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Making good decisions: Risk characterisation and management of CCA post hotspots at vineyards and kiwifruit orchards

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1 Introduction

Copper, chromium, arsenic (CCA) treated timber posts have been commonly used in New Zealand vineyards and kiwifruit orchards for decades, and continue to be used. From the moment posts are installed, they begin to leach CCA into the soil immediately adjacent and below them, creating small ‘micro hot-spots’. Our aim is to determine whether these ‘micro-hotspots’ could pose a risk to human health under a changing land use. Arsenic is the most toxic of the three components to human health (Read, 2003), and so the focus of this document is the health risk posed by arsenic.

Regional/unitary authorities have a role in determining the nature and extent of contaminated land. Territorial/unitary authorities use this information to evaluate the suitability of proposed land use, subdivision and land redevelopment. Local government agencies work closely to ensure that decisions are made effectively and consistently; and this issue has relevance to local government roles and functions at territorial, unitary and regional levels.

The land area of producing vineyards in Marlborough increased from 2,000 ha in 1996 to 15,000 ha in 2006 (Greven et al., 2007); and nationwide, the land area in viticulture more than tripled over the same time period (New Zealand Wine Growers, 2017). Conversely, the discovery of the kiwifruit PSA virus in 2010 may have contributed to the 9% reduction of Waikato kiwifruit hectares between 2011 and 2012 (© AsureQuality 2017 - AgriBase® Data). The number of hectares employed in viticulture in the Waikato has dropped by 25% in the 10 years until 2017 (© AsureQuality 2017 - AgriBase® Data) which could be due to a number of factors, one of which is increasing pressure for urban land in prime viticulture areas. This data tells us that land use is in flux and unpredictable, and regulators need to be ready with robust policies for assessing and imposing conditions on land use change to protect people and the environment.

Contaminated land investigation and management for broad acre pesticide use and fuel and chemical storage are well understood and represented in best practice literature. However; risk from the ‘halo’ of contamination around each intensively located CCA treated post used in vineyard/kiwifruit orchards is not well understood, and as a result, risk characterisation is not undertaken consistently across various redevelopment projects.

Vineyards and kiwifruit orchards employ 500-600 posts per hectare. New Zealand research and contaminated site investigations identify arsenic in soil within 400 mm of posts at concentration well in excess of both soil guideline values for long term human health protection and levels which may result in a health response in children. Although these ‘hotspot halos’ are small, they are numerous and highly elevated; and many hotspots may be included within the exposure area of a residential back yard.

Given the potential health risk indicated by these elevations, it is important for regulators to address this issue. Given that micro hot-spots elevations are typically more than 2-3 times the relevant human health guideline (the generally accepted rule of thumb), it would be a departure from best practice to remediate these micro hot-spots using soil mixing techniques. Traditional soil remediation options for this scenario (e.g. dig and dump) are expensive, labour intensive and unlikely to be financially or environmentally sustainable. It is well known that traditional land development techniques usually involve much soil movement, but it is not known to what extent that might mitigate risk. Regulators are required to make responsible and effective decisions, which may occasionally warrant a departure from conventional best practice to enable the most effective and sustainable solutions to be employed.

This document shares our initial risk characterisation findings for numerous small but intensive ‘micro hot- spots’ at former vineyards and kiwifruit orchards under a residential land use scenario; and discusses the potential scale of mitigation provided by traditional land development techniques which can provide a practical and cost-effective means of risk mitigation at these sites.

2 Scope and limitations

This document solely explores human health risk under a residential land use scenario posed by arsenic originating from leaching of CCA from vineyard and kiwifruit orchard frameworks. It does not explore risks from pesticide use or bulk storage of treated timber; nor potential risks from ordinary fence lines or other applications of CCA treated timber; particularly domestic applications such as paling fences, decks, retaining walls etc.

This document does not consider risks to the environment or off site discharges. It does not consider risk to human health under existing use or under other future land use scenarios.

This document does not consider the potential risk posed by elevated arsenic to storm water and groundwater. Likewise, there has been no assessment of potential migration, via preferential pathways (e.g. sewer or electrical lines) or otherwise. However, the data does not support that leaching from posts results in contamination at significant depth and given that the mixing generally reduces the levels below the SCS, effects on offsite migration may not be more than minor.

This document does not address offsite disposal of soil which may exceed soil guideline values; this element is likely to be region and disposal site specific.

This document discusses potential mitigation techniques which strictly go against generally accepted best practice in New Zealand; although it highlights why these are scientifically viable and sustainable options (both socially and environmentally). This document has done so within the context that the New Zealand regulatory framework currently poses no restriction on the use of CCA treated timber. Once land use change has occurred, there are no measures to stop CCA contaminants being ‘reapplied’ to the land in the form of fencing, decks, garden structures and retaining walls. For this reason, our approach has been pragmatic and focusses on the ‘clean up to the extent practicable’ approach; which may well be different under a regulatory regime where the use of CCA timber is controlled. This document provides a bridge between the ‘do-nothing’ approach and an approach which may not be economically, or ethically, viable.

Interestingly, very few (if any) of the case studies used here suggested low level homogenous contamination with arsenic-containing pesticides. For this reason, statistical analysis of soil arsenic concentrations distant from micro-hotspots have been considered ‘background’.

3 A regulator’s role

Literature shows that the leaching of arsenic can result in soil around posts exceeding recommended standards by multiple orders of magnitude. Under the New Zealand regulatory framework, contaminants in soil that may affect human health are managed under the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health (hereafter referred to as NESCS) during a change in land use, development or subdivision. However, there is no reliable guidance to guide a consistent pattern of regulatory action for assessing and addressing the risks to human health posed by CCA treated timber posts; particularly in areas of heavy use such as vineyards and kiwifruit orchards.

Currently, regulators take a variety of approaches to the issue of fence post hotspots in soil; largely led by the recommendations of the consultants acting on behalf of their clients. In most cases, the issue is neglected or ignored in conceptual site models; only to raise its head in investigation or validation sampling results once the posts have been removed. Significant, sporadic and isolated elevations of arsenic are rarely accurately attributed to CCA timber when perhaps they should be (instead often attributed to historic pesticide use); and so the risk they pose and appropriate remediation options are not accurately characterised.

Occasionally, the contamination (usually arsenic) around posts *is* identified and accurately attributed to posts but the risk they pose to human health poorly characterised. A misunderstanding of risk, over-sensitised risk perception or a risk averse approach, can lead to total removal of affected soil to landfill; at considerable cost to the developer. While ‘cost’ itself should not be the principle driver to avoid a particular remediation technique; it should be noted by regulators and practitioners alike that risk and harm caused by vehicle movements, filling of valuable landfill space and the opportunity cost of using that money towards other environmental protection measures are also considered to be ‘costs’ of this particular remediation technique.

These variable approaches leave regulators in a difficult position. If the posts do still remain in situ, should they demand that the soil around fence posts is analysed (assuming that the current post location represents the only post locations, and disregarding post replacements which may either increase arsenic loading or displace/enlarge the ‘micro-hotspot’)? Because of the absence of risk characterisation in New Zealand, this will invariably result in excessive costs for the landowner to remediate the hotspots that will be found. Along with resistance to these costs, regulators are also faced with arguments regarding the end use of the land, which will customarily include the installation of other CCA treated timber structures such as fences, decks and garden edging which is still an accepted and permitted use of CCA timber in New Zealand. Appendix B provides an overview of regulatory decisions regarding applications of CCA treated timber both in New Zealand and other international jurisdictions. It is not the place of this paper to make recommendations regarding the ongoing use of treated timber in New Zealand; but it is important to highlight that our current regulatory framework adds a layer of complexity to risk assessment and holistic management of arsenic in soil from CCA treated timber use at historic vineyards and kiwifruit orchards.

All of these things leave regulators open to inconsistencies and accusations of ineffective or unclear policies and therefore risk. Decision-making should be based on solid science and best practice; this document serves to fill this gap by presenting and summarising existing knowledge.

4 Literature review

4.1 Fence post impact on soil and groundwater quality

The use of treated timber is not generally noted in New Zealand as a significant source of arsenic contamination in soil (e.g. McLaren, 2006); however, many recent publications are beginning to note potential health and environmental effects from the *use* of treated timber. Of particular note in New Zealand, horticultural operations such as vineyards and kiwifruit orchards rely heavily on timber supports. More than 95% of vineyard posts in Marlborough are made from H4 CCA treated *pinus radiata* timber to prevent insect damage and fungal rot (Greven et al., 2007; Vogeler et al., 2005).

Grapes and kiwifruit are typically grown on a linear row pattern with typical post spacings of 6-7.5m within rows; meaning that a New Zealand vineyard/kiwifruit orchard typically contains 450-580 posts per hectare. Given that timber is treated to result in wood concentrations of 1,730 mg/kg copper, 3,020 mg/kg chromium and 2,410 mg/kg arsenic (Greven et al., 2007), this results in an arsenic loading per hectare of 17 kg (Robinson et al., 2006; Greven et al., 2007). Replacement rates are typically 4% per annum (Robinson et al., 2006; and Vogeler et al. (2005)). Robinson et al. (2006) sampled post timber and soil samples 50 mm and 100 mm lateral distance from each post at 6 vineyards. While post wood above ground contained CCA similar to new posts; timber below ground had considerably less CCA, indicating leaching had occurred. Greven et al. (2007) indicate that leaching rates for arsenic are approximately 5mg per post per month. This is reinforced by the work of Sorensen (2007) who found that that the older vineyards contain higher levels of arsenic in the topsoil and subsoil, both 50 mm and 500 mm from the posts.

Greven et al. (2007) noted that for all 6 sites included in their study, 25% of samples collected adjacent to posts contained more than 100 mg/kg arsenic and nearly half exceeded 30 mg/kg. The NESCS guidelines for arsenic in rural residential and residential scenarios are 17 mg/kg and 20 mg/kg respectively. They identified elevations of copper and chromium above potential plant toxicity levels but noted that this was very localised and rapidly approached background levels at 50mm from the post. Robinson et al. (2006) found that 25% of the soil samples they collected from six vineyards exceeded 100 mg/kg arsenic. Sorensen (2007) identified elevated arsenic at all 35 post sites they tested, considerably in excess of the NESCS soil guideline values. Townsend et al. (2001) found that the highest concentrations of arsenic, chromium, and copper were located within five centimetres (laterally) of the CCA-treated timber, with the soil metal levels decreasing rapidly with distance.

In comparison to Greven et al. (2007) and Robinson et al. (2006); Zagury et al. (2003) discovered that arsenic leaching from posts is more mobile and elevated levels were found 500 mm out from posts, and up to 1 m below the base of the post. They expect that end-grain leaching is considerably higher than leaching from the sides of the posts due to the internal structure of the posts, and Ko et al. (2006) has noted that treated posts with painted ends showed a >50% reduction in CCA leaching compared with non-painted posts. Sorensen (2007) identified that arsenic accumulated in greater concentrations in soils with higher organic matter/clay content and lower sand, while arsenic was more mobile in acid soil types with low organic matter and clay content.

The literature evidences variability around the potential size of the leaching impact zone. Gerven et al., 2007, Robinson et al., 2006 and Zagury et al. (2003) indicate that leaching of arsenic beyond 50 mm of a post is typical, with halos up to 500 mm from posts not unusual. In comparison, Barlow & Prew (2005) undertook a study of four kiwifruit orchards (aged up to 8yo) and found little or no evidence that leaching of CCA extends beyond 50-100 mm of posts. In addition, Chirenje et al. (2003) indicate that elevated Cu, Cr and As around utility poles in Florida was only noted in comparatively new structures, hypothesising that a combination of weathering and leaching over time may reduce the impact. This is contradicted by Vogeler et al. (2005) who suggest that the mass flux of arsenic leaving the posts over their lifespan is critical compared with other factors such as soil type, and also Stilwell and Gorney (1997) who identified typical concentrations of arsenic around 76 mg/kg, increasing with age.

