A proposed, more realistic and simpler proforma for classifying earth materials containing elevated concentrations of trace elements

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Abstract

Current routines followed by ANZECC/NHMRC and the Victorian Environment Protection Authority (EPAV) for classifying earth materials such as soils or rocks as clean fill, low level contaminated material, or high level contaminated material (and hence a prescribed waste) can be simplified and lead to more realistic decision making if the prime aim of classification is the protection of human health and the environment as a habitat for other life. The current Victorian routine starts with the implicit assumption that any soil taken off-site for treatment and disposal is a "waste" requiring classification (EPA Publication 448, 1995). Classification of this waste is shown in a diagram - a decision tree for contaminated soils - necessitating determination of total trace element concentration in a sample, and then, when these concentrations exceed specified thresholds, determining elutriant concentrations using a milder extraction method to further classify the material as clean fill, low level contaminated soil or prescribed waste. The ANZECC/NHMRC scheme has environmental investigation levels that are far too low.

In another EPA Draft document (1996) on assessment of low level contaminated soil for disposal it is stated that: *"In cases where the high analytical results are due to naturally high background levels the soil is still to be treated as low level contaminated soil"* and may be sent to some landfill *"based on the background levels occurring at the receiving site and demonstrated negligible environmental risk."*

The fundamental criterion of environmental or toxicological meaningfulness is conspicuously absent. The pertinent question "When is a soil contaminated?" - in reality "When is there a risk to health or environment?" - cannot be answered by referring to a certain trace element concentration determined by a particular method, but it has to be related to a potential biological effect. The implicit assumption that soil on the move is potentially contaminated has costly ramifications for the community. The decision tree for classification can be simplified, and alternative test methods can provide better indications of environmental risk.

Keywords: soil contamination assessment methodology, bio-availability.

Introduction

In a recent Issues Paper (EPAV, 1997) the Victorian Environment Protection Authority proposed to distinguish the terms 'contamination' and 'pollution' as follows:
"contamination is the addition to land of chemical substances at above (natural) background concentrations",
and
"pollution of land occurs when the condition of the land is so changed as to make the land or produce of the land -
a)   *noxious or poisonous;*
b)   *harmful or potentially harmful to the health or welfare of human beings;*
c)   *poisonous, harmful or potentially harmful to animals, birds or wildlife;*
d)   *poisonous, harmful or potentially harmful to plants or vegetation;*
e)   *obnoxious or unduly offensive to the senses of human beings; or*
f)   *detrimental to any beneficial use made of the land.*

The Issues Paper goes on to say that :

"Since it is quite possible for the concentration of chemical substances in land at a site to be raised above background levels (i.e. for the land to be contaminated) without producing any of these adverse effects, the fact that the land is contaminated does not necessarily mean that it is polluted within the terms of the EPA Act. Polluted land is in fact a subset of contaminated land."

In Victoria the Environment Protection Authority is developing a State Environment Protection Policy (SEPP) for Land Contamination. The crux of making decisions about whether land is contaminated or polluted depends on an issue also highlighted in the Paper:

"What indicators of contamination should be employed and how should they be measured and evaluated?"

At a national level this question is answered in the ANZECC/NHMRC Guidelines (ANZECC/NHMRC, 1992). In Victoria one must rely on various EPAV guidelines such as Information Paper 448 and ANZECC/NHMRC (1992). These guidelines do not distinguish well between natural background levels and contamination, and between contamination and pollution. Environmental protection authorities do not have the level of in-house expertise available in CSIRO, a body with a national perspective, in developing criteria for soil pollution (see, for example, Tiller, 1992) and rarely employ soil scientists. At State level, a degree of institutional parochialism detracts from the expertise that would otherwise benefit the nation and the environment as a whole.

The Victorian system for classifying wastes

Insufficient Recognition of Natural Background Levels

This system appears to give insufficient consideration to the varying natural abundances of trace elements in different geological materials, nor to the forms in which these elements occur in them, which ultimately determine the mobility and bio-availability and hence the hazard to health or life. The inadequate weight being given to speciation and solubility in water of trace elements detracts from the credibility of official management systems for contaminated soil.

