
Guideline for Contaminated Land Remediation by Soil Mixing

✦ Prepared for

Hawke's Bay Regional Council

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Executive Summary

Former agricultural or horticultural land intended for residential use may have unacceptable soil contamination from fertiliser or agrichemical use. Such contamination is typically shallow, with concentrations dropping off rapidly with depth, and relatively consistent from place to place. An option to make the land suitable for residential use is mixing the contaminated surface soil with sufficient deeper or other clean soil to dilute the contamination to acceptable levels. This guideline describes the options available, and the controls necessary, to successfully carry out soil mixing. It is intended for council regulatory staff, contaminated land practitioners and those carrying out the mixing.

Soil mixing described in this guideline may be one or a combination of:

- ∴ in situ vertical mixing;
- ∴ ex situ by cultivating in a stockpile or using fixed mixing machinery;
- ∴ surface stripping and disposal followed by mixing the remainder; and
- ∴ using imported clean soil for mixing.

Feasibility of mixing, and the best mixing method, will depend on the site circumstances, including maximum contaminant concentration and vertical profile, the soil suitability for mixing and the depth to the watertable. As rules of thumb, maximum concentrations of less than twice and up to three times the target may be remediable using in situ mixing and ex situ mixing, respectively. Mixing light soils will be easier and require less control than heavy clay soils.

Remediation of greater concentrations may be feasible by stripping and disposal of surface soil with high concentrations, followed by mixing the remainder. Soil mixing is not capable of nor intended for mixing “hotspot” areas. Attempting to mix a hotspot could result in making a large volume of soil unusable.

Suitable characterisation of the initial soil in place and close control of mixing, followed by validation sampling is essential. The mixed in situ soil, or soil placed back on a residential lot after ex situ mixing, must be shown to meet the target criteria, on average on each residential lot. A detailed site investigation is recommended before carrying out soil mixing, so as to be able to determine basic feasibility and design the mixing process. Thorough initial investigation and well-controlled mixing will mean less validation sampling will be required later. Conversely, minimal initial investigation and/or poorly controlled mixing will require more intensive validation sampling later.

Poorly controlled mixing risks unacceptable final concentrations, with no easy remedy available. Given this, soil sampling, oversight of the mixing and subsequent validation sampling should be under the control of a suitably qualified and experienced contaminated land practitioner, as defined in the contaminated soil NES. Given the volumes of soil involved, resource consent to disturb soil will be required under the contaminated soil NES.

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1.0 Introduction

Redevelopment of former agricultural or horticultural land for residential use may encounter unacceptable soil contamination from using fertiliser or agrichemicals on crops and fruit trees. Such contamination is typically shallow, contaminant concentrations generally drop off rapidly with depth and the contamination is relatively consistent from place to place without concentration extremes.

Options for remediation of such land are typically limited to:

- ✧ removing the contaminated surface soil to on-site containment or to off-site disposal, typically a landfill;
- ✧ capping with at least 500 mm of clean soil; or
- ✧ mixing the contaminated surface soil with sufficient clean soil to dilute the contamination sufficiently to be below human health criteria.

Remediation by capping or removal may not be appropriate for the particular development. In such cases vertical soil mixing may provide an appropriate remedial technique.

In general, soil mixing is only practical for broad-acre contamination where the contaminant concentration for the critical contaminant is at or near the surface and less than two to three times the acceptance criterion. It is generally not appropriate for “hotspot” contamination where high concentrations are present, or for deep contamination.

This guideline is intended to provide guidance for council staff, environmental practitioners and site owners/developers on the general principles and specific guidance on pre-remediation sampling, the mixing process and validation sampling. A variety of mixing methods is considered, including one or a combination of:

- ✧ in situ vertical mixing;
- ✧ ex situ mixing;
- ✧ surface stripping and disposal followed by mixing the remainder;
- ✧ using imported clean soil for mixing.

While this guideline is mainly intended for remediation of agricultural and horticultural land for residential use, the principles can be applied to other types of past and future land uses.

2.0 Regulatory Context

2.1 The Contaminated Soil NES

For land to be requiring remediation for redevelopment purposes, the soil remediation activity can be assumed to fall within the scope of the *Resource Management (National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health) Regulations 2011*¹ (the NES). This is because the NES controls change of use (e.g. from horticultural to residential), disturbance of soil (e.g. by mixing) and subdivision of land that falls within one of the categories described in the Hazardous Industries and Activities List (HAIL)². As land requiring remediation will automatically fall within at least one of the categories in the HAIL (Category H, if not others), the regulations must apply.

Except in situations with very minor amounts of soil mixing, soil-mixing projects will exceed the soil disturbance volume thresholds of the NES (equivalent to an average mixing depth of 50 mm), and will therefore require resource consent for soil disturbance from the relevant territorial authority. Similarly, as soil mixing would not normally be required unless soil concentrations exceed the relevant standards as set out in Regulation 7 of the NES, change of use and subdivision will also need consent under the NES.

2.2 Consenting under the NES

It can be assumed that some form of soil investigation has been carried out to determine that soil remediation is required. If that investigation fulfils the requirements of a detailed site investigation (DSI) as set out in Regulation 3 of the NES, then the soil disturbance activity will be a restricted discretionary activity under the NES requiring consent from the territorial authority. Otherwise the activity will be discretionary.

2.2.1 Soil mixing as a restricted discretionary consent

There are a number of matters over which the territorial authority has discretion in evaluating and granting consent for a restricted discretionary activity under the NES. The matters relevant to soil mixing are restricted to (Regulation 10 (3)):

- (a) *the adequacy of the detailed site investigation, including—*
 - (i) *site sampling;*
 - (ii) *laboratory analysis;*
 - (iii) *risk assessment;*
- (b) *the suitability of the piece of land for the proposed activity, given the amount and kind of soil contamination:*

¹ See <http://www.legislation.govt.nz/regulation/public/2011/0361/latest/DLM4052228.html>

² See <http://www.mfe.govt.nz/land/risks-contaminated-land/my-land-contaminated/hazardous-activities-and-industries-list-hail>

- (c) *the approach to the remediation or ongoing management of the piece of land, including—*
 - (i) *the remediation or management methods to address the risk posed by the contaminants to human health:*
 - (ii) *the timing of the remediation:*
 - (iii) *the standard of the remediation on completion:*
 - (iv) *the mitigation methods to address the risk posed by the contaminants to human health:*
 - (v) *the mitigation measures for the piece of land, including the frequency and location of monitoring of specified contaminants:*
- (d) *the adequacy of the site management plan or the site validation report or both, as applicable:*
- (e) *the transport, disposal, and tracking of soil and other materials taken away in the course of the activity:*

The adequacy of the DSI will be judged against MfE's Contaminated Land Management Guidelines No. 1 and No. 5 (see list of documents below). These documents are referenced by the NES in Regulation 3 and therefore it is necessary to follow their requirements where a detailed site investigation is used to support a consent application. It is also likely (recommended, where relevant) that consent conditions will reference these documents.

Typically, the approach to the proposed soil mixing would be detailed in a remediation action plan (RAP) which would be prepared as part of the consent application (so as to address Regulation 10(3)(c)), or be required as a condition of consent. Preparation of a validation report following the remedial works would typically be required as a condition of consent to demonstrate the adequacy of the remediation (as per 10(3)(d)) .

