crop and Horticultural Science 29: 125–136.

FAO/WHO 1989. Toxicological evaluation of certain food additives and contaminants: Cadmium. WHO Food Additive Series 24. Thirty-third meeting of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization: Geneva.

Joy M, 2012 Opinion: The long-term poisoning of our rural soils with the heavy metal cadmium threatens vast tracts of rural land and will soon affect the exportability of crops and animals. Rural News August 23, 2012.

Kim, ND 2005. Cadmium accumulation in Waikato soils. Environment Waikato Technical Report 2005/51.

MAF 2008. Cadmium in New Zealand Agriculture. Report of the Cadmium Working Group August 2008. Wellington, Ministry of Agriculture and Forestry Available at http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/land-management/cadmium-in-nz/.

MAF 2011. Cadmium and New Zealand agriculture and horticulture: a strategy for long term risk management. Wellington, Ministry of Agriculture and Forestry. MAF Technical Paper No: 2011/03. Available at http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/land-management/cadmium-in-nz/

MPI 2012. Working towards New Zealand risk-based soil guideline values for the management of cadmium accumulation on productive land. Wellington, Ministry for Pimary Industry. MPI Technical Paper No: 2012/06. Available at http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/land-management/cadmium-in-nz/

McDowell RW, Taylor MD, Stevenson BA 2013. Natural background and anthropogenic contributions of cadmium to New Zealand soils. Agriculture, Ecosystems and Environment 165: 80-87.

McDowell RW 2012. The rate of accumulation of cadmium and uranium in a long-term grazed pasture: implications for soil quality. New Zealand Journal of Agriculture.

McDowell RW 2010. Is cadmium loss in surface runoff significant for soil and surface water quality: a study of flood-irrigated pastures? Water Air and Soil Pollution 209: 133–142.

NZWWA 2003. Guidelines for the safe application of biosolids to land in New Zealand. Wellington, New Zealand Water and Wastes Association.

Rodrigues SM, Pereria ME, Duarte AC, Romkens PFAM 2012. Soil-plant-animal transfer models to improve soil protection guidelines: A case study from Portugal. Environment International 39: 27–37.

Rys GJ 2011. A national cadmium management strategy for New Zealand agriculture. In: *Adding to the knowledge base for the nutrient manager*. (Eds LD Currie and CL Christensen). *Occasional Report* **24**. Palmerston North, Fertilizer and Lime Research Centre, Massey University. 14 p. http://flrc.massey.ac.nz/publications.html.

Schipper LA, Dodd MB, Fisk LM, Power IL, Parenzee J, Arnold G. 2011a. Trends in soil carbon and nutrients of hill-country pastures receiving different phosphorus fertilizer loadings for 20 years. Biogeochemistry 104:35–48

Schipper LA, Sparling GA, Fisk LM, Dodd MB, Power IL, Littler RA. 2011b. Rates of accumulation of cadmium and uranium in a New Zealand hill farm soil as a result of long-term use of phosphate fertilizer. Agriculture, Ecosystems and Environment 144: 95–101.

Taylor M, Gibb R, Willoughby J, Hewitt A, Arnold G 2007. Soil maps of cadmium in New Zealand. Report for Ministry of Agriculture and Forestry, Landcare Research, Hamilton, New Zealand. 55 p.

Warne M 2011. Review of, and recommendations for, the proposed New Zealand Cadmium Management Strategy and Tiered Fertiliser Management System for Ministry of Agriculture and Forestry, 46p. MAF Technical Paper No: 2011/03. Available at http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/land-management/cadmium-in-nz/