Threshold levels are frequently set well below the upper level of common trace element concentrations, making the official criteria harsher, and more costly to the community, than is necessary for protection of public health and the environment, a fact also noted by Tiller (1992). Victorian criteria are largely adopted from the Dutch A-B-C value system even though geology, hydrology, sources of potable water, population density and industrial history are entirely different. Also, the A-B-C system has been abandoned by Dutch Authorities nearly 10 years ago (Moen, 1988) because single value criteria did not cope with inherent soil properties which modified biological effects and hence environmental risks. Even the Australian data base is not well reflected in current EPAV or ANZECC/NHMRC threshold values, as is illustrated in the Table below, taken from Tiller (1992), and modified to show Dutch B and EPAV values.

Table   Ranges of background concentrations (*mg/kg*) of some potentially toxic elements in Australian rural surface soils

Element	Approx. # samples	Range	Old Dutch A Upper limit background	Old Dutch B Investigation trigger	EPAV Maximum Clean Fill	EPAV Maximum Low Level	ANZECC-NHMRC Env. Invest'n
As[*)]	26	<1-8	20	30	30	300	20
Cd	-	-	1	5	5	50	3
Cr	180	5-110	100	250	250	2500	50
Co	250	<2-170	20	50	50	500	-
Cu[*)]	500	1-190	50	100	100	1000	60
Mo	300	<1-20	10	40	40	400	-
Ni	200	2-400	50	100	100	1000	60
Pb[*)]	160	2-160	50	150	300	3000	300
Zn	500	<2-200	200	500	500	5000	200

[*)] Excludes orchard soils treated with As, Cu and Pb.

The Dutch A-B-C system was intended as a first cut basis for assessing risk to ground water, applicable to a small country with soils derived almost wholly from alluvial and marine sediments, whose heavy metal contents were the end result of the blending and partial homogenisation of sands, silts and clays from the catchments of two major rivers, the Rhine and Meuse, as well as materials brought in by long-shore currents in the North Sea. Only the southernmost province of Limburg has areas with residual soils where the underlying lithology (limestone) does affect the soil composition. Moreover, nearly all potable water comes from the ground water and hence has to pass through the soil first, so that soil composition could be a determinant of water quality. In Australia, Perth is the only major city using ground water. The use of the Dutch criteria in Australia is logically unsustainable.