Soil mixing projects require close control to ensure their success. Therefore it is recommended that a RAP be part of the consent application, rather than be a condition of consent. The RAP should specify the mixing process intended in sufficient detail to show it can be successful, and also specify the sampling necessary to demonstrate the mixing is successful and the resultant soil is "safe" for the proposed use.

This guideline is intended to assist with developing RAPs and provide guidance in developing soil-validation sampling plans. Expected contents for RAPs and validation reports are set out in Contaminated Land Management Guidelines No. 1.

It will be necessary to employ a suitably qualified and experienced contaminated soil practitioner (a SQEP) to comply with the NES regulations. The expected qualifications and experience of a SQEP are set out in the NES Users' Guide (see list of documents below). Such a practitioner would be expected to be involved

in initial sampling, preparation of the RAP and certifying the final result complies with standards. Preferably the practitioner would be involved throughout the planning and implementation of the remedial works.

2.2.2 Soil mixing as a discretionary activity

In theory, application for consent under the NES could be as a discretionary activity without the need for a DSI complying with Regulation 3. The applicant could just have a small amount of sampling showing that soil concentrations were excessive. However, such an approach is not recommended. This is because it is difficult and expensive to “rescue” a poorly executed or marginally feasible soil-mixing project that has gone wrong and, obviously, it is not possible to rescue a project that was not feasible from the outset and should never have been contemplated. It would therefore be prudent of the developer to have a DSI before committing to soil mixing.

It is also strongly recommended that a council not process a soil mixing consent application without a sufficiently detailed investigation to show that soil mixing is capable of ensuring soil standards will be met for each residential lot (including satisfying the mixing prerequisites outlined in Section 7). To proceed without a DSI would be to leave all the detail, including the RAP, for consent conditions. It is arguable that a consent application for change of use or residential subdivision would be incomplete without a detailed site investigation (i.e. not satisfy section 88 and Schedule 4 of the Resource Management Act).

2.3 Land use register

Land that falls within a HAIL category will often, or should, be registered on a council register of land use (MfE, 2006). As noted earlier, land requiring remediation must be HAIL and the register entry should include a reference to actual contamination.

Land becomes HAIL land because of past site activity or use and therefore the land should always remain on the register (or be entered on the register), even after remediation. This is because site history is a matter of fact, which cannot be changed. In addition, as soil mixing can never reduce soil concentrations to background (natural) concentrations, the remediated land can never be considered “not contaminated”.

However, the intent of the mixing is to make the land suitable for the proposed use (typically residential use). If the remediation is successful, the category under which the land is registered should be changed to (or first entered as) “managed/remediated, suitable for current use”, or equivalent category.

2.4 District and Regional Plans

Depending on the specific situation, there may be a need to comply with various district or regional plan, and Resource Management Act 1991 requirements with respect to soil disturbance, erosion and sediment control, fugitive dust, proximity to environmentally sensitive areas such streams and wetlands, the potential to affect shallow groundwater, and discharges of contaminants to land during the mixing process. Resource consent other than that required under the NES may be required. This guideline does not address such requirements.

The relevant councils, territorial and regional, should be consulted when planning soil mixing as a remedial method.

2.5 Health and Safety

Mixing contaminated soil has the potential to expose workers and off-site receptors to contact with the soil or contaminated dust or sediment. Addressing legal requirements with respect to occupational health and safety is beyond the scope of this document. It is expected that occupational health and safety would be addressed in a site-specific site management plan.

A guidance document published by the Occupational Safety and Health Service of the former Department of Labour may assist in developing site management plans (DoL, 1994).

2.6 Other Guidance

This guideline has drawn on and should be read in conjunction with the following MfE and other guidance:

- ∴ *Contaminated Site Management Guidelines No. 1 - Guidelines for Reporting on Contaminated Sites in New Zealand revised 2011* (MfE, 2011a)
- ∴ *Contaminated Site Management Guidelines No. 5 – Site Investigation and Analysis of Soils* (MfE, 2011b)
- ∴ *Methodology for Deriving Standards for Contaminants in Soil to Protect Human Health* (MfE, 2011c)
- ∴ *Users' Guide, National Environmental Standards for Assessing and Managing Contaminants in Soil to Protect Human Health* (MfE, 2011d)
- ∴ *Contaminated Sites: Guidelines for the Vertical Mixing of Soil on Former Broad-Acre Agricultural Land*, New South Wales Environmental Protection Agency (NSWEPA, 2003)

3.0 Types of Soil Mixing

3.1 In Situ Vertical Mixing

In situ vertical mixing is where deeper, less contaminated or “clean” soil is mechanically brought to the surface and mixed with the more contaminated shallow soil so that after mixing the contaminant concentration is an average of the deeper and shallower soil contamination. The term “in situ” means the mixing occurs at the location where the contamination exists and “vertical” indicates there is no significant lateral movement of the soil.

The term comes from NSW EPA (2003), which defines in situ vertical mixing as:

...the process of remediating contaminated surface soils by mechanically mixing them with cleaner soil found at greater depths. This method is based on the theory that the environmental and public health risk from contaminants is a function of the surface soil concentrations of contaminants to which a person is exposed; lowering the concentrations of contaminants lowers the risk to the person exposed to them.

As an in situ technique, it is limited by the size of the machinery that can be devoted to the task. The largest equipment is unlikely to be able to mix deeper than about 500 mm, which imposes practical limits on the excessive contaminant concentration, and the depth of contamination, that can be successfully dealt with. Assuming a simple layer of contamination overlying “clean” soil, the required mixing depth at a particular location can be calculated using the following equation (NSW, 2003):

$$Y = \frac{X(a - b)}{0.9 \text{ SCS} - b}$$

Where:

Y = estimated vertical mixing depth (mm)

x = depth of soil profile in which concentration is ‘a’ (mm)

a = average concentration of the principal contaminant over depth X (mg/kg)

b = average concentration of the principal contaminant in the underlying soil (mg/kg)

SCS = soil contaminant standard target concentration for the principal contaminant (mg/kg)

and the value of 0.9 is a safety factor to allow for variations in the depth and concentration of the principal contaminant.

To assess the depth of mixing required, and therefore establish feasibility of in situ mixing, it will be necessary to sample and carry out this calculation at a number of locations, as the necessary depth of mixing could be variable. The greater the variability, the greater the number of locations needed to assess that variability, with sampling and calculating potentially an iterative process.

A variety of mixing methods and equipment may be employed, depending on the calculated depth of mixing required. From a practical point of view, while in situ mixing to a depth of about 250 – 300 mm is possible with readily available agricultural equipment, mixing deeper than about 300 mm requires heavy, specialised equipment or substantial earthworks, with the practical maximum being 500 - 600 mm. Techniques include:

- ∴ large rotary hoe-like equipment, e.g. that used for road stabilisation;
- ∴ agricultural power harrows (generally suitable for shallower mixing – typically no more than 300 mm);
- ∴ deep ripping followed by blade mixing or successive windrowing and re-spreading with a grader.

3.2 In Situ Vertical Mixing with Imported Soil

A variation on the in situ vertical mixing is using a layer of imported clean soil, spread over the contaminated surface and mixing this in to sufficiently dilute the contaminated layer. This may be practical where there is a cheap source of imported soil and/or the subsoil below the contamination is not suitable for mixing.