When considering risk posed by leaching from individual vineyard and kiwifruit supports, we also need to consider the context of our risk assessment under likely future use scenarios. For example, we need to ensure that any risk mitigation recommendations are proportionate to the potential risk posed by a CCA treated timber deck and/or paling fence that may be established once the subdivision is complete. Stilwell and Gorny (1997) found that soil beneath CCA treated timber decks was consistently and significantly elevated with respect to arsenic, and on average, contained 76 mg/kg arsenic; almost four times the current soil guideline value for arsenic in a residential setting under the NESCS (Ministry for the Environment, 2012). While copper and chromium reduced rapidly with depth, they found that arsenic was more mobile and tended to persist at depth. While it is unlikely that exposure to the soil beneath a deck will be regular and significant, we also need to consider that there will also be a 'halo' of leaching from the sides of these structures that will be relevant to ongoing risk exposure during residential occupation. It should also be noted that CCA treated decking or other structures in accessible areas can result in intakes through the transfer of arsenic residues from the timber surfaces to hands and then into the body via the mouth.

The work of Sorensen (2007) did not identify significant arsenic in ground water from the leaching of CCA posts at several Hawkes Bay vineyards, although it is noted that groundwater in the area was deep, present at 30 to 40 m below ground level (bgl). Greven et al. (2007) indicate that the leaching of CCA from vineyard posts is *unlikely* to pose a risk to aquifers given the substantial dilution effect; however, this work did not assess the movement of soil to being close to a waterway or the installation of a pond or other water body in a residential redevelopment area. For the purposes of this document, we assume that these aspects should be precluded in the development of former orchards and thus this work will primarily focus on potential impact on human health posed by contamination remaining in soil.

Although it is very difficult to identify where bulk storage of posts may have occurred during orchard development; bulk storage locations may have an impact on sample sites selected as control sites. Davies (2016) on behalf of Marlborough District Council, undertook a detailed site investigation of bulk storage piles at ten sites in Wairau and Awatere Valleys in Marlborough to determine the spatial extent and amount of contamination from bulk storage of the posts. The soils underlying the storage areas of new posts indicate that leachate is being generated from the piles of CCA treated posts and the highest concentrations of arsenic, chromium and copper are present in the upper (<100 mm to 150 mm bgl) soils (which are more organic rich). Arsenic concentrations in the soil samples analysed were greater than the relevant residential guideline value from the NESCS (2012). Concentrations of CCA beneath the stacks of old posts were lower than that beneath stacks of new posts, despite the fact that the old posts may have been stored on site for longer timeframes. The lateral and vertical penetration of the CCA was considered to depend on the permeability of the soil and the capacity of the soil to bind these heavy metals. Below 100 mm to 150 mm bgl the concentrations of arsenic, copper and chromium reduce rapidly and are generally close to or below background concentrations. Soil CCA concentrations generally decreased rapidly with increasing horizontal distance from the stacked posts, particularly notable for copper and chromium, which approached background levels at 50 mm away from the posts. In contrast, arsenic concentrations appeared to extend out up to 500 mm horizontally from the stacked posts. This matches with lateral distance findings identified by Gerven et al., 2007, Robinson et al., 2006 and Zagury et al. (2003).

4.2 Application of soil standards to protect human health

There is a significant amount of information available in relation to understanding human health effects associated with exposure to arsenic. These health effects include:

- **Acute effects**: health effects associated with either one high dose or a short duration exposure to high doses. For arsenic, these effects include nausea, vomiting, diarrhoea, cardiovascular effects and encephalopathy. A guideline or reference dose of 0.015 mg/kg/day is available to protect against acute effects (Tsuji et al 2004, Mazumder et al 1998). Lethal effects can also occur, at doses of 1 mg/kg/day and higher (ATSDR 2007).
- **Chronic effects:** health effects associated with long-term (typically between a year and up to a lifetime) exposures to lower doses. For arsenic, these effects include dermal effects (e.g. hyperpigmentation, hyperkeratosis, corns and warts), peripheral neuropathy and an increased risk of skin cancer, bladder cancer and lung cancer. For soil, the NESCS has established guidelines for arsenic for a range of land uses that are based on the protection of chronic health effects (based on an incremental lifetime cancer risk of 1 in 100,000). Other guidelines that are based on the protection of chronic health effects are based on threshold values, from human studies, in the range 0.0008 to 0.008 mg/kg/day (Baars et al., 2001; United States Environmental Protection Agency 1991 and ATSDR 2007).

For arsenic, the margin of safety between doses at which chronic or long-term effects may occur and doses at which acute effects may occur is not large. However acute exposures occur over a short period of time (such as one event, a day or perhaps a week) whereas chronic exposures occur every day for a lifetime. By adopting the soil guidelines based on protecting the most sensitive chronic effects, this will also be protective of acute and lethal effects.

It is established that leaching of arsenic can result in soil arsenic around posts exceeding recommended standards by multiple orders of magnitude. While this issue would be managed under the NESCS during a change in land use, development or subdivision; no pattern of regulatory action is seen in existing residential and public spaces. Given the level of risk estimated using best practice risk assessment and characterisation methods, some researchers believed that a regulatory health crisis of sizeable magnitude was imminent (Belluck et al., 2003).

Belluck et al. (2003) conducted a health literature review by contacting all 50 Unites States government health departments and 19 international agencies. Their research did not reveal any cases of human morbidity or mortality from exposure to elevated soil arsenic. While they did find evidence of adverse health effects from exposure to burning CCA treated wood and from improper handling of wet treated timber; they only discovered one case of possible adverse effects from arsenic contaminated soil. They could not conclude whether a lack of impact from arsenic contaminated soil was due to an actual lack of toxic effect or a failure to detect and measure those effects. They conclude that the common assumption of risk managers that CCA leaching from timber structures does not pose a risk is based on the lack of adverse effects data, when in reality there is plenty of scientific literature indicating that soils under or adjacent to CCA structures routinely exceed risk-based soil guideline values. Either the method used to derive guideline values is too conservative (including bioavailability considerations discussed below); or we are not accurately measuring and recording human health effects from exposure to arsenic contaminated soil.

Limited biomonitoring data is available in relation to arsenic exposures that may occur as a result of access to, and use of CCA treated timber in residential and recreational settings. However, Hemond and Solo-Gabriele (2004) concur that the most important exposure pathways for children are (in decreasing order): (1) oral ingestion of arsenic directly from timber via hand/mouth activity; (2) dermal absorption directly from timber, and (3) the ingestion of contaminated soil (which is less important except for pica[1] children). The scenario we are considering is that timber post structures have been removed, and only impacted soil remains; but with a possibility of new structures (decks, fences, play structures) being erected. This suggests that any risk associated with new structures is likely to overshadow the risk from the former post hotspots, and supports our holistic and practical approach given the current lack of regulation or control around the use of CCA treated timber in residential applications.

Somewhat contrary to the above, Lew et al (2010) conducted a biomonitoring study of arsenic in urine and saliva of children playing on CCA treated timber, and non-CCA treated playground equipment in the United States. The study found no significant difference in the concentration or speciation of arsenic in the samples from children playing on CCA and non-CCA playgrounds, concluding that contact with CCA playgrounds is not likely to significantly contribute to the overall arsenic exposure in children. However, there are several applications of CCA treated timber in a residential setting that this study does not explore (e.g. decks, access ways, fences, retaining walls, garden edging etc) and so is unlikely to fully characterise risk in a typical New Zealand residential setting.

A review of the risks posed by CCA treated timber, in the New Zealand context, was undertaken by Read (2003). This review identified the following in relation to arsenic leaching from CCA treated timber:

- It is assumed that the form of arsenic in CCA treated wood is pentavalent, being less toxic than trivalent forms.
- There are no epidemiological studies or human case reports involving disease related to direct contact with CCA-treated timber (let alone contaminated soil associated with treated timber).
- The exposure of children is most likely to be dominated by the ingestion of dislodgeable residues from the surface of timber and the contaminated soil adjacent to the structure being a minor pathway and not further assessed.
- CCA treated timber is only one source of human exposure to arsenic; with all New Zealanders exposed to low level arsenic in food, water, air and soil, particularly in areas

[1] Pica is the abnormal desire to eat substances (such as chalk, ashes or soil) that are not normally eaten.

of NZ affected by volcanic and mineralised geology (e.g. Waikato, Coromandel, Central Otago).

- Children 2-6 years old are considered the most at risk due to hand to mouth behaviour.
- The hazards posed by chronic arsenic exposure can be evaluated on the basis of a tolerable intake (threshold) of 2 µg/kg body weight/day (available from the Joint Food and Agriculture Organisation, World Health Organization Expert Committee on Food Additives, 1989). This threshold addresses all health effects associated with arsenic exposure including skin, lung and bladder cancer.
- There is insufficient data on inorganic arsenic intake to complete a risk assessment with reasonable certainty. However, where the limited data was considered, intakes of arsenic by young children from CCA treated timber playground equipment was below the tolerable intake.

The Reed (2003) review concluded that the use of CCA treated timber in New Zealand should be able to continue with no additional controls, based on the fact that no significant health risk via exposure was able to be determined. This decision was further reviewed in 2009 (Graham 2009) with the outcome supported. The Graham (2009) report did recommend that further work be undertaken to consider the review and outcomes of the United States Environmental Protection Agency assessment of child exposures and its relevance to the assessment of risk in New Zealand.

The continued use of CCA treated timber in New Zealand is contrary to reviews and approaches adopted in other jurisdictions. Appendix A presents a summary of the regulatory decisions and basis for those decisions across a number of jurisdictions including Australia, the US, Canada, the European Union and the UK. The use of CCA treated timber in domestic or residential settings has been banned in all these other jurisdictions, in some cases on the basis of the precautionary principle[2], and in some cases based on the outcome of a risk assessment, where unacceptable risks were identified.

<u>Soil standards</u>

In New Zealand the current soil standards for arsenic are provided in the **Table 1** below.

Table 1: Soil contaminant standards for arsenic – protective of chronic and acute effects

Land use scenario	SCS for arsenic (mg/kg)
Rural residential/lifestyle block 25% produce	17
Residential 10% produce	20
High-density residential	45
Recreation	80
Commercial/industrial outdoor worker (unpaved)	70

The above soil standards assume that arsenic is 100% bioavailable [3]which is likely to overestimate the risk associated with soil ingestion (Martinez-Sanches et al., 2013). In reality, arsenic in soil derived from CCA treated timber, is typically only 10-33% bioavailable compared with soluble arsenic forms (upon which the toxicity of arsenic is based) (Kelley et al., 2002) (Australian Pesticides and Veterinary Medicines Authority, 2005).

[2] The **precautionary principle** is a strategy decision-makers may adopt when scientific evidence about an environmental or human health hazard is uncertain but the stakes are high.

[3] **Bioavailability** refers to the proportion of a substance that reaches the systemic circulation after is has been absorbed or ingested.

While small particles sizes (including those most likely to adhere to skin and be found in household dust) are likely to represent higher bioavailability (Smith et al., 2009), the work of Juhasz et al. (2007) suggests that the bioavailable fraction of arsenic in soils may decrease with increasing age (i.e. time since arsenic entered the soil). In addition, the work by Smith et al (2009) and Ollson et al (2016) indicates that bioavailability appears to be greater with arsenic that is derived from an anthropogenic source, compared with geogenic sources, and greater in finer-grained soil compared with coarse grained soil. Data from the United States Environmental Protection Agency (2012), and Australia (Smith et al 2009 and Diamond et al 2016) indicated that in a wide range of soils, arsenic bioavailability rarely exceeded 60%. Pouschat and Zagury (2006) found bioavailability of arsenic in soil (containing 37-251 mg/kg total As), surrounding 18 month old CCA treated utility poles in the US to range from 25-66% bioavailable.

An assessment of arsenic bioavailability from soil in former orchards in the Tasman District (HAIL Environmental, 2017) indicates arsenic bioavailability between 10% and 16% (14% as the 95% upper confidence limit [UCL]) for Ranzau type soil and between 15% and 47% (38% as the 95% UCL) in Mapua type soil.

It is expected that the actual bioavailability of arsenic associated with leaching from CCA treated timber will be variable, depending on the age of the source, particle size, soil properties and competing ions.

5 Case studies

Twelve case studies for former vineyards and kiwifruit orchards have been considered as part of this review. These case studies have been selected as they represent a selection of both vineyards and kiwifruit orchards, cover a large geographical spread and represent a variety of different soil types and climates with the New Zealand context. Some of the studies were conducted primarily for the purposes of site redevelopment, and some (e.g. 10, 11 & 12) represent our own research targeting the extent of arsenic elevations and their distance from CCA treated timber posts.

All of the case studies have had identifying features removed to protect the privacy of landowners.