Trace elements that have a biological significance and can potentially be toxic occur in the majority of natural earth materials at varying concentrations. Figure 1, taken from Mitchell (1965), illustrates this for 22 selected trace elements using a logarithmic vertical scale. The Figure has been modified by adding the current Victorian threshold levels (See small arrows) for listed elements that discriminate between "Clean Fill" and "Low Level Contaminated Soil", illustrating that in the cases of arsenic, copper, nickel and chrome the thresholds are well below the upper end of a commonly found abundance. In viewing the Figure it must be remembered that where the measured concentrations exceed the common range there is not necessarily a toxicity problem.
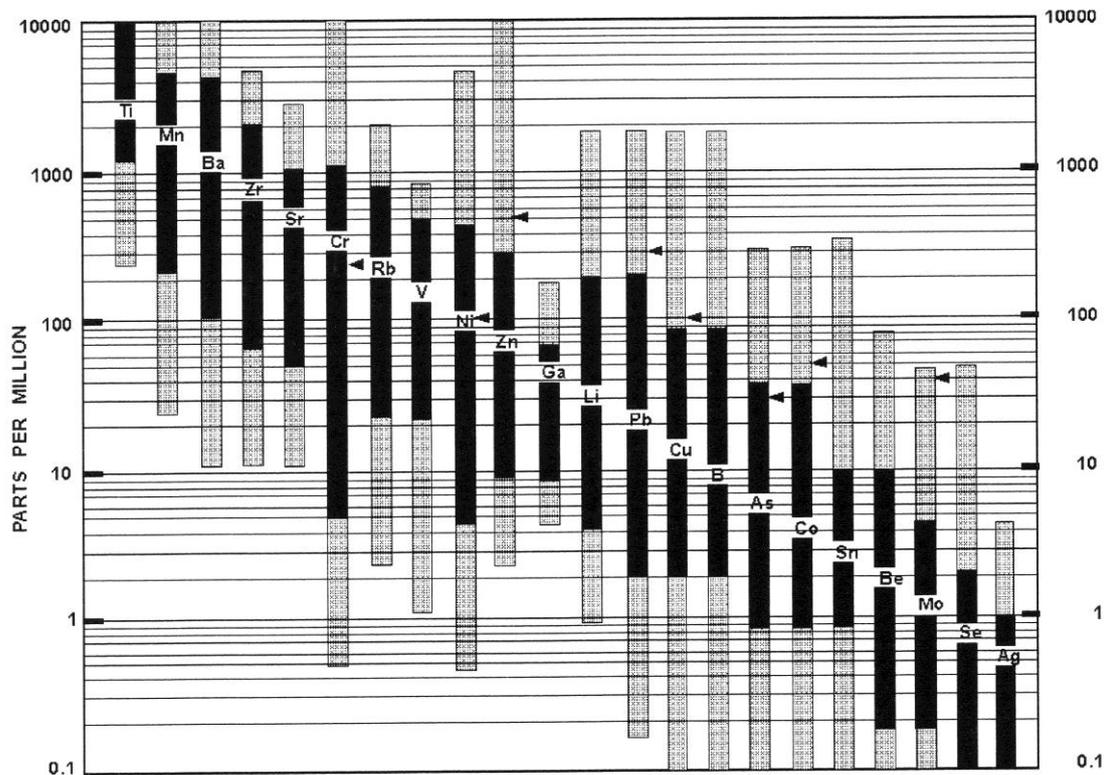

Figure 1   Range of contents of some trace elements commonly found in mineral soils. Stippled sections indicate more unusual values; certain extremely high values from localities influenced by ore deposits have been ignored (Mitchell, 1965). The arrows indicate EPAV clean fill maximum limits. *(Note: mineral soils may be residual or transported)*

The use of total concentration and elutriation tests for classification

EPAV Publication 448 summarises waste types as fill, solid inert, putrescible, low level contaminated soil and prescribed waste. Fill is described as *"soil (sand, clay & silt), gravel, rock; contamination levels must be less than*

listed in Table 2". This Table lists a range of contaminants with the maximum allowable total concentration for each of the contaminants to be acceptable as "fill". If this waste exceeds these concentrations, then Table 3 is to be used for classification of the waste as a low level contaminated soil or a prescribed waste. Table 3 lists both total concentrations and elutriable fraction in the extract in *g/m³* at pH 5.0. The classification scheme is reproduced below.