The same constraints with respect to contaminant concentrations and mixing depths as conventional in situ vertical mixing otherwise apply.

3.3 Ex Situ Soil Mixing

Ex situ mixing, by definition, is moving the contaminated soil to a separate mixing area, mixing the contaminated soil with clean soil, whether from the same site or imported, and then replacing the mixed soil to the original or some other location.

Mixing typically occurs in a long, low stockpile built up as thin alternating layers of clean and contaminated soil (no more than 150 mm each), with the two layers then thoroughly cultivated or otherwise mixed.

Alternative mixing methods may be suitable for smaller volumes, including specialised soil mixing/blending machines, mixing small stockpiles together (no

more than a several tens of cubic metres in each stockpile at a time) using a front end loader or hydraulic excavator, and even using a rotary screen .

3.4 Combination: Soil Stripping and Soil Mixing

Various combinations of soil stripping, in situ and ex situ soil mixing and adding imported clean soil are possible. It is beyond the scope of this guideline to describe all the possible combinations. The best method for a particular situation will depend on such things as:

- ∴ contaminant concentrations;
- ∴ depth of excessive contaminant concentrations;
- ∴ depth of soil that is physically suitable for mixing;
- ∴ availability of suitable imported soil;
- ∴ suitability of reusing the mixed material;
- ∴ ability to dispose of or reuse contaminated soil (e.g. under roads or recreational land) that might be stripped and not mixed;
- ∴ availability of suitable mixing equipment; and
- ∴ economic considerations.

As most sites are unlikely to be completely consistent across the entire site, it is possible that a number of soil mixing combinations may be utilised.

Examples of combinations that could work in particular situations are:

1. Stripping the worst of the contamination for landfill disposal or reuse on recreational land (stripping to 150 mm depth, say) and in situ mixing of the remaining surface soil. This could be successful where otherwise too great a depth of mixing would have been necessary, but a sufficient depth of suitable soil is otherwise available.
2. Stripping a shallow depth to stockpile and mixing with clean soil (whether from elsewhere on site or imported) and in situ mixing of the underlying soil before replacing the mixed stockpile. This may be successful where contamination extends to a greater depth than is practical for in situ mixing and clean soil is readily available.
3. Stripping the worst of the surface contamination to stockpile. Stripping and ex situ mixing of the next 500 mm depth. Replacing the stockpiled contaminated surface soil, placing a marker layer of geotextile and then capping with not less than 500 mm of the mixed soil. This may be successful where contamination extends to a greater depth than is practical for in situ mixing and there is a sufficient depth of soil after initial stripping suitable for mixing.

4.0 The Remedial Intent and Applying Standards

The intent of soil mixing is to dilute excessive soil concentrations so the soil which a person is exposed to complies, on average, with the relevant human health criteria (soil contaminant standards or equivalent).

Soil mixing is more commonly applied to residential developments than other types of land use, although the same principles apply regardless of use. For residential use, there are soil contaminant standards for three standard residential scenarios; rural residential, residential (the typical single-dwelling urban residential subdivision), and high-density residential (for multi-unit “town house” types of development). In addition, as green space and grassed road verges are common in residential subdivisions, the parks/recreation may also be relevant. These scenarios are described in MfE (2011c and 2011d).

While the ideal is to have every bit of soil completely homogenised during mixing so that soil concentrations are the same everywhere, it is not necessary to actually achieve this ideal to ensure human health is protected. In a residential situation residents are principally exposed to their own property and then principally exposed to near-surface soil, rather than deeper soil. Soil remediation is sufficient when the average concentration over a resident’s property complies with the relevant soil criteria, and then only to the depth that a resident would most commonly encounter.

The area over which the resident is exposed – the residential lot – can be considered to be the exposure or averaging area. Guideline No. 5 (MfE, 2011b) provides for calculating an upper bound estimate of the average concentration using the 95% Upper Confidence Limit (95% UCL) estimate for the mean. In calculating that estimate, MfE (2011b) permits concentrations to be up to twice the relevant standard, provided the calculated average complies with the standard. This recognises that an isolated higher concentration contributes only a small part of a person’s contaminant exposure, provided that the isolated high concentration is not so high as to present a health risk in its own right, irrespective of whether every other location is sufficiently low.

It is beyond the scope of the guideline to go into the detail of calculating a 95% UCL (see, for example, US EPA (2013)³). However, it is generally necessary to have at least eight samples to obtain a valid UCL and the samples should be collected as random samples or systematic samples on a grid with a random starting point, to avoid sampling bias.

Locations where concentrations are in excess of twice the SCS should be regarded as “hotspots” and dealt with separately to ensure a person is not exposed to such high concentrations, whether by removal, further mixing or some other method.

³ Available at http://www.epa.gov/osp/hstl/tsc/ProUCL_v5.0_user.pdf

It is not necessary to ensure contamination is below the standard for all depths. The standards are derived for surface soil, but that then requires a definition of surface soil, and therefore the necessary depth for remediation. There is no regulatory definition, but in New Zealand surface soil is typically regarded as the top 500 mm, with soil down to this depth expected to comply (on average) with the relevant standards.

Potential exposure to soil rapidly reduces with increasing depth of that soil. Most contact is with the very surface while some deeper contact (say to 300 mm) occurs with activities such as gardening. Contact with soil deeper than 500 mm is rare during day-to-day activities but may occur occasionally, for example during planting of large shrubs or digging holes for fence posts. Given contact with deeper soil is rare, contaminated soil remaining at depth can generally be tolerated, although concentrations more than several times the SCS, such as might occur from a spill of chemical concentrate, may need to be dealt with as a hotspot.

In the case of broad-acre contamination from surface-applied agrichemicals on former horticultural land, most of the contaminant mass will be shallower than 500 mm with a considerable drop-off of contaminant concentrations generally occurring within this distance. This is particularly true of silty and clayey soils, but less true of sandy and gravelly soils in which deeper contaminant migration may occur. Given this, it would be an unusual former horticultural site where contamination exceeded standards at depths greater than 500 mm.

5.0 Practical Considerations and Constraints

The following is intended to provide information on some of the practicalities and constraints of soil mixing. This is not intended to be a definitive guide. Those involved in carrying out and regulating soil mixing should make their own enquiries and carry out such tests as are necessary to ascertain what is best for their particular situations. Some experimentation, including properly controlled mixing trials, is recommended to determine the optimum mixing regime.

The soil intended for mixing needs to have a suitable texture and moisture content so that it readily breaks down to a reasonably fine state when mixed. A soil that remains as clods (or clods bound with vegetation roots) will not mix in a satisfactory manner. Prior application of a non-residual herbicide to kill pasture or other vegetation may be advantageous, particularly for heavier soils, by reducing the tendency of clods to remain bound by roots.

Successful mixing is more difficult to achieve with heavy, clay soils, whereas silt loams and sandy soils are more readily mixed. Soils that tend to remain as clods (e.g. clay soils) will require greater energy to be applied to the mixing, using equipment similar to that used for agricultural cultivation, rather than just pushing the material around as would occur with mixing using a bulldozer or

grader. The aim is to produce intimate mixing so as to achieve homogeneity throughout the vertical profile, rather than just mixing soil clods or clumps together, or having large concentration variations at different depths. Multiple passes of the mixing equipment will typically be required, with heavier soils typically requiring more passes than will be required for sandier soils, so as to ensure lumps are broken down.