Table 2 overleaf provides a summary of the overview details of each case study site. A more detailed summary of relevant details from each case study is provided in the figures included in Appendix A. These includes site details (including horticulture type), proposed development, site history, geology, hydrogeology, depth to groundwater, details of CCA treated posts used (e.g. installation dates, replacement rates, density, array, ½ ¼ or full round posts etc.), soil sampling methodology and results and any adopted mitigation measures.

Table 2: Summary of case studies

Case Study	Horticulture type	Location	Climate[4] Mean annual rainfall (mm)	Mean Annual temperature (°C)	Geology	Soil Type	Age/dates of operation	Framework type/density	Future land use scenario
1	Vineyard	Northern Waikato	1,000-1250	14.1-16	Pumiceous Clays with Lignite, gravel and some pumice silt and sand	Volcanic origin, deposited as alluvium with interbedded peat materials	Approximately 74 years from ~1942 until 2016	A mix of round strainers (140-225mm diameter) and half rounds (140-180mm) at typical density 500-600 posts per hectare	Residential
2	Vineyard	Northern Waikato	1,000-1250	14.1-16	Volcanic ash	Clay loam	Approximately 73 years from 1930-2003	Initially hardwood replaced by CCA timber at unknown density	Rural Residential
3	Vineyard	Marlborough	500-750	12.1-14	Free-draining gravels with minor sand/silt	Gravel	Approximately 12 years from 2003-2015	550 CCA treated posts per hectare	Residential
4	Vineyard	Marlborough	500-750	12.1-14	Gravels with minor sand/silt	Gravelly	Approximately 20 years from the late 1990s until ~2015	A mix of large round strainers at ends of rows and smaller standard posts; standard density 500-600 per hectare	Residential

[4] Climate data source = National Institute of Water and Atmosphere (2018)

Case Study	Horticulture type	Location	Climate[4] Mean annual rainfall (mm)	Mean Annual temperature (°C)	Geology	Soil Type	Age/dates of operation	Framework type/density	Future land use scenario
5	Vineyard	Banks Peninsula	1,000-1,250	10.1-12	NA	Brown silty loam	Variable across site; approximately 15 years from ~2000 until 2015	Round strainers at row ends with metal stakes within rows	Residential
6	Multiple Vineyards	Hawkes Bay	750-1,500	12.1-14	River sediments and free draining gravels	Fine sand to fine loamy sand soil overlying stony gravels interlaid with sand.	Frameworks 6-16 years old	Full round posts of variable density 500-600 posts per hectare	Ongoing viticulture
7	Kiwifruit	Tauranga	1,500-2,000	14.1-16	Poorly to moderately sorted gravel with minor sand and silt	NA	Approximately 30 years from the mid 1970s until the early 1990s.	Unknown	High density residential
8	Kiwifruit	Northern Waikato	1,250-1,500	14.1-16	Basalt lava of the South Auckland Volcanic field	Allophanic soils with high organic content	Approximately 30 years in two periods; one in the 1980 and then 2000-2016.	Not provided but likely that a second framework was built for the second horticultural period.	Rural residential
9	Kiwifruit	Tauranga	2,000-4,000	12.1-14	Well drained tephra and alluvium	Sandy loam	Approximately 35 years from the late 1980s until ~2015	Unknown	Residential

Case Study	Horticulture type	Location	Climate[4] Mean annual rainfall (mm)	Climate[4] Mean Annual temperature (°C)	Geology	Soil Type	Age/dates of operation	Framework type/density	Future land use scenario
10	Kiwifruit	Hamilton	1,000-1,250	12.1-14	Late Pleistocene River deposits	Orthic gley soil, poorly drained sandy loam	Frames are 30 years old, established mid 1980s	Two large strainers at row ends, 6 inch posts at 6m spacings within rows which are 4m apart = ~450 posts per hectare	Ongoing horticulture
11	Kiwifruit	Central Waikato	1,250-1,500	12.1-14	Early-mid Pleistocene ignimbrite deposits	Well drained Orthic Allophanic soils	Frames are ~13 years old, established ~2005	Two large strainers at row ends, quarter round posts at 6m spacings within rows which are 3.5m apart. This equates to ~514 posts per hectare	
12	Vineyard	Central Otago	375-400	8.1-10	Middle quaternary glacial outwash deposits	Typic immature semiarid soil, well drained sandy loam	Two areas sampled; one 16 years old (est ~2000) and the other planted only two years previously	100mm quarter round posts, 8m apart with 2m between rows equating to approximately 500 posts per hectare	Ongoing viticulture

6 Risk characterisation

6.1 General

Risk characterisation is the assessment of the potential for adverse health effects to occur, in this case from arsenic concentrations in soil originating from the use of CCA posts in vineyards and kiwifruit orchards. Risk characterisation conveys the risk assessor's judgement as to the nature and existence (or lack of) human health risks, in an informative and useful manner for decision makers.

The risk to a future receptor (e.g. a child or adult) will depend on the type and amount of exposure the receptor has to impacted soil. It is clear from the available information in the literature and the available case studies (Section 4) that arsenic impacts in soil associated with CCA posts are localised to an area around each post. Therefore, if impacts were to remain at the site following development for residential use (without any form of remediation or risk mitigation), the following exposures are possible:

- Scenario 1: The receptor could come into contact with soil from across the whole residential lot. In this case, the exposure concentrations would be the average concentrations in soil across the lot (including those around the posts).
- Scenario 2: The receptor could come into contact with soil in one specific part of the lot only. For example if a child were to play frequently in one specific area of a garden which happened to be in the location of a former post.

The exposure point concentrations and subsequent health risks for Scenario 2 would be higher than for Scenario 1, and as the future activities of a residential receptor cannot be controlled, soil remediation targets are often applied across the whole lot. For this document, assessment of exposure will consider the above scenarios for a typical residential lot, which is taken to be approximately 600m^2.

6.2 Distribution of soil impacts

A further review has been undertaken to determine the likely extent of arsenic impacted soil at a future residential lot that may have been previously used as a vineyard or kiwifruit orchard. This review is presented below.

A standard residential lot is assumed to be 600 m^2, which is 0.06 ha. Assuming the installation of 600 posts/ha as a reasonable upper estimate for a standard vineyard/kiwifruit orchard, this means there could be 36 areas of arsenic impacted soil around former posts in each residential lot. Review of the information from the literature review and case studies provides the following information in relation to these areas of impact:

- Arsenic concentrations were in the range 10 to 220 mg/kg. The nature of sampling undertaken in each of the case studies varied, with only a few collecting or reporting sufficient data to enable the calculation of a 95% UCL. Where sufficient data were available (i.e. Case Studies 1, 10, 11 and 12), arsenic concentrations close to the posts (i.e. within 100 to 200 mm) reported maximum concentrations in the range 89 to 220 mg/kg, with the range of 95% UCLs for these soil in the range 51.8 to 104 mg/kg.
- While there is the suggestion that the extent of impacts differs between the smaller and larger posts, the more detailed data collected from Case Studies 10 and 11 do not

support this assumption. It is noted that if the extent of impact is larger around the larger posts, the calculations below may underestimate potential risk issues.
- The extent of the impacted soil around the posts was up to approximately 200 mm laterally from the post and approximately 500 mm deep.

Background concentrations of arsenic (away from posts) were typically close to or less than 10 mg/kg.

The potential volume of impacted soil around each post, and potential volume of impacted soil within a future residential lot (based on the information available), is summarised in Table 3Table 3 below.

Table 3: Summary of potential extent of arsenic impacts in soil around posts

Parameter	Value
Radius of impacted soil around post	0.2 m
Area of impacted soil around post	0.13 m^2
Total area of impact on site (36 posts/lot)	4.7 m^2
% impacted soil on area basis over 600 m^2 site (surface soil)	**0.8%**
Depth of impacted soil around post	0.5 m
Volume of impacted soil around post	0.07 m^3
Volume of impacted soil per 600 m^2 lot (36 posts/lot)	2.3 m^3
Total volume of soil per 600 m^2 lot (to 500 mm depth)	300 m^3
% impacted soil in top 500 mm of a residential lot	**0.8%**

Review of Table 3 above indicates that approximately 1% of soil between 0 to 500 mm bgl in a lot could be impacted with arsenic from CCA posts above the relevant soil standard.

For stacks/piles of CCA treated timber posts, Davies (2016) found that the highest concentrations of arsenic were present in the upper 100 mm to 150 mm bgl of soil beneath the stored posts, with the lateral and vertical penetration of the CCA dependent on the permeability of the soil and the capacity of the soil to bind heavy metals. Below 100 mm to 150 mm bgl, arsenic concentrations were reported to reduce rapidly to close to or below background concentrations. In contrast, arsenic impacts in soil appeared to extend out up to 500 mm horizontally from the stacked posts. This distribution of arsenic contamination from stacks/piles differs somewhat from that reported for the individual posts used in vineyards and orchards. CCA treated timber posts are commonly stored on site, with piles at the head rows of the vineyard. The storage area is estimated to be 50 m^2 per hectare[5].

If the potential extent of arsenic impacts within each lot is re-estimated for timber piles/stacks assuming a maximum vertical extent of 150 mm (and a maximum lateral extent of 500 mm), the % arsenic impacted soil per lot is 1.2% (refer below). If this were considered in the top 500 mm soil on the site the % arsenic impacted soil would be 0.4%.

When considered in conjunction with the impacts from the posts, for surface soil, approximately 2% of the site may be impacted. Where soil in the top 500 mm is considered, this is lower, at 1.2%, as shown in Table 4Table 4.

[5] From Davies (2016) – Generally stacks are delivered to site in bundles of 50 posts, each bundle measuring 2.6 m long, 1.5 m wide and 1 m high. The posts are generally stored in rows 1 m apart, along the head rows of the vineyard. For a 1-hectare site with 55 posts, this represents a storage area of approximately 50 m^2 per hectare. This means that the stacks are present throughout the vineyard (at the head rows), and any future subdivision of the land may include soil impacted by both posts and former stacks/piles.

Table 4: Summary of potential extent of arsenic impacts in soil around stacks/piles of posts

Parameter	Value
Area of soil potentially used for piles (assuming 600 m^2 size block and 50 m^2 per ha*)	3 m^2
Lateral extent of impacted soil around pile	0.5 m
Area of arsenic impact on residential lot (assuming square pile area)	7.5 m^2
% impacted soil on area basis over 600 m2 site (surface soil)	**1.2%**
Depth of impacted soil beneath piles	0.15 m
Volume of impacted soil on residential lot	1.1 m^3
Total volume of soil per 600 m^2 lot (to 150 mm depth)	90 m^3
Total volume of soil per 600 m^2 lot (to 500 mm depth)	300 m^3
% impacted soil in top 150 mm of a residential lot	**1.2%**
% impacted soil in top 500 mm of residential lot	**0.4%**

* refer to footnote 5, where the placement of stacks/piles on a vineyard may result in soil impacts that may be distributed across the vineyard, with the stack/piles commonly placed at the head row. It is noted that should a subdivision result in land that is dominated by the former head rows only, the calculations in the above table may underestimate potential risk issues. If the subdivision does not include any land that was used for stacks/piles of posts then the above may underestimate potential risk issues. As the specific relevant to any one site are not know, the above is adopted as an indicative average.

6.3 Potential risks to health

The NESCS soil contaminant standards for residential land use have been derived on the basis of general exposure assumptions, relevant to the assessment of potential long-term or chronic exposures. Arsenic is evaluated on the basis of a non-threshold dose-response relationship, where the SCS is derived on the basis of exposures to occur as a child (aged 1-6 years) and an adult (aged 7-20 years for standard residential and 7-30 years for rural residential) combined. The guideline is based on the use of a non-threshold risk-dose of 0.0086 µg/kg/day, which is based on a 1 in 100,000 (or 10^{-5}) risk level[6].

For the assessment of exposures by young children and adults the following default exposure assumptions are adopted (Ministry for the Environment, 2011a):

Table 5: Summary of exposure assumptions in SCS: standard/rural residential

Exposure assumption	Value adopted for standard residential (values that differ for rural residential in brackets)	
	Child	Adult
Body weight (kg)	13	70
Averaging time (non-threshold)	75	75
Exposure frequency (days/year)	350	350
Exposure duration (years)	6	14 (24)
Soil ingestion rate (mg/day)	50	25
Inhalation rate (m^3/day)	6.8	13.3
Skin surface area that is dirty (cm^2)	1900	4850
Soil adherence (mg/cm^2)	0.04	0.01
Homegrown produce (% total intake)	10%	10% (10% to 25%)
Produce ingestion rate (kg/day DW)	0.0105	0.0322

The SCS for arsenic, for the standard residential scenario is dominated by intakes from soil ingestion (83% of the SCS) and ingestion of home-grown produce (16% of the SCS).