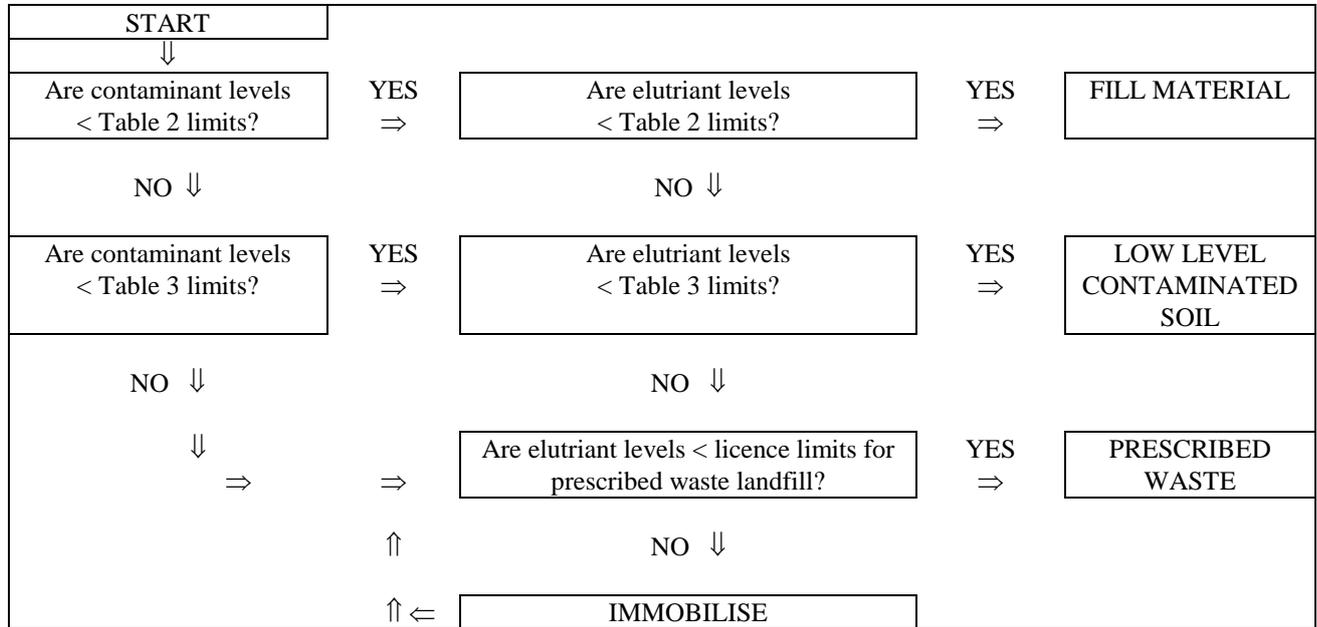| START				
⇓				
Are contaminant levels < Table 2 limits?	YES ⇒	Are elutriant levels < Table 2 limits?	YES ⇒	FILL MATERIAL
NO ⇓		NO ⇓		
Are contaminant levels < Table 3 limits?	YES ⇒	Are elutriant levels < Table 3 limits?	YES ⇒	LOW LEVEL CONTAMINATED SOIL
NO ⇓		NO ⇓		
⇓ ⇒	⇒	Are elutriant levels < licence limits for prescribed waste landfill?	YES ⇒	PRESCRIBED WASTE
⇑		NO ⇓		
⇑ ⇐	IMMOBILISE			

Figure 2. Decision tree for contaminated soils (EPAV, 1995).

The EPAV uses USEPA Method 1311-Toxicity Characteristics Leaching Procedure (TCLP) as described in the Draft Guidelines for the Analysis of Contaminated Soils (ANZECC, 1995) as the elutriation test for leachable metals. Extraction fluid No.1 is a buffered solution of acetic acid and sodium hydroxide at pH 4.93±0.05. If during extraction the pH of the mixture rises above 5.0, extraction fluid No.2 must be used. This is a solution of acetic acid at pH 2.88±0.05. The original, intended purpose of the TCLP was to classify a waste for disposal in a well-drained unsaturated landfill capable of generating organic acids, such as domestic waste landfills (SPCC, 1988). TCLP simulated the amount of inorganic chemical that can be extracted by an acidic extractant solution containing an organic ligand (Dragun, Barkach and Mason, 1990). It has wrongly been used to predict the transport of contaminants in and from landfills not containing putrescible wastes to assess the risk to ground water. It is not suited to determine the leaching and migration potential of metals in soils. For the latter, a distilled water leaching was considered satisfactory (SPCC, 1988).

From a soil chemical point of view, the use of these solutions on soil samples already at a pH of approximately 5 will bring about an extraction without a change of pH. Soil pH is a major determinant of the solubility of many trace elements so that at constant pH during the extraction one may expect that ion exchange is the chief process by which trace elements are liberated from the soil. If the soil is normally at a higher pH, for example at a pH close to 8 as in many calcareous soils, the extraction with fluid No.2 will cause major reactions and any liberated elements merely represent an artefact caused by the method of extraction. It will have no predictive power in terms of biological effects.

Since all plant uptake of trace elements from the soil takes place through the medium of soil water, and uptake of trace elements by humans and animals generally takes place through the consumption of vegetable matter, assessments of the harmfulness of contamination must concern themselves with the bioavailability of trace elements. Therefore any leaching test should be "site specific" in that it should not significantly alter the chemical environment of the sample from the condition of the soil in the field, in particular the soil pH and salinity.