Greater attention to moisture content will be necessary for heavier soils, possibly involving wetting and allowing time for conditioning or, alternatively, preliminary cultivation and allowing time for drying, depending on the time of year and preceding weather conditions and soil moisture content.

Thin topsoil over gravelly subsoil may also not be suitable for mixing, for two reasons. Firstly, the contamination may extend deeper (migrate by leaching) within a gravel soil, than within a fine-grained soil, requiring deeper remediation. Secondly, a gravelly soil may not produce a final mixed soil suitable for the surface of a residential lot. A sufficient thickness of additional topsoil may need to be imported to produce a satisfactory final surface.

A shallow watertable may also create difficulties for mixing. In situ mixing should not be contemplated where a very shallow watertable is present (i.e. watertable or excessive moisture within the depth of mixing) as successful mixing will not be possible. In that case, either building up the surface with clean soil followed by in situ mixing, or ex situ mixing with appropriate drying of the wetter material, should be considered.

Sufficient sampling at multiple locations must be carried out of the soil in situ to obtain a good idea of the soil profile and soil concentrations, so as to properly plan the remedial work (see Section 7). However, some rules of thumb can be established from the mixing equation presented in Section 3 and some typical real-world situations.

For ex-orchard land the principal contaminant is often arsenic. For a residential development the SCS for arsenic is 20 mg/kg. Arsenic tends to bind to silt-loam and clayey soils, limiting the depth it migrates to. Concentrations in the range 40 – 90 mg/kg at the surface are not unusual, reducing to background concentrations (say 5 – 10 mg/kg) at depths of 300 – 450 mm.

The following table gives a range of mixing ratios for various scenarios as guidance for what may be possible in particular situations.

The first part of the table assumes a 500 mm mixing depth, and calculates average concentrations after mixing over that depth for various surface concentrations (90, 60 and 40 mg/kg – shown by different colours), extent of contamination (300 and 450 mm depths) and two background concentrations (10 and 5 mg/kg – shown by different shades of colour). Feasibility is assessed based on whether the 20 mg/kg SCS is achieved.

| Table 1: Examples of in situ and ex situ mixing requirements for different surface and background concentrations and depths | | | | | | | | | | | | |
|---|-----------------|-----------|------------|-----------|------------|-----------------|------------|------------|------------|------------|------------|-----------------|
| Surface concentration (mg/kg) | 90 | 90 | 90 | 90 | 60 | 60 | 60 | 60 | 40 | 40 | 40 | 40 |
| Background concentration (mg/kg) | 10 | 10 | 5 | 5 | 10 | 10 | 5 | 5 | 10 | 10 | 5 | 5 |
| Depth to background conc. (mm) | 300 | 450 | 300 | 450 | 300 | 450 | 300 | 450 | 300 | 450 | 300 | 450 |
| Calculated average concentration over 500 mm mixing depth (mg/kg) | 34 | 46 | 30.5 | 43.3 | 25 | 32.5 | 21.5 | 29.8 | 19 | 23.5 | 15.5 | 20.8 |
| In situ mixing feasible? | No | No | No | No | No | No | No | No | Yes | No | Yes | Marginal |
| | | | | | | | | | | | | |
| Stripping depth (mm) to obtain SCS (20 mg/kg) | 263 | 394 | 247 | 371 | 240 | 360 | 218 | 327 | 200 | 300 | 171 | 257 |
| Average concentration over stripping depth (mg/kg) | 55 | 55 | 55 | 55 | 40 | 40 | 40 | 40 | 30 | 30 | 30 | 30 |
| Depth of soil at background conc. necessary to obtain SCS after mixing (mm) | 919 | 1378 | 576 | 865 | 480 | 720 | 291 | 436 | 200 | 300 | 114 | 171 |
| Total depth of mixed soil (mm) | 1181 | 1772 | 824 | 1235 | 720 | 1080 | 509 | 764 | 400 | 600 | 286 | 429 |
| Mixing ratio (Contaminated : Background) | 1 : 3.5 | 1 : 3.5 | 1 : 2.3 | 1 : 2.3 | 1 : 2 | 1 : 2 | 1 : 1.3 | 1 : 1.3 | 1 : 1 | 1 : 1 | 1 : 0.7 | 1 : 0.7 |
| Ex situ mixing feasible? | Marginal | No | Yes | No | Yes | Marginal | Yes | Yes | Yes | Yes | Yes | Yes |

The second part of the table assesses feasibility of ex situ mixing assuming the soil is first stripped down to whatever depth is necessary to obtain the SCS, based on a linear drop-off in concentration with depth. The depth of clean soil (at background concentration) required to be mixed with the stripped soil to obtain the SCS is then calculated, and converted to a ratio of contaminated to clean soil. Feasibility of ex situ mixing is then approximated on a combination of total depth of soil involved and mixing ratio, as a crude measure of practicality.

Note that feasibility will depend on particular situations and this table provides examples rather than a firm guide. Feasibility is limited to assessing whether the required concentration is achievable, not whether it would be economic to carry out. However, as rules of thumb to achieve the desired SCS, surface concentrations of less than twice the SCS could be feasibly remediated using in situ mixing, while surface concentrations up to about three times the SCS could be feasibly remediated using ex situ mixing, whether using deeper clean soils (at background) from the site or imported clean soil. Remediation of greater surface concentrations may be feasible by initial surface stripping and disposal (either onsite encapsulation or offsite disposal) followed by mixing the remainder (on the assumption that deeper soil will have lower concentrations).

In all cases, feasibility of mixing should be assessed by appropriate characterisation of site conditions. It may also be prudent to perform a mixing trial before full scale mixing is carried out.

Soil mixing is not intended to (or capable of) remediating hotspots, which MUST be dealt with separately. This means likely hotspot areas (spray sheds, farm buildings, and the like) have to be identified prior to any mixing occurring and enough sampling carried out to have a reasonable degree of certainty that no hotspots exist within the area to be mixed.

Failure to do so may result in the rejection of large areas of supposedly remediated land with, in the very worst cases, no practical means of rescuing the situation. This is because, whether in situ or ex situ mixing is performed, a hotspot is capable of excessively contaminating a volume of soil many times the volume of soil that would otherwise be dealt with by removing the hotspot.

For example, ex situ mixing of 1000 m³ of soil intended to be at 18 mg arsenic/kg after mixing (i.e. below the 20 mg/kg SCS for arsenic) requires only 10 m³ of soil at 500 mg/kg to result in the mixed soil being at about 23 mg/kg. Contamination hotspots associated with spray sheds, for example, can have concentrations of several hundreds or even thousands of mg/kg, and, if not identified, could result in rendering unusable very large volumes of soil if inadvertently mixed with otherwise suitable soil. What could have been removal of 10 m³ of soil off site for disposal may result in the need to remove 1000 m³. Suitable characterisation is therefore critical in the success of using mixing as a means of remediation.