[6] This risk level is the specified acceptable cancer risk for non-threshold compounds in New Zealand; see Ministry for the Environment (2011b) for further detail.

The above assumptions for the standard residential scenario relate to soil exposures that may occur for a child aged 1-6 years, then as an adult (or older child and adult) for another 14 years living at a residential home. When living at the home it is assumed that 10% of the individual's intake of fruit and vegetables are grown at home. The derivation of the SCS (as outlined in Ministry for the Environment, 2011a) also includes the calculated soil standard where there is no home-grown produce. In addition criteria have also been presented for a rural residential scenario where the key difference is that an adult spends 24 years on the property (rather than 14 years).

When considering exposures that may occur for a young child, it is likely that these may occur in the same or similar location in a backyard. In an area where child may play regularly, there may be at most 1 post hole, and as a conservative assumption 100% of the child's soil intake may be from the small hotspot[7].

However, exposures that may occur as an adult would be more likely occur across all accessible soil within the lot, where the small hotspots only contribute between 1% and 5% of the total soil area. In addition, uptake into produce grown on the site would more likely reflect the wider soil impacts.

To evaluate the potential risks associated with exposures that may occur within a residential property, the approach adopted has been to calculate a weighted residential soil exposure concentration and compare with the SCS for residential soil. The calculations have been undertaken as outlined in Appendix B, with the following assumptions:

- For adults and children, exposure to surface soil is most relevant, where it is estimated that up to 2% of the surface soil may be impacted by elevated levels of arsenic from former posts and a former pile of posts;
- The background concentration of arsenic in soil is 10 mg/kg;
- Adults are exposed to soil from across the whole site, where the hotspot concentration is present in 2% of the surface soil and background soil is present in 98% of the surface soil. Adults are assumed to be exposed to soil at any one residential property for 14 years for a standard residential scenario and 24 years for a rural residential scenario (i.e. exposure duration);
- Young children are assumed to be exposed to the hotspot concentration (i.e. all exposure at single location where a hotspot is located) for 6 years (exposure duration).

For this assessment, a weighted residential exposure concentration has been calculated based on a range of hotspot arsenic concentrations. The hotspot arsenic concentrations considered include:

- The maximum recorded value of 220 mg/kg
- The mean maximum arsenic concentration adjacent to posts from all case studies (except Case Study 8) of 109 mg/kg which is similar to the highest 95% UCL reported in the case studies; and

[7] The SCS for standard residential land use is dominated by ingestion of soil, which comprises 83% of the SCS. The assumption adopted for intakes as a child has not accounted for intakes from home-grown produce that may be grown in areas where arsenic concentrations are lower (than in the hot spot). As ingestion of soil dominates the SCS, the above is considered to provide a reasonable approximation of potential intakes that may occur on the site (noting the uncertainties inherent in all the adopted exposure parameters used to derive the SCS). For comparison the soil criteria that is based on no home-grown produce has also been included in this assessment.

- 55.3 mg/kg which is the 95% UCL of arsenic concentrations close to posts reported in Case Study 12[8]. This value is similar to the 95% UCL from Case Study 11 and representative of the lower end of the 95% UCL values reported.

The calculated weighted residential soil exposure concentrations relevant to these hotspot concentrations are presented in the following table with comparison against the residential SCS.

Table 6: Calculated weighted exposure concentrations of arsenic at residential property*

Aspect/calculation	Hotspot concentration (mg/kg)		
	220	**109**	**55.3**
Standard residential scenario:			
Child exposure concentration (C_C) (mg/kg)	220	109	55.3
Adult exposure concentration (C_A) (mg/kg)	14	12	11
Weighted residential exposure concentration (mg/kg)	**76**	**41**	**24**
SCS for standard residential soil (mg/kg)	20	20	20
Soil criteria for standard residential soil – no produce*	24	24	24
Rural residential scenario:**			
Child exposure concentration (C_C) (mg/kg)	220	109	55.3
Adult exposure concentration (C_A) (mg/kg)	14	12	11
Weighted residential exposure concentration (mg/kg)	**55**	**31**	**20**
SCS for rural residential soil (mg/kg) (10% and 25% produce)	17	17	17
Soil criteria for rural residential soil – no produce*	21	21	21

* refer to Ministry for the Environment (2011a)

** this scenario has been evaluated assuming that the distribution (number of posts and stacks per hectare) of former posts and stacks across the rural residential lot (which is assumed to be larger in area) is the same as for a standard residential lot.

The above table indicates that for all the hotspot concentrations considered, the weighted residential exposure concentration for arsenic in soil exceeds the SCS. This indicates that there is the potential for long-term exposures to arsenic in residential lots to be elevated.

If arsenic bioavailability were also considered, with a value of 40% adopted as a reasonable upper value from the limited data available (discussed in Section 4.2), the weighted residential exposure concentration where the maximum arsenic hotspot concentration (220 mg/kg) is considered, remains above the SCS. The weighted exposure concentration for the other scenarios are lower than the SCS.

It should also be noted that when evaluating potential exposures to arsenic, threshold effects, which relate more directly to the period of exposure and are of most significance for young children, should also be considered. The use of a threshold approach was adopted by Reed (2003) in the assessment of CCA treated timber exposures. This approach involves the calculation of a hazard index, which is the ratio of the intake of arsenic from the site compared with the tolerable intake (allowing for all intakes). For this assessment, calculations have been undertaken for the following (refer to Appendix C for further detail and calculations):

- Chronic exposure occurs as a young child (aged 1-6 years), where intakes via ingestion of soil have been considered based on the default assumptions adopted in the

[8] It is noted that the UCL relevant to soil adjacent to the posts will vary depending on how far away from the post soil data is considered. In this assessment soil concentrations immediately adjacent to the post were used from Case Study 12. If a radius of 0.2 m were considered the 95% UCL decreases to 38 mg/kg for this case study. Other case studies reported 95% UCL levels similar to that reported close to the posts in Case Study 12, and hence this has been adopted in this review.

derivation of the soil contaminant standard (refer to Table 5), which is directly relevant to children being exposed at a hot spot. For this assessment a threshold toxicity reference value (TRV) of 0.002 mg/kg/day has been adopted, consistent with the former JECFA value considered by Reed (2003) and adopted in Australia (National Environment Protection Council, 1999 amended 2013), with intakes from sources other than soil ingestion taken to be 70% of the TRV. For the maximum soil concentration, the calculated HI = 1.4, which just exceeds the acceptable value of 1. This indicates the potential for long-term intakes of arsenic, as a child, to be elevated.

- Short-term pica behaviour has also been considered. This may result in intakes of soil around 1 g/day (United States Environmental Protection Agency 2008a) and potentially up to 50 g/day. While this scenario is not likely to occur every day, intakes for young children ingesting 1 g soil on one day, may occur. For the maximum soil concentration of 220 mg/kg the peak daily intake of arsenic ranges from 0.017 mg/kg/day (where 1 g/day is ingested) to 0.85 mg/kg/day (where 50 g/day is ingested), both in excess of the acute arsenic TRV of 0.015 mg/kg/day. This indicates that short-term intakes of arsenic, where there is pica behaviour has the potential to be elevated.

The above indicates that, if nothing is done to address the small arsenic hotspots that are left behind in a future residential yard, there is potential for short term and long-term exposures to be elevated. As a result, it is not considered appropriate to “do nothing” for these sites.

7 Soil mixing as a mitigation method

Vertical mixing of soil is one risk management strategy that can be utilised as a risk mitigation strategy for large sites that contain chemicals above the soil guideline value. The generally accepted rule of thumb in the New Zealand contaminated land sector (Ministry for the Environment, 2006) is that soil mixing is inappropriate for hotspot contamination containing contaminants more than 2-3 times the relevant guideline. In addition, New South Wales Environmental Protection Agency (2003) and Pattle Delamore Partners (2015) indicate that vertical mixing is not recommend for “isolated hotspots”; however, given the number of CCA posts normally installed at vineyards and kiwifruit orchards (up to 600/ha), the term “isolated hotspot” is not representative of the distribution of potential impacts present in this instance.

What is considered more important is the number of hotspots and arsenic concentration in the hotspots as this will affect the validity of the use of vertical or lateral mixing to reduce concentrations in soil to below the guideline levels. Further, a hotspot is often defined in guidance documents as a concentration greater than 2-3 times the guideline value. While this may be appropriate for large volumes of impacted soil in individual hotspots, it may not be appropriate for small soil volumes that are numerous, and spread across larger areas. Therefore, in this document, the term “arsenic impacted soil”, or “micro-hotspot” has been used in preference to the generic term “hotspot”.

If the estimated depth of mixing required to achieve a safe contaminant concentration is greater than 500 mm, New South Wales Environmental Protection Agency (2003) and Pattle Delamore Partners (2015) do not recommend vertical mixing as a risk mitigation strategy as homogenisation of soil to a depth greater than 500 mm is difficult to achieve. This presents a complication as the information from the case studies indicates that arsenic impacts may extend to 500 mm (or in one case study – greater than 600 mm) depth. It is, however, evident from the case studies that the highest arsenic concentrations are present closest to the posts and in the upper parts of the soil profile. This is supported by an additional investigation by Davies (2016) who investigated the extent of contamination from the bulk storage of CCA posts. Davies (2016) found that the highest concentrations of arsenic were present in the upper 100 mm to 150 mm bgl of soil beneath the posts, with the lateral and vertical penetration of the CCA dependent on the permeability of the soil and the capacity of the soil to bind heavy metals. Below 100 mm to 150 mm bgl, arsenic concentrations were reported to reduce rapidly to close to or below background concentrations. In contrast, arsenic impacts in soil appeared to extend out up to 500 mm horizontally from these stacked posts. These more laterally spread impacts reflect the larger mass of CCA posts stored in stacks rather than the use of these posts in vineyards.

New South Wales Environmental Protection Agency (2003) (also adopted by Pattle Delamore Partners, 2015) provides an approach/equation for calculating the required mixing depth for impacted soil with a known concentration and depth. This equation is only suitable to apply where there is contamination in surface soil, where vertical mixing with underlying less contaminated soil is required.

To evaluate the use of surface mixing to manage many smaller micro-hotspots associated with former vineyard and kiwifruit orchard framework, the following equation can be used to calculate the maximum soil concentration that may be present (where the posts were located) to ensure that the soil remains suitable for the proposed use:

$$C_{max} = \frac{H - B(1-F)}{F} \times 0.9$$ ...**Equation 1**

where:

H = soil guideline value (mg/kg)
B = background concentration (mg/kg)
F = fraction of site volume in top 500 mm (considered relevant for soil mixing) contaminated from posts (unitless), which is calculated to be approximately 1.2% (or 0.012).
The value of 0.9 is a safety factor which takes into account inefficiencies in the mixing process (consistent with the New South Wales Environmental Protection Agency approach).

For an urban/standard residential area, a soil contaminant standard for arsenic of 20 mg/kg can be adopted. Where the background soil concentration is assumed to be 10 mg/kg, and a fraction of contamination of 1.2% is adopted, the maximum arsenic concentration allowable in soil at an individual soil sampling location (prior to mixing) is 760 mg/kg.

If mixing only extended to 150 mm, then the same calculation can be undertaken; however, the fraction of contamination that needs to be considered is higher at 2%. Where this is considered, the maximum arsenic concentration allowable in soil at an individual location (prior to mixing) is 460 mg/kg.

A summary of the arsenic concentrations reported in soil around CCA posts from the case studies (Section 4) and the calculated concentration post mixing within 150mm and 500 mm depth and comparison against the SCS and the maximum allowable concentrations for vertical mixing is provided in Table 7Table 7 below.