Total concentrations are meaningless, except to indicate when a site specific leaching test is warranted. It is doubtful that the TCLP test can give useful information; if so, then only in soils at a similar low pH. However, if the decision tree for contaminated soils is modified, and the elutriation tests are selected to leave the soil pH unchanged during extraction, it could be more realistic for classifying soil materials.

How do the ANZECC/NHMRC and EPAV classification systems work at present?

The use of single value cut off levels, often set far too low, for earth materials has resulted in crushed rock of basaltic origin having too high Ni, say 70-80 *mg/kg*, for classification as uncontaminated material by ANZECC/NHMRC criteria, so that an environmental investigation is required. The outcome of this, at best, is a Statement of Environmental Audit saying that the site with the crushed rock is "contaminated" but can be used safely for all intended purposes, except that plants grown on the site may take up the "contaminant". Basaltic soils west of Melbourne often have 120 *mg/kg* Cr, and near old volcanic vents it may go up to 250 *mg/kg,* with the concentration often increasing with depth (private communication, P. Thornton, Golder Associates, Melbourne). The ANZECC/NHMRC threshold for environmental investigation is set at 50 *mg/kg* and the EPAV clean fill limit is 250 *mg/kg*. Near Wollongong, volcanic extrusive rocks contain around 200 mg/kg of Cu, and the soils derived from these rock often have up to 400 *mg/kg* of Cu (private communication, P. Mulvey, Environmental and Earth Sciences Ltd, Sydney), compared to an environmental investigation limit of 60 *mg/kg* (ANZECC/NHMRC), or a clean fill maximum of 100 *mg/kg* (EPAV). These artificial thresholds are costly and cause unnecessary anxiety to the public.

Costly budget overruns can result from the inability to distinguish between natural, harmless concentrations of heavy metals and those that indicate contaminated/polluted soil conditions. An example of this is a major excavation in Melbourne, where "elevated" total arsenic concentrations were found in the strongly weathered Silurian mudstones and sandstones at considerable depths. The weathering process has operated for very long periods (Neilson, 1970), possibly since the Pliocene.

About 30 sampling holes were drilled at the site, and about 100 samples were analysed. In about 80-90% of the samples As levels were below the EPAV criterion of <30 *mg/kg* for clean fill, with most the samples exceeding this level being between 30-50 *mg/kg*, but a few samples were up to about 300 *mg/kg*. This result caused the EPAV to require further investigation.

In the meantime, soil and decomposed rock had to be stockpiled on the site for further laboratory testing, causing delays in the excavation and removal of material, considered not to be clean fill. The workforce went on strike for reasons of environmental health and heavy machinery and trucks stood idle for two to three weeks. The excavation budget was based on the cheap removal of clean fill, not on disposal of contaminated soil to a licensed land fill. Yet the arsenic levels were hardly dramatic, but some exceeded the EPAV level of 30 *mg/kg*, the old Dutch B-value, regardless of the nature of the earth material.

EPAV staff made videos of dust movement and soil spills at the excavation site and on nearby roads, and As levels in the dust were measured. The work was delayed by about 2 months, costing the Victorian taxpayer approximately $2 million in extra charges. As the excavation was for a major Government-initiated project, it was possible to negotiate higher cut off limits for As in material to be classified as clean fill. A small private operator might not have had the same consideration. Judicious mixing and sampling of spoil also helped to keep average As levels down.