6.0 The Mixing Process

The following prerequisites are necessary for successful soil mixing (modified from NSW EPA, 2003):

1. The degree of contamination and the lateral and vertical extent of contamination have been established (see Section 7).
2. The background concentration of the principal contaminant has been assessed (and where imported soil is to be used in addition to or instead of the local soil), the concentration within the imported soil.
3. There is a sufficient depth of clean subsoil or imported soil available for mixing.
4. The depth of soil that needs to be vertically mixed (contaminated and subsoil) is within the capability of the plant to be used, with a maximum of 500 mm (whether in situ mixing or for layers in an ex situ stockpile).
5. The land does not have any hotspots (or the hotspots have been separately dealt with).

6.1 In Situ Vertical Mixing

Trials carried out in New South Wales, Australia, have demonstrated that successful in situ mixing down to 500 mm can be achieved using:

- ∴ dozer ripping only, with wing-tine rippers (six passes);
- ∴ dozer ripping with wing tine (two passes), followed by mixing with a road stabiliser, in effect deep rotary hoeing (three passes); and
- ∴ dozer ripping with standard tine (two passes), followed by blade mixing.

No information on soil type is given in NSW EPA (2003), but it is expected that ripping and blading would be best on lighter, more friable soils, whereas more vigorous mixing would be required on heavier soils.

Trials were also carried out by the Auckland Regional Council in 2002 (Vujnovich *et al*, 2002) on two soil types, an organic-rich clay topsoil underlain by a stiff clay and an organic-rich clay topsoil underlain by a loose to firm silty clay. Several mixing methods were trialled:

- ∴ dozer ripping (three 500 mm long tines), with various numbers of passes including cross-ripping;
- ∴ tractor drawn ripper, disc plough and rotary hoe, using various combinations of these implements.

In all cases mixing was effective to only 200 – 300 mm, with the following combinations giving the best performance:

- ∴ tractor ripping (four passes), rotary hoe, cross disc at right angles, rotary hoe;
- ∴ tractor ripping, cross disc at right angles (two passes), rotary hoe (two passes);
- ∴ dozer ripping (four passes), cross-ripping (two passes).

Blading was also tried as part of some mixing combinations but was abandoned when it was found to predominantly move the soil horizontally rather than mixing vertically.

It should be noted that most agricultural equipment is capable of cultivation depths of only 150 – 250 mm, which will be insufficient for most soil mixing projects. The heaviest agricultural equipment may be able to cultivate to a depth of 300 mm. Heavy road-stabilisation equipment (used for lime or cement stabilisation of road bases) may be able to mix up to 500 mm.

As noted earlier, the success of any particular method will depend very much on soil type and moisture content and, as shown by the trials, multiple passes of whatever equipment is used will be required. As noted earlier, trials on the particular soil being mixed are recommended.

6.2 Ex Situ Mixing

Ex situ mixing is the only feasible option where the available equipment is not capable of mixing to the required depths, or where imported soil is necessary to achieve the required dilution. Where shallow depths are involved, in situ mixing is preferred because of greater certainty obtainable from prior pre-sampling and more certain dilution calculations. Removing the soil to stockpile loses the sampling information, except in a bulk sense, and reduces the certainty of achieving the desired effect. Double-handling soil may also be less efficient.

As noted previously, there are a number of possible methods such as building a stockpile in layers, soil-blending machines and mixing small stockpiles on a mixing pad with an excavator or front-end loader. The following description assumes mixing layers in a long, low stockpile, but the basic principles can be transferred with suitable modification to other types of mixing.

Successful mixing in a layered stockpile requires:

- ∴ careful planning;
- ∴ knowing (sampling and calculating) the average in situ concentrations for the depth of soil being excavated from the respective clean and contaminated areas being worked;
- ∴ keeping track of soil as it is stripped;
- ∴ building the mixing stockpile as soil is stripped, rather than using intermediate stockpiles;

- ∴ calculating the correct mixing ratio (and therefore layer depths) for the particular stripped soil;
- ∴ accurately placing the layers to be mixed, measuring the depth of each layer; and
- ∴ keeping the mixing layer within the capability of the mixing equipment (certainly less than 500 mm and generally less than 300 mm for the equipment typically available).

The starting point for ex situ mixing is selecting a mixing location that is convenient, minimises haul distances, is level (to better control runoff and sediment migration) and at least 20 m and preferably more from a sensitive environment such as a stream or wetland.

The area should have drainage ditches and/or confining bunds constructed to contain any sediment and runoff, which should be directed to a suitably sized sediment pond. Mixing should not be carried out in wet weather.

The maximum mixing layer thickness should be selected based on the plant to be used, allowing for a small penetration (25 mm) into the preceding layer. Rotary cultivation equipment (e.g. road stabiliser, rotary hoe, power harrows) will be most successful on narrow stockpiles, whereas blading or windrowing may be appropriate on wider stockpiles (where material falling down the sides of the stockpile will be less of a problem than for a narrow stockpile).

The thickness of the contaminated material layer should be calculated from:

$$x = \frac{y (0.9 \text{ SCS} - b)}{a - b}$$

where the variables are as before (Section 3), except y is the mixing depth less the 25 mm allowance to penetrate into the previous layer.

The amount of clean soil should then be calculated (from y - x) and this layer **MUST** be placed first in the mixing pile and the layer of contaminated soil second. It is important to place the contaminated soil on top of the clean soil before mixing so that if the full mixing depth is not achieved the contaminated soil will at least have undergone some mixing in the event under-depth mixing is not detected and remedied, and will otherwise show up as not achieving the target concentration when tested. Conversely, if the contaminated soil is placed first and the full mixing depth is not achieved, there will be a layer of unmixed soil left at the base of the layer, with the under-depth mixed layer being tested as more diluted than intended, giving a false impression of successful mixing.

It is recommended that, at least for the first (and generally most contaminated) cut from the existing surface, the depth of this cut be approximately the same as the depth of the contaminated soil layer placed in the soil mixing stockpile.

Doing so will make the task of calculating the average concentration of the layer to be mixed easier (and more accurate) and reduce the loss of concentration information that would otherwise occur if a deeper cut were made.

The typical original soil concentration profile is highest at the surface, with a rapid and often approximately linear drop-off with depth. Using the linear assumption, the average concentration for a cut is simply the average of the concentration at the surface and the concentration at the depth of the cut (in turn probably interpolated from samples taken at some other depths). If the soil is then re-laid at about the same depth within the mixing layer, the same average concentration will be approximately the average concentration within that layer.

However, if the cut is very much deeper (say one and a half to two times as deep), then because of uncertain and uneven mixing during the stripping process (e.g. within the motor scraper bowl if using a motor scraper for stripping), there is a risk of quite uneven contaminant concentrations along the stockpile layer prior to mixing and therefore an uncertain outcome after mixing.

This will depend on what method is used for stripping and some stripping methods will provide better mixing than others. For example, an elevating scraper will provide better mixing during stripping than a non-elevating scraper.

It is recommended that the surface of the stockpile is trimmed and/or rolled to eliminate undulations and ruts, and provide a sufficiently level surface that the next layers can be placed to a measurably accurate depth.

Example:

Surface soil averages 45 mg/kg, decreasing linearly to 4 mg/kg background at 350 mm below the surface. Ex situ mixing is planned using equipment capable of 250 mm, with effective mixing depth of 225 mm allowing for a margin. The mixing target is 18 mg/kg. Find stripping depth and mixing ratio.