Table 7: Summary of reported arsenic concentrations in soil around posts from case studies

Post Type	Background	Maximum Arsenic Concentration	Concentration post mixing
Vineyards			
Case Study 1	4-10 mg/kg	220 mg/kg (Consultant B) 39 mg/kg (Consultant C)	Calculated, 150 mm mix = 15 mg/kg Calculated, 500 mm mix = 13 mg/kg Measured: <17 mg/kg
Case Study 2	6-9 mg/kg	153 mg/kg	Calculated, 150 mm mix = 12 mg/kg Calculated, 500 mm mix = 111 mg/kg No mitigation/mixing conducted
Case Study 3	NA (assume 10 mg/kg)	57 mg/kg	Calculated, 150 and 500 mm mix = 11 mg/kg Measured: <20 mg/kg
Case Study 4	<17 mg/kg (assumed 10 mg/kg)	89 mg/kg	Calculated, 150 mm mix = 12 mg/kg Calculated, 500 mm mix = 11 mg/kg Measured: <10 mg/kg
Case Study 5	NA (assume 10 mg/kg)	32 mg/kg	Calculated, 150 mm mix = 11 mg/kg Calculated, 500 mm mix = 10 mg/kg No mitigation/mixing conducted
Case Study 6	3-6 mg/kg	157 mg/kg	Calculated, 150 mm mix = 9 mg/kg Calculated, 500 mm mix = 8 mg/kg No mitigation/mixing conducted
Kiwifruit Orchards			
Case Study 7	6 mg/kg	152 mg/kg	Calculated, 150 mm mix = 9 mg/kg

Post Type	Background	Maximum Arsenic Concentration	Concentration post mixing
			Calculated, 500 mm mix = 8 mg/kg No mitigation/mixing conducted
Case Study 8		No information	
Case Study 9	NA (assume 10 mg/kg)	39 mg/kg	Calculated, 150 mm mix = 11 mg/kg Calculated, 500 mm mix = 10 mg/kg Measured: 3-10 mg/kg
Case Study 10	9-11 mg/kg	151 mg/kg	Calculated, 150 mm mix = 14 mg/kg Calculated, 500 mm mix = 13 mg/kg
Case Study 11	8 mg/kg	89 mg/kg	Calculated, 150 mm mix = 10 mg/kg Calculated, 500 mm mix = 9 mg/kg
Case Study 12	8.7 mg/kg (average)	92 mg/kg	Calculated, 150 mm mix = 11 mg/kg Calculated, 500 mm mix = 10 mg/kg
SCS: Standard residential with 10% produce (100% bioavailable arsenic Rural residential with 10% or 25% produce (100% bioavailable)		 20 mg/kg 17 mg/kg	
Maximum allowable arsenic concentration at posts, where mixing in top 500 mm will address impacts		Background = 10 mg/kg Standard residential: Cmax = 760 mg/kg Rural residential: Cmax = 534 mg/kg	
Maximum allowable arsenic concentration at posts, where mixing in top 150 mm will address impacts		Background = 10 mg/kg Standard residential: Cmax = 460 mg/kg Rural residential: Cmax = 324 mg/kg	

Review of Table 7 above indicates that:

- The maximum concentration reported in soil in all of the Case Study sites is below the theorectical maximum that would be allowable for situations where soil mixing is proposed address the hot-spot contamination, with a final lot suitable for standard and rural residential land use.
- For the sites where soil mixing has been conducted, the samples collected post mixing show good agreement with the levels that may be expected based on the calculations undertaken (noting some small variability principally due to the background arsenic concentration assumed in the calculations).
- The use of mixing adequately addresses the risks posed by arsenic derived from former CCA treated posts. This can be achieved without consideration of arsenic bioaccessibility.

8 Effective soil mixing techniques

This section discusses typical New Zealand land development techniques and equipment as known to the document authors and how they might be implemented to mitigate risk to protect human health. The authors recommend that while soil mixing might be a viable remediation method, effective soil mixing is not easily achieved and certain standards will be required to achieve the desired result (some more rigorous than other depending on soil type and condition).

Not all in-situ soil mixing techniques are equally effective and so the case study examples given here may give regulators and developers a better idea of techniques that may prove effective for their own regions. However, regardless of this there are multiple methods that can achieve effective soil mixing and we make it clear that the methods noted below are examples only rather than an exhaustive list. For untested methods, regulators may wish to consider recommending a more iterative process where mixing can be repeated based on validation results until clean-up goals are attained.

Although there are numerous different methods of land development, they can generally be broken into three types:

1. Developments where topsoil is pre-stripped, allowing the site to be re-levelled using motor scrapers. Topsoil is generally stockpiled, often screened, and then re-spread upon completion of earthworks and stormwater system development. These sites are generally large scale developments, involving a large number of resulting sections and tend to utilise more specialist and large scale equipment.
2. Smaller scale developments where the soil is stripped but retained on the subject site; the landowner redistributes the soil around the individual property as they see fit. Commonly used equipment includes smaller scale ploughs, rotary hoes and non-motorised scrapers or levelling bars (often readily available farming/contracting implements). Topsoil is rarely screened unless there is special circumstances (e.g. stony ground).
3. Small sub-lot developments (generally up to 6 subdivided lots or individual long association titles) where no ground wok or re-levelling is required and all topsoil remains in situ.

Scenarios 1 and 2 above involve both lateral and vertical mixing, while scenario 3 generally involves much less soil disturbance. Literature suggests that several passes of soil mixing equipment is required to get a significant degree of lateral mixing. It is not an unreasonable assumption that the significant nature of earthworks required in scenarios 1 & 2 would be sufficient to achieve effective soil mixing (see Case Study #1 and section 6.4 above). However, effective in-situ soil mixing is more difficult to achieve. It is important to note here that the authors recommend that in any of these scenarios, soil validation sampling is a critical step required to confirm that soil remediation objectives have been achieved post mixing.

In the situation of CCA leaching from kiwifruit and vineyard framework, the issue is of hotspot near surface as well as at depth. An Auckland Regional Council in-situ soil mixing remediation trial targeted contamination from pesticide use and broad scale shallow soil contamination but may still be useful for comparison. This study found that a bulldozer with a ripper only conducting multiple passes was not as effective as a tractor using ripping, ploughing, deep hoeing and chip hoeing techniques (Vujnovich et al., 2002).

In Marlborough various ploughing and cultivation methods have been used, with effective blending proven at two sites using the following specific methodologies:

Site One (Davies, 2015):

1. Chisel plough to 200mm both directions north/south and east/west
2. Rotary hoe/rotary power harrow
3. Cultivate

Site Two (Davies, 2014):

1. Deep rip to 700 m both directions north/south and east/west
2. Chisel plough to 400mm in both directions
3. Combine rotary hoe and cultivate

Trials in Australia (New South Wales Environmental Protection Agency, 1995) were used to test different combinations of ripping and mixing. Effective mixing was proven using the following three specific techniques:

- Dozer ripping, with wing tine only (6 passes completed)
- Dozer ripping with wing tine (2 passes completed), followed by mixing with a road stabiliser (3 passes completed) (homogeneous mixing using the rotary hoeing principle)
- Dozer ripping with standard tine (2 passes in opposing directions completed), followed by blade mixing (1 pass completed).

9 Outcomes applicable to good decision making

These suggestions are designed to sum up the risk assessment research and literature review above and assist New Zealand regulators considering land use changes from vineyard/kiwifruit orchard to residential or rural residential use.

Points to consider in formulating good policy on the management of contamination from CCA treated fence posts:

- It may not be necessary to require detailed site investigations for CCA leaching from framework on broadacre areas of vineyards and kiwifruit orchards. There is a reasonable body of evidence provided in both the literature, New Zealand NESCS assessments and our additional research which arguably provides broad characterisation of the nature of the contamination and its potential health risk; and it may be possible for regulators to opt for a suite of standard risk assessment and mitigation options. This may relieve some of the inconsistent assessments and risk characterisations that regulators receive.
- The above does not in any way apply to investigation of other types of hotspots (e.g. spray storage and mixing areas, fuel storage etc) and low level, homogenous pesticide contamination which should be investigated and remediated if necessary prior to application to change land use.
- Wherever possible, to encourage sustainable and economically feasible mitigation options, soil mixing methods utilising common land development techniques should be employed or recommended. These include topsoil stripping and stockpiling in the case of larger developments where relevelling of subsoil is required, and the use of in-situ mixing via deep rotary/power hoe or deep spading implements and multiple passes in the event of smaller developments or where large scale earthworks are not required.
- Validation samples should always be collected and a Site Validation Report prepared subsequent to any soil mixing to prove that the measure has sufficiently removed the human health risk.
- All investigation and reporting work should still be carried out in accordance with the Ministry for the Environment's Contaminated Land Management Guidelines.

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Appendix A. Case study details

Case Study 1. Vineyard 1, Te Kauwhata

Site details/Site history	The site has an approximate area of 17 ha. The adjoining properties are residential, rural residential and pastoral. Two ponds and a wetland area are present at the site. The site was formerly a vineyard with the whole site used for growing vines at some stage. Vineyard activity evident in aerial photographs (including 1942, 1963 and 1977). Vines were still present at the time of site investigation in 2016. A mix of strainers (full round posts 140 mm-225 mm diameter) and half rounds (generally 140 mm-180 mm).
Proposed development	Sub-division into approximately 130 residential lots of approximately 800 m^2 each.
Geology/Soil type	The 1:250,000 and 1:63,360 scale geological maps show the site to be underlain by pumiceous clays with lignite, gravel, and some pure pumice silt and sand from Pliocene epoch. Soils are volcanic in origin, deposited as alluvium with interbedded peat materials and are part of the Whangamarino and Puketoka Formations. Intrusive investigations have proved the site to be underlain by interbedded clayey silt/silty clay and sandy soils with varying proportions of silt in them. On the hill sides and ridgeline the topsoil is underlain by low permability clay rich soils. In the valleys the topsoil is underlain by thick silt rich soils which is expected to have a low to intermediate permeability.
Depth to ground water	Groundwater was not encountered in any of the trial pits or hand auger holes along the ridgeline. Interpretation of the site investigation data indicates groundwater potentially ranging from 6 m to 16 m below ground level (mbgl). This variability of groundwater level may indicate perched water tables within the soil profile, one of which may also be the source of the spring on the eastern face of the ridgeline.
Soil sampling	Investigation works undertaken by Consultant A comprised the collection of 11 samples from the wider vineyard area, avoiding treated timber posts. Arsenic concentrations in the range 4-10 mg/kg were reported. These can be considered to be background concentrations. Investigation works undertaken by Consultant B comprised the collection of 22 (typically) ten-part composite samples from across the vineyard and pastoral area, and 24 discrete samples from adjacent to the treated timber posts. Arsenic concentrations fell between 44-220 mg/kg. The 95% UCL for arsenic in soil within 200 mm of the posts was calculated to be 104 mg/kg Investigation works undertaken by Consultant C comprised the collection of 173 soil samples at increasing distance increments (both laterally and vertically) from the CCA treated vineyard posts. Two to three of each type of post were selected as representative of across the site. The posts included strainer posts and adjacent half round posts in both the older and newer parts of the site. Reported arsenic concentrations varied significant from those reported by Consultant B, with only three of the results from sampling by Consultant C exceeding NESCS. Two of these

	samples (39 mg/kg and 25 mg/kg) were collected 200 mm from a post with one additional sample (25 mg/kg) collected 600mm from a post. The majority of the results for the remaining samples were considerably below the adopted guideline value of 20 mg/kg. Testing of subsoils below the posts and strainers in the vine growing areas consistently found levels of arsenic below the selected SCS.
Adopted mitigation measures	A Remediation Action Plan (RAP) was developed with remediation works proposed to be undertaken in three stages as follows: **Topsoil strip and storage** 1. Remove all vines, vegetation and posts. 2. Use earthworks discs to rip up the topsoil, this will be carried out in at least 2 different directions to get a good mix and rip of the soil and grass. 3. Use power harrows to further mix/blend the topsoil – these are like a rotary hoe but spin around horizontally whereas rotary hoe works vertically. 4. Uplift topsoil to stockpile using conventional earthworks plant, ensuring that the topsoil gets further mixed during the pickup from the ground to the stockpile. **Underlying subsoils: Once the topsoil is removed** 5. Use the rippers on a dozer to rip up the soil. 6. Use the earthworks disc to further breakup and blend the soil – likely 2-3 passes at different angles to best achieve this. 7. Uplift the soil from the ground with earthworks plant. 8. Lay the fill out and re-disc and then compact using the large (long) sheep foot type feet on the earthworks roller 9. On completion at final level repeat insitu blending of surface soils or remove to landfill as necessary following results of verification testing. **Topsoil re-spread** 10. Utilising the earthworks plant - take a layer off the stockpile and re-spread over sections/lots in layers. 11. Use the power harrows to do a further mix of all topsoil prior planting/sowing of grass. 12. Repeat insitu blending of top soils or remove to landfill as necessary following results of verification testing. The RAP also included requirements for validation sampling post remediation and environmental management measures (dust, sediment and odour control). The above remediation works were subsequently implemented with combination of in-situ and ex-situ soil blending completed. Over much of the site, the subsoil was excavated and used as fill to create the desired ground profiles. By the nature of this operation soils excavated as near surface soils tended to be placed at the base of fills. However, to give added confidence, the upper 500 mm of subsoils was mixed/blended before placing as fill. A total of 335 samples were obtained from stockpiles of the blended/mixed topsoil during the works (approximately one sample per 100 m^3 of topsoil). Except for one sample (44 mg/kg), samples reported arsenic concentrations below 17 mg/kg. A volume of soil 200 m^3 around the exceeding sample was collected was remixed/blended, sampled and retested. Test results from the remixed soils were below 20 mg/kg. Consultant C concluded that the treated soil was acceptable for use on the residential development. Results from the final validation sampling of blended/mixed material were not available for review.