Total arsenic concentrations in geological materials quoted in scientific literature is as follows:

Source	Typical range *(mg/kg)*	Extreme limits *(mg/kg)*
Dragun, James (1988)	1.0 - 40	0.1 - 500
O'Neill, P (*in* Alloway, B.J., Ed., 1990)	1 - 1.5 (mean in igneous rocks) 13 (mean in shales)	<1 -15 (igneous rocks) <1 - 900 (shales, mudstones)
Adriano, D.C. (1986)	0.2 - 13.8 (igneous rocks) 0.3 - 500 (shales) 0.1 - 55 (world soils)	no data given do do

The Silurian sedimentary rock formations in Victoria are the source of significant gold deposits, often accompanied by arsenic. For example, shallow subsoil samples collected in a pasture at Coldstream, on the eastern periphery of Melbourne, with soils developed on Silurian sediments, and with no history of arsenic pesticide use, gave a geometric mean concentration of 97 *mg/kg* total As. Ironically, the two "background" samples collected especially to represent sites least likely to have been enriched in As by humans resulted in relatively high values of 100 and 340 mg/kg As.

Sample #	GS01	GS02	GS05	GS06	GS08	GS09	GS12	GS13	GS32	GS35 B	GS36 B
Total As	150	120	74	97	78	120	51	170	72	100	340
TCLP As	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2

B = background sample

Subsequent sampling of ferruginised and kaolinised sedimentary beds at the excavation site was undertaken on 3 December 1996. These samples, and earlier core samples taken by other consultants, were analysed by the same laboratory for the same parameters as in the original sampling: total As, total Fe, TCLP As, but in addition total As after citrate-dithionite extraction, As in the citrate-dithionite extract and Fe in the citrate-dithionite extract. The results are shown in the Table with the ferruginised beds shown with dark banding and the kaolinised beds left blank.

That As is precipitated, occluded or adsorbed by iron oxy-hydroxides is well known. Jacobs, Syers and Keeney (1970) found that iron oxides play a role in the uptake of As by soils, and, more specifically, Fordham and Norrish (1974) showed that goethite was able to retain added As. What applies to artificially added As also applies to geochemical enrichment of As (Smith and Perdrix, 1983). The highest As concentrations are characteristically located in the ferruginised beds, but only 1 sample in this series exceeded the EPAV threshold of 30 *mg/kg*. However, the citrate-dithionite extraction removed only a small fraction of all the Fe, while a significant fraction of the As remains in the sample. The laboratory results suggest it may be safely assumed that the As in the Silurian beds occurs in extremely stable and inert forms.

Depth (m) & Sample #	Banding	Total As (mg/kg)	Total Fe (mg/kg)	TCLP As (mg/L)	Total As after C/D (mg/kg)	As in C/D extr. (mg/kg) (%)	Fe in C/D extr. (mg/kg) (%)
9.8 (C)		4.0	20,000	<0.001	1.8	2.2 (55)	--- (28)
10.2 (C)	▓	4.5	178,000	<0.001	3.6	0.9 (20)	--- (7.8)
10.5 (C)		5.0	24,000	<0.001	2.8	2.2 (44)	--- (24)
11.0 (C)	▓	7.5	180,000	<0.001	4.5	3.0 (40)	--- (7.8)
2.0 (V)		13	20,000	<0.001	2.3	10.7 (82)	--- (41)
2.5 (V)	▓	40.0	36,000	<0.001	24.0	16.0 (40)	--- (47)
4.9 (V)		<2	2,000	<0.001	<2	<0.1	--- (<0.1)
5.1 (V)	▓	13.0	42,000	<0.001	6.1	6.9	--- (36)
7.0 (V)		7.0	124,000	<0.001	1.3	5.7 (81)	--- (25)
9.9 (V)		<2	680	<0.001	<2	<0.1	--- (<0.1)
10.0 (V)		<2	6800	<0.001	<2	<0.1	--- (74)
10.1 (V)	▓	5.2	124,000	<0.001	0.7	4.5 (86)	--- (81)
10.2 (V)		11.0	114,000	<0.001	0.3	10.7 (97)	--- (23)
3.0 (BH85)	▓	25.0	38,000	<0.001	15.0	10.0 (40)	--- (14)
3.2 (BH85)		8.5	55,000	<0.001	3.5	5.0 (59)	--- (11)
3.6 (BH85)		2.8	5,100	<0.001	0.3	2.5 (90)	--- (7.5)
6.0 (BH85)	▓	4.0	25,000	<0.001	1.2	2.8 (70)	--- (30)

Notes: C = Coffey Partners core samples; V = van de Graaff pit face samples; BH85 = CMPS&F core samples

The TCLP test results, although in fact superfluous, also show that the As extracted by a relatively gentle extraction method is always below detection. In the soil water phase the As concentration must be regarded as

negligible. The nature of the As compounds in the ferruginised beds is unknown, but perhaps they may be compared to Fe-arsenate. According to Adriano (1986) the As concentration in equilibrium with Fe-arsenate is approximately 10^{-11} Molar, or 0.000,749 $\mu g/L$, an order of magnitude below the permissible NHMRC standard for drinking water.