Exact solution requires solving a quadratic equation – use trial and error solution. Try stripping depth of 100 mm. Average concentration is $(45 + 4 - (45 - 4) \times 100/350)/2 = 39$ mg/kg.

Mixing with 125 mm (i.e. 225 - 100) of soil at 4 mg/kg gives average of $(125 \times 4 + 39 \times 100)/225 = 19.6$ mg/kg. Too high

Try stripping depth 80 mm, average concentration 40.3 mg/kg. Mix with 145 mm (225 mm total) at 4 mg/kg gives 16.9 mg/kg. OK (exact solution is between 80 and 90 mm, but exact not practical).

Next layer down, try 120 mm depth at calculated average 28.6 mg/kg. Mixing with 105 mm at 4 mg/kg gives 17.1 mg/kg. OK.

7.0 Sampling

7.1 Soil Sampling to Delineate Contamination

It is essential in planning and carrying out soil mixing that sufficient sampling is carried out before remedial work commences to characterise the soil contaminant concentrations, and variability of such concentrations, both laterally and vertically. Failure to do so is essentially “flying blind” and invites a poorly executed or failed project. As noted previously, it is strongly recommended that the relevant consenting authority requires such sampling before issuing consent for subdivision, change of use or soil disturbance under the NES. Soil sampling should be carried out in accordance with MfE (2011b) and reported in accordance with MfE (2011a).

It is not possible to be definitive on how much sampling is required as each situation will vary. However, sufficient sampling needs to be carried out to enable mixing feasibility to be determined, using whatever combination of methods outlined in Section 3 is best suited to the site, and using the equation presented in Section 3.1 and similar calculations to those demonstrated in Table 1.

A different sampling approach may be appropriate depending on the end use.

7.1.1 Residential development

As a starting point for broad-acre sampling with the land intended for conventional urban development, it is recommended that initial sampling be carried out on a grid with at least one sample per final lot (or notional lot if the subdivision layout is not known). If this sampling shows considerable variability from place to place, then a closer grid spacing will be required, i.e. more than one sample per final lot. This sampling is intended to determine the need for remediation and give a sense of the lateral variability, not establish whether particular areas meet human health standards⁴.

Sampling at vertical intervals at each sampling location is essential to determine the depth, and basic feasibility, of in situ vertical mixing, or the depth of soil stripping necessary for ex situ mixing and the mixing ratio of contaminated to “clean” soil necessary to achieve the remediation goals.

The surface samples should be taken from 0 – 75 mm, and then deeper samples to suit the particular contaminant concentration profile and soil types encountered, but down to at least 500 mm below the final ground levels (the definition of surface soil) or until concentrations are typical of background

⁴ Note that this density of sampling will typically not be sufficient to satisfy the requirements of a detailed site investigation to demonstrate compliance with the NES, but is intended as an initial screen to determine whether broad-scale remediation is required. If remediation does not appear to be required, further testing will often be required to demonstrate each lot complies with the NES.

concentrations. It is expected a staged approach and some experimentation will provide the best results from data quality and economy points of view. Starting intervals below the surface could be 200 – 275 mm, 425 – 500 mm and, as necessary, deeper. Samples deeper than 500 mm may be necessary, depending on the concentration profile, if the final ground surface level is to be lower than the pre-remediation level. The important parameter is ensuring 500 mm of complying soil below the final surface.

Former orchard land that has been ploughed will quite likely not have the highest concentrations at the surface because the original surface has been turned under. Given this, the suggested sampling interval of 200 – 275 mm (typical of the depth of ploughing) may be just as important as the surface sample for defining the need for, and establishing the feasibility of, soil mixing. Because of this, it is never sufficient to just take surface samples.

Initial sampling may show that particular proposed lots, or sub-areas of the proposed subdivision, do not require remediation to meet human health standards. Sufficient sampling to demonstrate compliance with SCSs, in effect validation sampling, will then be required. A single sample per lot is generally not sufficient to show this definitively, noting the concept of exposure areas discussed earlier. Validation is discussed in Section 7.3.

7.1.2 Rural residential development

For rural residential developments there is generally concern for human health for the house site only (the curtilage area) as being where future residents (particularly children) are mostly exposed to soil. Typically this would be an area of several hundred to perhaps two thousand square metres within what is otherwise a several thousand square metre to a few hectare site. For the purposes of sampling to determine remedial requirements, the exposure area should be conceptualised as the area which might be fenced off around the house to stop children wandering and within which there would often be ornamental and vegetable gardens.

If house sites are not defined within a subdivision consent application, then sufficient sampling needs to be carried out over the complete future rural residential lot(s) so that feasibility of soil mixing can be established anywhere on the site (and in turn may define the best location for the house and gardens). A broad grid at 50 m centres would be a typical starting point, but more intensive sampling may be necessary if concentrations prove laterally variable.

Sampling should also seek to establish soil concentrations at potential hotspots such as spray sheds and chemical stores. Background history enquiries will be necessary to establish such locations. As noted previously, it takes only a relatively small amount of soil with high contaminant concentrations to upset an otherwise carefully planned remediation.

7.2 Soil Sample Analysis and Use of Portable XRF

It is beyond the scope of this guideline to go into the detail of soil sampling and analysis. Detailed guidance is provided in MfE (2011b) and other similar documents. It is appropriate, however, to provide some basic guidance on sampling and analytical techniques.

All sampling should be carried out by environmental practitioners trained in soil sampling under the guidance of, and planned by, a suitably experienced and qualified senior contaminated land practitioner.

Soil sampling conventionally involves grab sampling and submitting the samples for analysis to an IANZ accredited laboratory for “total recoverable” analysis of the passing 2 mm fraction. This is appropriate for human health risk assessment, as it is the fine fraction that contains most of the contaminant and presents the potential risk.

Rather than single grab sample, which may not be fully representative of the vicinity, a better sample may be obtained using the cluster sampling technique. A cluster sample involves collecting several sub-samples over a small area (e.g. five samples in the pattern on a dice over a 2 m square area), thoroughly homogenising the sample in the laboratory and analysing as a single sample. This should not be confused with a composite sample, which is taken over a much larger area.

There has been increasing use of portable X-ray Fluorescence (XRF) instruments to provide field measurements of heavy metal contamination. Such instruments are very good for quickly analysing large numbers of samples, and are therefore very good for guiding remediation, but they have their limitations when quantitative human health risk assessment is required, particularly for some contaminants (e.g. arsenic). At best the instruments are capable of semi-quantitative analysis, which may be sufficient for human health risk assessment when the principal contaminant is at concentrations well below the relevant standard, but otherwise requires supporting information provided by conventional laboratory analysis.

Detailed guidance for the use of portable XRF analysers is beyond the scope of this guideline. Guidance is provided in the Environmental Protection Agency’s Method 6200 (US EPA, 2007) and detailed guidance is provided in a guideline being prepared for several regional and unitary councils (PDP, 2015).

In order to obtain the best performance from an XRF analyser (necessary for semi-quantitative assessment) the following things should be kept in mind:

- ∴ The limited accuracy of the instrument, sometimes with detection limits close to the SCS (e.g. for arsenic).
- ∴ Matrix interferences causing systematic biases.