Figure 1: Case Study 1 - Vineyard 1, Te Kauwhata

Case Study 2. Vineyard 2, Te Kauwhata	
Site details/Site history	The site has an approximate area of 14 ha. Vineyard activity on part of the property (approximately 1 ha) from 1930-2003. Initially hardwood posts gradually replace by CCA posts. No detail on type of posts but estimated to number around 350.
Proposed development	Sub-division into approximately 17 rural residential lots.
Geology/Soil type	Soil is derived from volcanic ash (Churchill clay loam). No other details available.
Depth to ground water	Not provided. Some springs identified around the base of the hills.
Soil sampling	A total of 4 samples were collected from the vineyard area: - 2 (9-part) composite samples were taken between fence posts (i.e. more than 300 mm from a post or at locations stated as avoiding posts). Arsenic concentrations of 6 and 9 mg/kg were reported. - 1 discrete sample was taken 0-50 mm from a fence post. Arsenic concentrations of 153 mg/kg were reported. - 1 discrete sample was taken 50-100 mm from a fence post. Arsenic concentrations of 10 mg/kg were reported.
Adopted mitigation measures	A RAP was developed with remediation comprising the excavation and off-site disposal of soil to landfill. The need for erosion and dust control during excavation works was considered. Soil from around and below 25 CCA treated post was excavated by hand to a depth 50 cm and to a distance of 10 cm from the sides of the posts. It is unclear whether excavation works were undertaken around the remaining 325 posts. Validation samples were collected from the undisturbed soil remaining around 4 of the posts (1 sample from each of 4 posts at varying depths). Arsenic concentrations in the range 9 to 27 mg/kg were reported with one sample collected from 50-60 cm depth exceeding 20 mg/kg. It was concluded that as this sample was located underneath a proposed access road the commercial/construction and not the residential soil guidelines were applicable. In addition, the exceedance was located at depth and soil relating to CCA treated posts was estimated to constitute around 0.25% of the area of the vineyard. On this basis it was concluded that residual soils were highly unlikely to pose a health risk to future uses of the site.

Figure 2: Case Study 2 - Vineyard 2, Te Kauwhata

Case Study 3. Vineyard 3, Blenheim

Site details/Site history	The site has an approximate area of 21.4ha. The adjoining properties are rural residential and pastoral. The site is approximately 400 m from the Taylors River. The site was historically used for grazing and cropping prior to the development of the vineyard that covered the whole site in 2003/2004. 550 treated timber posts per hectare. Full rounds at the row ends with half rounds over the remainder of the row.
Proposed development	Sub-division into residential lots in the range 400 to 800 m^2 each.
Geology/Soil type	Poorly to moderately sorted (free draining) gravels with minor sand or silt.
Depth to ground water	5 m
Soil sampling	Five random locations were selected from across the vineyard to represent the potential contamination issues associated with the posts. A shallow spade wide trench was excavated up to 400 mm away from each post, towards the centre of the row. An X-Ray Fluorescence (XRF) machine was then used to measure concentrations of arsenic in soil *insitu* at 50 mm, 100 mm, 200 mm, 300 mm and sometimes 400 mm from post at two different depths (30 mm bgl and 100 mm bgl). A shallow soil sample was also collected in the middle of each row for confirmatory laboratory analysis. Three further trenches were subsequently excavated with XRF readings collected from 50 mm, 100 mm and 200 mm bgl. Arsenic concentrations exceeding 20 mg/kg were reported in small columns of soil surrounding each vineyard post tested. The extent of the impacted soil had a radius of 150-200 mm and a depth of 150-200 mm. This represents <1% of the total soil on each of the proposed 600 m^2 subdivisions (when measured to 200 mm bgl and based on approximately 31 posts per section). The maximum measured arsenic concentration with the XRF was 57 mg/kg. Arsenic was not detected in samples submitted for laboratory analysis.
Adopted mitigation measures	Soil blending (lateral and vertical mixing) was undertaken using the following methods: - Chisel plough to 200 mm both directions north/south and east/west - Rotary hoe/rotary power harrow - Cultivate Blended soil was analysed for arsenic using an XRF (150+ samples) with confirmatory laboratory analysis (20 samples). Arsenic concentrations were reported below 20 mg/kg in all samples. Regression analysis was used to confirm a high degree of correlation between the XRF and laboratory analysis results.

Figure 3: Case Study 3 - Vineyard 3, Blenheim

Case Study 4. Vineyard 4; Blenheim

Site details/Site history	The site has an approximate area of 1 ha. The majority of the site is located on a large river terrace. The adjoining properties are residential and agricultural (vineyards). The site has been used as a vineyard from the late 1990's/ early 2000's to the current day. Prior to this the land was used for crops/grazing animals. In total there were approximately 52 large (end) posts and 270 standard posts.
Proposed development	Sub-division into two lots and construction of a residence.
Geology/Soil type	Well sorted floodplain gravels and poorly to moderately sorted gravel with minor sand or silt.
Depth to ground water	<2m
Soil sampling	Arsenic concentrations were measured using an XRF and the following methodology: - Readings were collected at 15 m intervals down every 3rd row. Samples were taken at a depth of 75 mm bgl using a spade. In total 44 soil samples were analysed for arsenic. - Three trenches were excavated 1 m out from a post. One trench was excavated around the larger end post (160 mm in diameter). Two trenches were excavated around the smaller standard posts (100 mm in diameter). Arsenic concentrations were measured at 50 mm, 200 mm, 400 mm, 600 mm and 800 mm from the post, and at depths of 100 mm, 250 mm, 500 mm and 800 mm bgl. 41 soil samples were analysed for arsenic. Arsenic concentrations in between and at the end of the rows were less than 17 mg/kg. Elevated concentrations of arsenic (maximum of 89 mg/kg at large posts and 32 mg/kg at standard posts) were reported in soil around the posts. The arsenic concentrations were observed to quickly dissipate away from the post to background. The extent of the elevated arsenic concentrations was estimated to be as follows: - Large posts: approximately 200 mm to 400 mm out from the post to a depth of between 250 mm and 500 mm bgl. - Standard posts: approximately 50 mm to 150 mm out from the post to a depth of between 200 mm and 500 mm bgl.
Adopted mitigation measures	Soil mixing was undertaken using the following methods: - Deep rip to 700 mm both north/south and east/west - Chisel plough to 400 mm in both directions - Rotary hoe - Cultivate Blended soil was analysed for arsenic using an XRF (54 locations in a "x" across the site) with confirmatory laboratory analysis (6 samples). Arsenic concentrations were reported below 10 mg/kg in all samples. A good correlation was reported between the laboratory analysis results and the XRF results.

Figure 4: Case Study 4 - Vineyard 4, Blenheim

Case Study 5. Vineyard 5, Little River	
Site details/Site history	No details provided other than address and legal details. The site was undeveloped grassland until 1984 with residential development completed by 1994. By 2003 approximately half of the site had been developed as a vineyard with the remaining portion used as a tree plantation. Wide diameter full round posts at each end of rows; no posts within rows (metal "vin" stakes utilised). Posts inserted to a depth of 600 mm.
Proposed development	Development into a single residential dwelling.
Geology/Soil Type	Brown silty loam.
Depth to ground water	Unknown.
Soil sampling	A total of 10 samples from around two post locations were collected and analysed for arsenic. At each post location: - 3 surface samples were collected adjacent to a post and at 500 mm and 1,000 mm laterally from the post. - 2 deeper samples were collected at 300-400 mm and 600-650 mm bgl adjacent to a post. Concentrations of arsenic were below 20 mg/kg with the exception of the 2 surface samples collected adjacent to the post (26 and 32 mg/kg). The report concluded that that the lateral spread of arsenic contamination could be up to 500 mm downhill from the posts and the vertical spread of the contamination could extend to a depth of 600 mm bgl, or the depth of the base of any given post.
Adopted mitigation measures	None. More comprehensive sampling and the development of a RAP recommended.

Figure 5: Case Study 5 - Vineyard 5, Little River

Case Study 6. Multiple Hawkes Bay Vineyards	
Site details/Site history	Several vineyards in the Gimblett Gravels winegrowing region. Full round posts, age range from 6-16 years.
Proposed development	Not applicable (MSc Thesis).
Geology/Soil type	Dominated by the Omahu soils, fine sand to fine loamy sand topsoil overlying stony gravels interlaid with sand. River sediments, free-draining gravels, low organic content and water holding capacity.
Depth to ground water	30 to 40 m bgl
Soil sampling	Soil samples were collected at several depths and distances from 35 post locations throughout several vineyards. Groundwater samples were also collected from vineyards and several control sites. Elevated arsenic concentrations were reported adjacent to all 35 posts with arsenic found to accumulate to a greater extent in soils with a higher organic matter and clay content. Conversely, arsenic was found to be more mobile in the more acidic soils with a higher sand content and lower organic matter. No grounder samples contained elevated levels of arsenic. Approximately 250 samples were analysed for arsenic. The maximum reported concentration was 157 mg/kg, and four other samples returned results >100 mg/kg. The highest concentrations were reported soil surface closest to the posts, however results were variable. The median concentration of arsenic in soil adjacent to posts at 100 mm depth was in the range 30-64 mg/kg, while samples at the same depth but 500 mm away from each post had median arsenic concentrations in the range 3-6 mg/kg. Background arsenic concentrations were in the range 1-2 mg/kg. It was concluded that elevated arsenic concentrations in soil from CCA treated posts could be present up to 500 mm from each post location.
Adopted mitigation measures	Not applicable; ongoing viticulture use.

Figure 6: Case Study 6 - Hawkes Bay Vineyards

Case Study 7. Kiwifruit Orchard 1, Bethlehem

Site details/Site history	The site has an approximate area of 3.2 ha and is currently occupied by the Mills Reef Winery with associated residential properties, sheds, kiwifruit orchards and avocado trees. The adjacent land uses are vacant fields, fruit orchards and residential dwellings. No surface water bodies are located on the site. The Wairoa River is located approximately 950 m to the west of the site. The site has been used for used pastoral grazing with small orchards from the 1940s. By the mid-1970s, the site was established as a horticultural orchard and in the early 1990s part of the site was redeveloped for the construction of the Mills Reef Winery, which included wine making facilities, an attached restaurant, landscaped grounds and orchards/fruit trees. Post details not provided.
Proposed development	Residential retirement and care centre with 197 units.
Geology/Soil type	The IGNS 1:250,000 scale map sheet 5 'Geology of the Rotorua Area' indicates that the site is underlain by Pliocene age deposits of the Matua Subgroup. The Matua Subgroup is described as poorly to moderately sorted gravel with minor sand and silt underlying terraces, and can include minor colluvial fan deposits and loess.
Depth to ground water	32 m bgl.
Soil sampling	Preliminary Site Investigation (PSI): sampling for arsenic at 11 locations at depths between 0.5 to 2 m bgl. Arsenic concentrations were below 20 mg/kg with the exception of 1 sample. Detailed Site Investigation (DSI): sampling for arsenic at 37 locations (surface and sub-surface). Arsenic concentrations were in the range 6 to 37 mg/kg. Re-analysis of discrete samples from 0-0.1 m bgl reported arsenic concentrations in the range 36 mg/kg to 152 mg/kg. Toxicity Characteristic Leachate Potential (TCLP) arsenic concentrations of 0.29 mg/L were reported for total concentrations of 152 mg/kg.
Proposed mitigation measures	Two remediation options were considered in a RAP: - Excavation and off-site disposal of contaminated soil. - Capping of affected materials. Based on the planned earthworks and subsequent development plans, the recommended remediation option was excavation and off-site disposal. The RAP also included recommendations for validation sampling post remediation and environmental and health and safety management.