- ∴ Interferences from other contaminants affecting accuracy. Well-known is lead, a common co-contaminant of arsenic, affecting the instrument accuracy so that the detection limit is greater than the SCS.
- ∴ Inaccuracies introduced by not correcting for the soil moisture content and variation in moisture content from sample to sample. The best performance is obtained using ex situ, dried and properly homogenised samples.
- ∴ Penetration by the x-ray beam of only the top few millimetres of soil, whether the ground or an ex situ sample. Consequently, if an ex situ sample is not properly homogenised, or the instrument is used in the in situ mode and a thin layer of clean soil covers the surface or a gravel particle is immediately below the instrument, a false result will be obtained.
- ∴ Unsuitability for gravel soils unless the samples are sieved through a 2 mm sieve. Failure to sieve will most often mean a gravel particle will be all that the instrument can “see”, with the consequence that the result will be at the background concentration for the gravel particle, rather than the concentration of the more important fine material between.
- ∴ The need for confirmatory laboratory samples at a rate of at least 1 in 20 XRF analyses (US EPA, 2007), but not less than three samples (to allow a three-point calibration check) for a particular exposure area or set of samples (PDP, 2015).

7.3 Validation Testing

Validation testing is required to demonstrate the soil mixing has successfully achieved its goal. In some ways it is the most important part of the remediation process and requires careful planning, execution and reporting. Unsatisfactory or poorly presented validation results could result in the consenting authority not accepting the effectiveness of the remedial work, thereby preventing titles being issued to the new lots or preventing building work commencing.

The amount of validation testing necessary will depend on a variety of factors and therefore should be determined in consultation with, and supervised by, an experienced land contamination practitioner. It is recommended that the relevant territorial authority be consulted when devising the validation scheme.

The primary concern is for the soil in its final resting place as this is where the risk to human health exists for residential land use. As noted earlier, each individual lot must, on average, comply with the relevant standard, as it is over the individual lot (or curtilage area for rural residential developments) that a person is exposed to soil.

To demonstrate an individual lot complies with standards it is normal (MfE, 2011b) to take a number of samples in each lot and calculate a 95% UCL for each lot, with the result needing to comply with the relevant soil standards. This is generally the case whether it is an area of land that initial broad-scale sampling suggests does not require remediation but is sufficiently contaminated that validation is required, and land that has been remediated and requires validation post-remediation.

Given horticultural/agricultural contamination is often relatively consistent from place to place, it may be possible to use less intensive sampling than would normally be required to calculate a robust 95% UCL for a lot (eight samples or more), in conjunction with statistical analysis to show variability is not excessive. This will be easier to demonstrate when the contaminant concentrations are well below the relevant standards. Statistical analysis such as t-tests and ANOVA on groups of data may be appropriate in particular situations. The detail of such analysis is beyond the scope of this guideline.

For the ex situ mixing situation, adequate validation within the stockpile can considerably reduce the amount of validation required after re-spreading the mixed soil. But other circumstances can also reduce the amount of validation post-remediation, if properly justified. Factors affecting the amount of validation required include:

- ∴ The intensity of initial contamination delineation prior to soil mixing. Less initial delineation will require more intensive validation sampling to give the same level of confidence.
- ∴ The variability of the initial contamination. The greater the variability, the greater the amount of validation for particular areas and/or individual lots.
- ∴ The workability of the particular soil. A clay soil that is hard to mix may require more intensive validation than an easily mixed soil.
- ∴ How carefully planned and well controlled the mixing is, and how vigorous the mixing is. A process that ensures good mixing such as several passes of a rotary hoe may require less intensive validation than a less certain mixing process such as blading.
- ∴ If ex situ mixing, if the process is well controlled and validated in the stockpile, minimal validation will be required in the individual lots after re-spreading. Conversely, if the mixing is poorly controlled with minimal sampling in the stockpile, more intensive validation (validating individual lots with multiple samples) will be required after re-spreading.

With ex situ mixing it is always best to be certain of the validation before re-spreading because it is difficult to re-remediate a poorly executed remediation, including demonstrating the success of the re-remediation, after re-spreading has occurred.

7.3.1 In situ mixing

Following the in situ mixing of the soil, validation samples should be collected from the exposed ground surface and at intervals down to the depth of mixing or 500 mm, as appropriate.

Recommended steps for validation of in situ mixed soil are set out below:

1. Visually assess the effectiveness of mixing, checking that the soil has a consistent texture and colour vertically and laterally, and has been adequately broken down, without large clods or clumps of turf or soil attached to roots.
2. Check the depth of vertical mixing is as intended by excavating down to the base of the mixed zone. In the event that mixing is not as deep as intended, further mixing must be carried out until the intended depth is achieved.
3. Carry out sampling at the surface (0 -75 mm) and at the two-thirds depth of the mixing zone, if less than 300 mm depth of mixing, or at the surface, midpoint and base of the mixing zone if greater than 300 mm depth.
4. All surface samples should be analysed. Fewer deeper samples may be analysed if it can be shown that the deeper samples are the same concentration (within 20%) as the surface sample at the same location.
5. Calculate a 95% UCL for individual lots for the surface samples, or where insufficient samples exist for this calculation, demonstrate using less intensive sampling and statistical analysis that there is sufficiently low spatial variability that individual lots are likely to comply with relevant standards. It is recommended a minimum of two sample locations (surface and deeper samples at each) should be analysed per proposed lot.

7.3.2 Ex situ mixing

As noted above, validation soil testing for ex situ soil mixing should be carried out in both the stockpile and the final resting place of the soil, with more required in one location if less is carried out in the other, and vice versa. While the primary concern is for the soil in its final resting place as this is where the risk to human health arises, if sufficient confidence can be gained from stockpile sampling then sampling of the mixed soil after re-spreading can be reduced to a minimal level. Sampling after re-spreading may even be dispensed with entirely where it can be demonstrated sufficient control has been maintained over the mixing process. In addition to sampling the mixed soil, validation of the base of excavation following soil stripping should be carried out.

Excavation base sampling

Validation of the base of the excavation is essential if the depth of stripping is less than 500 mm below the post remediation surface level, to demonstrate the excavation is deep enough to comply with the SCS (on the assumption concentrations drop off with depth). Validation of the base of the excavation is optional (but good practice) for stripping depths greater than 500 mm below the finished post-remediation soil level.

Initial delineation samples may be used in place of post-excavation samples if these samples are at appropriate depths and a great enough density. Excavation-base validation samples at a frequency of one sample per proposed residential lot should be sufficient for large areas where consistent results are obtained, with not less than two samples for smaller excavated areas.

If excavation base samples do not comply with the relevant standards, further excavation and validation sampling should be carried out until complying results are obtained. The additional excavation should extend laterally to the adjacent complying points unless additional sampling is carried out to show a smaller extent of excavation is sufficient to deal with the non-complying zone.

Benchmarking the base of the excavation regardless of depth (i.e. at 500 mm or beyond) is recommended as good practice, as it provides information to guide future soil management in the event of future, deeper, excavation. It is recommended that not less than 10% of the sampling locations, or not less than three locations in each mixed area, whichever is the greater, will also be sampled from the residual soils at the base of the mixed soil layer.

Mixed soil sampling

The ideal situation is to carry out sufficient validation sampling in the stockpile to give confidence that the spread soil will comply, thereby minimising the risk of non-compliance after spreading and similarly minimising (or eliminating) the need for sampling in place after spreading. If not carried out in the stockpile the soil must be validated in place with sufficient samples to demonstrate that each proposed lot has an average concentration below the relevant standard at both the surface and below the surface.

Sampling within the stockpile should follow the following principles:

1. Sampling individual soil layers after mixing to ensure adequate vertical mixing of each layer.
2. Sampling at a sufficient lateral frequency within each layer to be equivalent to the sampling required to validate individual lots.
3. Sampling results that, on average (95% UCL) within each mixed layer, comply with the relevant standards.

Portable XRF analysers provide an efficient and quick means of controlling stockpile mixing, but require site-specific correlation between the XRF results and confirmatory laboratory results. As noted in Section 7.2, best performance with an XRF is obtained using ex situ (removed from the ground), dried and properly homogenised samples.

The following validation checks are recommended in the stockpile:

1. After each layer is mixed, excavate down to the depth of mixing at several locations along the length of mixing to ensure mixing has fully penetrated the two layers of contaminated and clean soil.
2. Carry out a visual check that the mixing has been thorough, that a consistent colour and texture has been achieved through the vertical profile, and that the soil has been adequately broken down without clods and clumps of turf or soil attached to roots.
3. After checking that the vertical profile appears to be consistent, sampling at two vertical points within the mixed layer if less than 300 mm thick, or three points in the layer if up to 500 mm thick, with the samples combined for analysis to give an average of the vertical profile, at a lateral spacing equivalent to eight samples per future residential lot.

Example:

Validation is to be primarily carried out in the mixing stockpile using portable XRF with laboratory confirmatory samples.

If the soil is to be spread 300 mm thick and the average lot size is 600 m², there should be eight samples per 180 m³ in the stockpile, which would be one sample location per 56 m² (approximately 7.5 m grid) if the stockpile layer was 400 mm thick.

Proving that the mixing method is effective by means of a field trial, and subsequent close quality control (inspection) of the mixing process, may allow the number of validation samples in the mixing stockpile to be substantially reduced. This requires an initial demonstration through validation sampling that good control of the mixing process does in fact achieve the necessary consistent mixing. Spot checks would still be performed.

An analogy is counting the number of passes of the roller when compacting a road base, with spot testing of the soil density as a check. Earlier, a compaction trial would have been carried out to determine, with a high degree of certainty, that a given number of passes would achieve the specified compaction.

If inspection (with record keeping and sign-off) is to be the primary means of control, in addition to close attention of the actual mixing, there also needs to be close control of layer thickness based on a good knowledge of starting concentrations (from initial sampling in the field) and keeping track of soil from stripping to the mixing pile. Additional confidence can be gained by ensuring the target has a built-in margin (at least 10% below the SCS).

It is recommended that at least two mixed layers are demonstrated to comply with the target within some predetermined range, before relaxing the amount of validation sampling required. Spot checks should continue on each layer and full validation carried out every few layers as a further check.

Example:

An ex situ mixing trial has been carried out to show that satisfactory mixing can be achieved on 250 mm deep layers with four passes of a rotary hoe.

Sufficient sampling has been carried out on the undisturbed land to allow reasonably accurate calculation of the average concentration of the soil as it is stripped. The stripped thickness will be the same as the contaminated layer to be mixed. The pile was to be monitored by counting and recording rotary hoe passes, independent visual inspection that the soil appeared to be broken down evenly with no major pockets of clods, digging down through the layer at random locations to inspect the depth of mixing and additional spot mixing where visual assessment suggested more mixing was required.

Mixing the first two layers was validated by XRF on a five-metre grid at two depths in each, with three laboratory samples from each layer on rapid turnaround to give a correlation. Each layer was found to be well mixed, achieving the target on average (95% UCL – calculated for the two depths in each layer), with concentrations varying within a 5 mg/kg range laterally and with depth.

The decision was then made in conjunction with the environmental consultant to intensively validate every third layer, with the intervening two layers subjected to the rigorous inspection regime but spot checks every 10 m along the stockpile with the XRF to be within the previous variation (checking with laboratory samples at the required frequency).

Validation after spreading

As noted above, validation of the land after the soil is re-spread will depend on how well controlled (and demonstrated to be well controlled) the mixing was.

Where the mixing is poorly controlled or not validated in the stockpile, the frequency of validation sampling for each lot should be the same as for in situ mixing (see 7.3.1 above).

The opposite extreme is where no validation of the final lots is required because the mixing has been properly planned and executed, a rigorous inspection regime maintained to ensure the mixing was carried out as planned, and sufficient validation sampling carried out to demonstrate with a high degree of certainty that the mixing target has been achieved. For this, variation around the target must be small enough to ensure that, on average, any particular lot will comply with standards.

Even well controlled projects may require at least some validation of the final lots, but perhaps as few as one or two surface samples per lot. Given the additional mixing the soil will receive when excavated from the stockpile and re-spread, deeper in-place samples of initially well-mixed soil should not be required.

If validation in the stockpile is to be relied on, it is recommended that the council be consulted, along with any reviewer the council may engage, to obtain agreement that the proposed mixing and validation regime is satisfactory.

Example:

Mixing in the stockpile relied entirely on the pre-mixing field sampling to define mixing layer thickness, and then mixing in the stockpile until it “looked about right”. Soil was re-spread 300 mm deep.

There should be a minimum of eight sample locations to calculate a robust 95% UCL. If each lot is to be validated and each lot is about 600 m², this means one location per 75 m² or an approximate 8 – 10 m grid, sampled at both the surface and at 200 mm depth.

This could be carried out using an XRF provided a satisfactory correlation between XRF and laboratory samples was obtained (minimum of three samples for a particular soil type) and not less than one laboratory sample per lot.

Stockpile location validation

If stockpiles are built directly on the ground, the ground beneath the stockpiles should be tested following removal of the stockpiles to ensure the ground meets relevant standards. If the land is to be residential, a frequency not less than the other residential lots should be employed. Only the ground surface needs to be sampled unless the surface results indicate deeper samples are required.

8.0 Record Keeping and Validation Reporting

Records should be kept of all stages of the remediation and validation process. These records should be summarised in a Validation Report (MfE, 2011a) and should include:

- ✦ a summary of the initial detailed soil investigation;
- ✦ a detailed description of the mixing process, including calculations showing the theoretical expected concentrations from mixing;
- ✦ records of any mixing trials;
- ✦ explanation of any changes to the intentions set out in the RAP, and reasons for and implications of the changes;
- ✦ photographs of the mixing process;
- ✦ locations, dimensions and depths of in situ mixing, if any;
- ✦ validation results for in situ mixed areas, including observations and original premixing samples where these are relevant for the validation;
- ✦ locations, dimensions and depths of areas excavated for ex situ mixing;
- ✦ excavation base sampling results;
- ✦ records of ex situ stockpile mixed layers, including thicknesses of layers to be mixed, concentrations of those layers if measured, post mixing observations, and layer concentrations post mixing (this could be as an inspection sheet for each layer);
- ✦ final mixed thickness of soil in place, showing adequate depth of compliant soil over any residues left below;
- ✦ soil validation results for the final soil locations (as appropriate for the level of validation carried out in the stockpile);
- ✦ any statistical analyses used; and
- ✦ the validation report should be written and certified by a suitably qualified and experienced practitioner as defined by the NES regulations.

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