Figure 7: Case Study 7 - Kiwifruit Orchard 1, Bethlehem

Case Study 8. Kiwifruit Orchard 2, Tuakau

Site details/Site history	The site has an approximate area of 5.3 ha and is used as a kiwifruit orchard with an associated residential dwelling and storage shed. The site is located in a rural area known for production. The Waikato River is located approximately 1.7 km to the west of the site. A small tributary of the Waikato River, which is the receiver for site drainage from the site, is located near the western site boundary. The site has historically been used as a kiwifruit orchard on two occasions - during the 1980s and again in the 2000s until 2016. Post details are not provided. It is also unclear whether the posts for the 1980s orchard were removed prior to the second stage of kiwifruit growing. However, the report notes that it is likely the posts were removed, and the ground deep ploughed to break up kiwifruit root work prior to pasture establishment. This means that is it likely that the posts used between 2000 to 2016 were newly established posts.
Proposed development	Subdivision into a 4,000 m^2 residential lot with the balance of the site to remain as production land.
Geology/Soil type	Basalt lava of the South Auckland Volcanic Field. Allophanic with high organic content.
Depth to ground water	Not provided. The report indicates it is "*not expected to be shallow/near surface*".
Soil sampling	The soil assessment focused on the potential for soil contamination as a result of the historical use of pesticides at the site, not the presence of CCA posts. Given this, soil samples were collected a minimum of 500 mm away from any known fencepost location. Only one portion of the site (Lot 1) was investigated. Soil sampling comprised the collection of 9 discrete surface samples which were initially composited into three. Arsenic concentrations in the range 20 to 21 mg/kg were reported. Analysis of the 9 discrete samples reported arsenic concentrations in the range 14 to 18 mg/kg, with 2 samples reporting concentrations of 18 mg/kg (greater than the rural residential guideline value of 17 mg/kg). The report concluded that soil has been impacted by low-level uniform arsenic contamination as a result of the historic use of agrichemicals. The vertical extent of the contamination was not identified. In a later addendum, the consultant indicated that "*while there may be minor hotspots immediately surrounding a treated timber post…those hotspots would be considered negligible when assessing risks associated with the conceptual site model and sources of contamination.*" It was however agreed that this could not be confirmed with absolute certainty and additional delineation sampling was recommended.
Adopted mitigation measures	None – impacts associated with CCA posts not investigated.

Figure 8: Case Study 8 - Kiwifruit Orchard 2, Tuakau

Case Study 9. Kiwifruit Orchard 3, Pyes Pa	
Site details/Site history	The site is located on an elevated ridge and comprises a kiwifruit orchard. Associated residential dwellings and infrastructure and a fruit orchard are also present. The site area is not stated. There are no surface water bodies onsite. The nearest surface water body to the site is an unnamed stream located approximately 340 m to the east. The Kopurererua Stream is located 600 m to the west of the site. The site comprises a kiwi fruit orchard which dates back on site through to the late 1980s. Prior to this, the site area comprised vacant paddocks most likely used for pastoral grazing. Post details not provided.
Proposed development	Stated to be currently undergoing development as part of the Lakes residential sub-division. No further details provided.
Geology/Soil Type	Regional mapping and investigation works have identified that the site is underlain by sandy loam, well drained tephra and alluvium.
Depth to ground water	Not stated. Bores are noted to be "*deep*" with standing water levels roughly conversant with the level of the two streams either side of the site.
Soil sampling	22 composite samples were collected and analysed for arsenic, with 36+ individual samples subsequently tested. Two samples reported concentrations of arsenic greater than 20 mg/kg (39 mg/kg and 28 mg/kg).
Adopted mitigation measures	Soil with arsenic concentrations exceeding 20 mg/kg was excavated and disposed of off-site to landfill. Validation sampling of the excavation confirmed residential arsenic concentrations were in the range 3 to 10 mg/kg.

Figure 9: Case Study 9 - Kiwifruit Orchard 3, Pyes Pa

Case Study 10. Kiwifruit Orchard 4, Hamilton

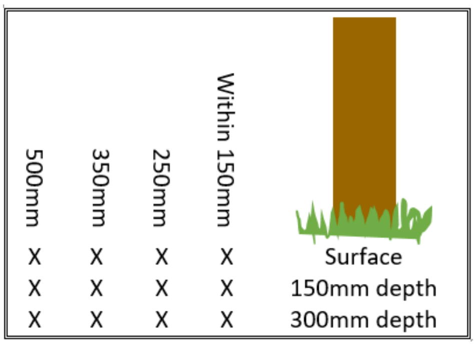
Site details/Site history	The site has an approximate area of 4.04 ha and is used as a Hayward variety kiwifruit orchard with currently no proposal to redevelop. The site is located in a rural area outside of Hamilton City known for horticultural purposes. The Mangaonua Stream runs along the southern boundary of the site, approximately 100m south of the sampling locations The frames in this orchard are approximately 30 years old. The framework consists of two 12 inch strainer posts at ends of rows (approx. 2 m apart) with a horizontal 6 inch post between them for bracing. 6 inch posts are used at a 6 m spacing within rows, with 4 m between rows. This equates to approximately 450 posts per hectare.
Proposed development	None.
Geology/Soil type	Late Pleistocene river deposits, Hinuera Formation, Tauranga Group. Orthic Gley soil, poorly drained sandy loam.
Depth to ground water	Domestic supply bore on a property across the road is drilled to a depth of 7 m; therefore groundwater is inferred to be less than 7 m deep.
Soil sampling	The soil assessment selected three post locations; two being 6 inch posts within rows and one 12 inch strainer at the ends of the rows. After soil samples were removed from the latter post; it was determined that there had been some soil disturbance in this area, probably designed to restabilise the post. Soil sampling comprised the collection and analysis of 12 samples around each post location as per the schematic below.  There did not appear to be a significant difference between the level of arsenic concentrations between the 6 inch and 12 inch posts (although this may be an artefact of soil disturbance around the 12 inch post). Without exception, all samples collected within 150 mm of the post exceeded the NESCS rural residential guideline value of 17 mg/kg; with a maximum concentration recorded of 151 mg/kg and a 95% UCL of 94.1 mg/kg. Arsenic concentrations in samples collected 250mm and further from the post were indistinguishable from local background, which was approximately 9-13 mg/kg. This indicates that the likely potential hotspot diameter from a post would be less than 0.5m.
Adopted mitigation measures	None – ongoing horticultural use.

Figure 10 Case Study 10 - Kiwifruit Orchard 4, Hamilton

Case Study 11. Kiwifruit Orchard 5, Te Awamutu

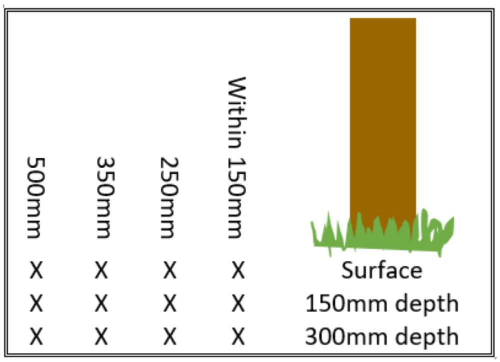
Site details/Site history	The site has an approximate area of 8.23 ha and is used as a Hayward variety kiwifruit orchard with currently no proposal to redevelop. The site is located in a rural area on the peri-urban fringe of Te Awamutu. The Mangapiko Stream is located approximately 1 km to the east of the sampling area. The frames sampled in this orchard are approximately 13 years old; although much of the orchard frames are 30 years old. The framework consists of two 12 inch strainer posts at ends of rows (one sawn off 30 cm above ground level), 1/4 round posts within rows at 6m spacings; with 3.5 m between rows. This equates to approximately 514 posts per hectare.
Proposed development	None.
Geology/Soil type	Early-mid Pleistocene ignimbrite deposits. Well drained Orthic Allophanic soil type.
Depth to ground water	Bores on an adjacent property are cased between 42-72 m, inferred depth to groundwater is 50-60 m.
Soil sampling	The soil assessment selected three post locations; two being ¼ round 6 inch posts within rows and one 12 inch strainer at the ends of the rows. Soil sampling comprised the collection and analysis of 12 samples around each post location as per the schematic below.  There did not appear to be a significant difference between the level of arsenic concentrations between the ¼ round 6 inch and 12 inch posts. Two thirds of all samples collected within 150 mm of the post exceeded the NESCS rural residential guideline value of 17 mg/kg; with a maximum concentration recorded of 89 mg/kg and a 95% UCL of 51.8 mg/kg. Arsenic concentrations in samples collected 250 mm and further from the post were without exception indistinguishable from local background, which was approximately 8 mg/kg. This indicates that the likely potential hotspot diameter from a post would be less than 0.5 m.
Adopted mitigation measures	None – ongoing horticultural use.

Figure 11. Case Study 11 - Kiwifruit Orchard 5, Te Awamutu

Case Study 12. Vineyard 6, Central Otago	
Site details/Site history	The site has an approximate area of 10.9 ha. Pinot Noir is the predominant variety grown. There is currently no proposal to redevelop the site. Lake Dunstan is located approximately 150 m from the closest part of the site. Annual rainfall is relatively low, with median rainfall between 375 and 400 mm per year. Two areas of the vineyard were sampled. The first area was planted approximately 16 years ago; the second was planted 2 years ago. 100 mm average face quarter round posts are used throughout the vineyards. The posts are spaced 8 m apart, with 2.5 m between rows. This equates to approximately 500 posts per hectare.
Proposed development	None.
Geology/Soil type	Middle Quaternary glacial outwash deposits. Typic Immature Semiarid Soil, schist and greywacke derived windblown sands, well drained sandy loam.
Depth to ground water	Depth to groundwater is not known, but it is inferred to be >20 m deep.
Soil sampling	The soil assessment selected thirteen random post locations; eight being from the 16 year old vines and 5 from the 2 year old vines. Posts were manually removed and samples were collected from the bottom of the post hole (typically 60 cm), and 20 cm deeper where possible. Surface samples were collected from immediately adjacent to the post hole, and then outwards at 10 cm increments. Samples were also collected at 20 cm depth, immediately adjacent to the post hole. Arsenic concentrations were assessed using a field portable XRF. Background concentrations of arsenic were found to vary between 6 and 11 mg/kg (average 8.7 mg/kg). Arsenic concentrations immediately below the posts were found up to a maximum of 77.5 mg/kg, with a 95% UCL of 52.4 mg/kg. Concentrations decreased with depth to a maximum of 33 mg/kg and a 95% UCL of 30.3 mg/kg at 20 cm below the posts. Surface concentrations immediately adjacent to the post holes were found up a maximum of 92 mg/kg with a 95% UCL of 55.3 mg/kg. 10 cm out from the post hole, concentrations decreased to a maximum 34 mg/kg and a 95% UCL of 20.6 mg/kg. By 20 cm out, all recorded concentrations were equal to or below the residential soil contaminant standard of 20 mg/kg and the 95% UCL was 16.4 mg/kg. Based on the rate of decrease, it is anticipated that background concentrations would be reached closely thereafter. There did not appear to be a significant difference in arsenic concentrations attributed to the age of the posts.
Adopted mitigation measures	None – ongoing horticultural use.

Figure 12. Case Study 12 – Vineyard 6, Central Otago

Appendix B. Overview of regulatory decisions on applications of CCA treated timber

The following table provides a summary of the regulatory decisions in relation to the domestic or residential use of CCA treated timber in New Zealand as well as other international jurisdictions. The table includes the regulatory decision, along with the basis for that decision. In many cases a risk-based approach has been adopted, and the table includes the key assumptions relevant to the risk assessment that has been completed. These key aspects are:

- Exposure – in particular which age group has been evaluated and some key assumptions, if the assessment has considered arsenic residues on CCA treated timber and arsenic in soil that has leached from these materials
- Hazard/toxicity – this summarises the approach adopted to quantifying the hazards/toxicity of arsenic. It is noted that different jurisdictions have adopted different approaches, with some considering a threshold approach (for all health effects including cancer) and other adopting a non-threshold approach for the assessment of carcinogenic effects.
- Risk estimates – this summarises the calculated risks presented in the reviews and whether these risks were considered acceptable or not.

In addition, Table 8Table 8 has also included a summary of the residential soil guidelines/standards available in each jurisdiction for easy reference for the users of this document. If the toxicological basis for deriving the soil guideline/standard differs from that adopted in the review of risks posed by CCA treated timber, this is noted.

Table 8: Summary of regulatory decisions and basis for the use of CCA treated timber for residential and domestic purposes

Country/ Agency	Regulatory decision for residential/ domestic use and basis	**Risk assessment approach** (refer to footnote below table for acronym definitions)			Residential soil guideline
		Exposure	**Hazard/ Toxicity**	**Risk estimates**	
New Zealand	Not banned – report by Read (2003) indicates insufficient evidence to demonstrate health risks. The report notes that arsenic is carcinogenic so it is prudent to avoid unnecessary exposure. This decision also reviewed and retained in 2009 (Graham, 2009).	Read (2003) based their assessment on a review of international assessments in NZ context and occupational data. Despite limitations identified with the data, risks were calculated for children aged 2-6 years. Intakes considered included food, water and residues from contact with CCA treated wood (no assessment of arsenic that has leached into soil).	Threshold approach: TDI = 0.002 mg/kg/day (JECFA) for chronic exposures. Threshold (LOAEL) of 0.05 mg/kg/day for short term exposures.	Chronic threshold HI around 0.6 which was considered acceptable. Short term MOE >10 which is was deemed acceptable.	17 to 20 mg/kg (based on a non-threshold approach and 10^{-5} acceptable risk level).
Australia	Banned for use in high contact structures – precautionary/ policy decision (variability and uncertainties in exposure studies/ data used) (Australian Pesticides and Veterinary Medicines Authority 2005).	3 year old child, 156 days per year playing on CCA treated timber structure, and exposure to soil contaminated from leaching (arsenic concentration considered was 24 mg/kg). Assessment also considered intakes from air, food, water and non-CCA treated timber affected soil. Include an assumption that arsenic in soil was 25% bioavailable (via ingestion).	Threshold approach: TDI = 0.002 to 0.003 mg/kg/day (JECFA and FSANZ). No acute assessment undertaken.	Chronic HI = 0.2 to 0.3 which was considered acceptable however a range of data limitations and uncertainties were identified.	100 mg/kg (National Environment Protection Council 1999 amended 2013).

Country/ Agency	Regulatory decision for residential/ domestic use and basis	**Risk assessment approach** (refer to footnote below table for acronym definitions)			Residential soil guideline
		Exposure	**Hazard/ Toxicity**	**Risk estimates**	
US (United States Environmental Protection Agency)	Banned from use in residential settings – based on health risks to children (United States Environmental Protection Agency 2008 and Boyce et al 2008)	Probabilistic assessment for children aged 1-6 years (averaged over a lifetime) where exposures from play equipment and soil were considered. Also looked at short term exposures (1 day to 1 month, and 1-6 months). The assessment considered exposures that may occur in warm and cold climates in the US.	Non-threshold for chronic effects: SF = 3.67 $(mg/kg/day)^{-1}$ Threshold for short term effects: LOAEL = 0.05 mg/kg/day	Chronic lifetime cancer risk calculated as a distribution, where 31% - 67% population predicted to have an additional lifetime risk $>10^{-5}$, and 1%-9% of the population predicted to have an additional lifetime risk $>10^{-4}$. These risks were considered unacceptable. Short term threshold: MOE >30 for 99th percentile exposure, which was considered by the United States Environmental Protection Agency to be unacceptable.	SSL = 0.4 mg/kg RSL = 0.68 mg/kg (based on a non-threshold approach and adopting a 10^{-6} risk)
Canada	Banned from use in residential settings since 2004, with the most recent re-evaluation completed in 2011 (Health Canada 2011). The review also considers evaluations conducted in the US.	NA	NA	NA	12 mg/kg (based on non-threshold approach and 10^{-5} risk)

Country/ Agency	Regulatory decision for residential/ domestic use and basis	**Risk assessment approach** (refer to footnote below table for acronym definitions)			Residential soil guideline
		Exposure	**Hazard/ Toxicity**	**Risk estimates**	
EU	Banned (from 2004) from residential use and in any use where there is repeated skin contact. Decision is based on risks to children and risks from disposal (The Commission of the European Communities, 2003). Risks also identified for certain marine environments.	Details not available – calculations undertaken for children in relation to exposure to residues form CCA treated timber and soil.	Threshold approach for chronic oral exposures: TDI = 0.002 mg/kg/day (JECFA).	Intakes for children > TDI which was unacceptable	30 mg/kg = trigger value
UK	Banned from use in residential or domestic constructions (Department for Environment, Food and Rural Affairs, 2003)	Review of exposure studies for children on CCA treated timber (no specific details available)	Index dose (based on cancer risk): ID = 0.0003 mg/kg/day (JECFA)	Chronic HI = 3 to 27, which was unacceptable	SGV = 32 mg/kg

TDI = tolerable daily intake; LOAEL = lowest observable adverse effect level; SF = slope factor; ID = index dose

FSANZ = Food Standards Australia New Zealand; JECFA = Joint FAO/WHO Expert Committee on Food Additives

HI = hazard index, which is the ratio of intake from all sources to the TDI (i.e. intake/TDI). A HI <= 1 indicates that intakes are less than the TDI which is acceptable. A HI > 1 indicates intakes that exceed the TDI with the risk of adverse health effects increasing the higher the intake is above the TDI

MOE = margin of exposure which is commonly used in the assessment of short-term effects, which is ratio of the short-term criteria to the intake. A MOE => 1 indicates that intakes from all sources is less than (or equal to) the threshold for potential effects, with the MOE indicating the magnitude of the difference or level of safety. A MOE <1 indicates intakes that are higher than the threshold, with the risk of adverse health effects increasing the higher the intake is above the threshold

SSL = soil screening level; RSL = regional screening level; SGV = soil guideline value

Appendix C. Exposure and risk calculations

Calculation of weighted exposure concentrations for arsenic in soil

Average concentration relevant to adult exposures:

$$C_A = C_{HS} \times \%A_{HS} + C_B \times \%A_B$$ **…Equation 2**

C_A = Concentration relevant to adult exposures (mg/kg)
C_{HS} = Concentration of arsenic in hotspot (mg/kg)
$\%A_{HS}$ = % area of surface soil comprising hotspot concentrations (%)
C_B = Concentration of arsenic in background soil (mg/kg)
$\%A_B$ = % area of surface soil comprising background concentrations (%)

Weighted lifetime exposure concentration:

$$C = C_C \times \frac{ED_C}{20 \text{ or } 30 \text{ years}} + C_A \times \frac{ED_A}{20 \text{ or } 30 \text{ years}}$$ **…Equation 3**

C_c = Concentration relevant to child exposures (mg/kg)
ED_c =Exposure duration as a child (years)
ED_A = Exposure duration as an adult (years)
20 years = total duration of residency at one home for the standard residential scenario
30 years = total duration of residency at one home for the rural residential scenario

Calculation of intake and threshold hazard index (HI) via soil ingestion

This assessment has focused on intakes via ingestion of soil, which is more relevant to the situation where a young child regularly accesses one area of a garden. Intakes via dermal absorption are much lower and do not significantly contribute to the risk. Where homegrown produce is present, the concentration of arsenic is expected to be lower in these areas (due to soil mixing where an average concentration is more relevant) and will less likely be a significant contributor to the total risk. Some allowance for intakes via these pathways has, however been considered in the assessment as detailed below.

Intakes from sources other than soil at the residential site have been assumed to be up to 70% of the TRV, to account for intakes from food, water (which may contribute 50% of the TRV as per National Environment Protection Council 1999 amended 2013) and other pathways not directly assessed (eg homegrown produce).

Intakes via soil ingestion have been calculated using the following equation

$$\text{Chronic Intake}_{soil} = C_S \times \frac{IR_S \times B \times CF \times EF \times ED}{BW \times AT_T} \text{ (mg/kg/day)}$$ **…Equation 4**

where:

C_s = Concentration of chemical in soil (mg/kg)

IR_s = Ingestion rate of soil relevant to the age group considered (mg/day)

B = Bioavailability of chemical in soil (%)

CF = Conversion factor (kg/mg)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (dependant on age) (kg)

AT = Averaging time for threshold (=ED x 365) and non-threshold exposures (=70 years x 365) (days)

So, for a maximum concentration of 220 mg/kg arsenic in soil at a hotspot, the chronic intake is calculated as follows:

$$\text{Chronic Intake}_{\text{soil}} = 220\,\frac{\text{mg}}{\text{kg}} \times \frac{50\frac{\text{mg}}{\text{day}} \text{x } 100\% \text{ x } 0.000001\frac{\text{kg}}{\text{mg}} \text{x } 350\frac{\text{days}}{\text{year}} \text{x } 6\text{years}}{13 \text{ kg x } 6 \text{ years x } 365\frac{\text{days}}{\text{year}}}\ (\text{mg/kg/day})$$

$$= 0.00081 \text{ mg/kg/day}$$ **…Equation 5**

The quantification of potential exposure and risks to human health associated with the presence of chemicals where a threshold dose-response approach is appropriate has been undertaken by comparing the estimated intake (or exposure concentration) with the threshold values adopted that represent a tolerable intake (or concentration), with consideration for background intakes[9]. For each exposure pathway the ratio is termed the Hazard Quotient (HQ), with the sum over all chemicals and pathways termed the Hazard Index (HI). For this assessment, where only one pathway and one chemical is considered, the calculation has been termed the HI and is calculated as follows:

$$\text{HI} = \frac{\text{Daily chemical intake from soil}}{\text{TRV - Background}}$$ **…Equation 6**

For this assessment, the HI is calculated as follows:

$$\text{HI} = \frac{0.00081\frac{\text{mg}}{\text{kg}}/\text{day}}{(0.002\text{-}0.0014)\frac{\text{mg}}{\text{kg}}/\text{day}}$$ **…Equation 7**

$$= 1.4$$

The interpretation of an acceptable HI needs to recognise an inherent degree of conservatism that is built into the establishment of appropriate TRVs adopted (using many uncertainty factors) and the exposure assessment. Hence, in reviewing and interpreting the calculated HI/RI the following is noted:

- A HI/RI less than or equal to a value of 1 (where intake or exposure is less than or equal to the threshold) represents no cause for concern;
- A HI/RI greater than 1 requires further consideration within the context of the assessment undertaken and may be considered to represent an unacceptable risk.

Calculation of peak short term intakes of arsenic

Where short term intakes are considered such as during pica behaviour, the intake is calculated for a peak daily intake as follows:

$$\text{Peak Daily Intake}_{\text{soil}} = C_S \times \frac{IR_S \text{ x B x CF}}{\text{BW}}\ (\text{mg/kg/day})$$ **…Equation 8**

For this assessment, the peak intake is calculated to be as follows:

Where pica involves ingesting 50 g/day:

$$\text{Peak Daily Intake}_{\text{soil}} = 220\,\frac{\text{mg}}{\text{kg}} \times \frac{50000\frac{\text{mg}}{\text{day}} \text{x } 100\% \text{ x } 0.000001 \text{ kg/mg}}{13 \text{ kg}}\ (\text{mg/kg/day})$$

$$= 0.85 \text{ mg/kg/day}$$

…Equation 9

[9] Background intakes are intakes of a chemical that are derived from sources other than the contamination being assessed. This may include dietary intakes and intakes from drinking water or urban air.

Where pica involves ingesting 1 g/day:

$$\text{Peak Daily Intake}_{soil} = 220\,\frac{\text{mg}}{\text{kg}} \text{ x } \frac{1000\frac{\text{mg}}{\text{day}} \text{x } 100\% \text{ x } 0.000001 \text{ kg/mg}}{13 \text{ kg}} \text{ (mg/kg/day)}$$

$$= 0.017 \text{ mg/kg/day}$$

…Equation 10