The EPAV classification system of earth materials, in this case, initially caused potentially unknown volumes of the excavated shale to be placed in the category of "low level contaminated soil", where common sense could have prevented hold ups in the excavation process. The failure stems from (1) the unrealistic threshold level of 30 mg/kg, (2) the initial assumption that slightly elevated As levels at 2 to 10 m below original ground level in low permeability shales could have an anthropogenic origin, and (3) the assumption that total concentrations or TCLP concentrations have a biological significance.

A modified classification system

A proposal is made for changing the proforma for classifying earth materials and for using more appropriate test methods, such as extractions with low concentration neutral salt solutions instead of EDTA or TCLP methods.

The behaviour of trace elements in the soil is controlled by the chemical properties of the forms of compounds in which they occur, which in turn is often strongly affected by other soil environmental factors. In order to assess whether elevated total concentrations pose a real hazard, now or in the future, some generalisations need to be made about this soil environment:

- does it contain a surplus of materials known to react with and immobilise the trace elements by strong adsorption, chemical binding and/or occlusion?
- is it, and will it remain, an oxidising environment or a reducing environment?
- will the pH of the environment remain unchanged, and if not, how is it likely to change in the future?
- will reduction or the change in pH cause the immobilising substances to liberate the trace elements?

Depending on the answers to these questions, a more purposeful program of sampling and analytical methods may be followed to assess such hazards.

Determination of Total Concentrations of trace elements in soils will remain necessary in order to:

- broadly assess the risk associated with ingestion of the soil itself;
- indicate the need for site specific leaching tests;
- assess the ability of the soil to continue to contribute trace elements to the soil solution; and
- estimate the possible increase in soil solution concentration as the chemical environment in the soil changes.

Determinations of plant-available trace elements must reflect the normal chemistry of the soil solution and must have been demonstrated to reflect the uptake by selected indicator plant species. Extractants must have a pH and salt concentration as well as salt composition similar to the pore fluid in most soils to avoid liberating or precipitating trace elements and create artefacts.

Unbuffered dilute solutions of 0.1 M $NaNO_3$, 0.1 M and 0.01 M $CaCl_2$ and 1.0 M NH_4NO_3 have given generally good results in Switzerland, Germany and The Netherlands when extracted heavy metals - Cd, Ni and Zn, but less so for Cu and Pb - concentrations were correlated to levels in plants. The results obtained with each of these extractants generally are well correlated with one another (Pepels and Lagas, 1993).

Extractions using dilute unbuffered salt solutions enable the determination of plant nutrients in the same extract, while extractions with $CaCl_2$ solutions enable soluble nitrogenous compounds to be determined as well if that is desired. The potential of anions and cations in the extracting solution to interfere with the trace elements to be determined must be considered in choosing a method for extraction. For example Cl- can complex Pb and increase its solubility, and Ca can precipitate soluble organic matter and decrease the solubility of Cu complexed on soluble organic compounds.

There are significant advantages in using unbuffered salt solutions. Novozamsky, Lexmond and Houba (1993) list the following advantages for 0.01 M $CaCl_2$ solution:

a) it is a solution which has more or less the same salt concentration as the average soil solution;
b) Ca^{2+} is the dominant cation on the adsorption complex of soils. Therefore the $CaCl_2$ solution is better able to extract other adsorbed cations, without appreciable changes in the final equilibrium solution compared with the extraction solutions containing other cations. In this situation it is possible to use heavy metal concentrations in the extract as the sole intensity parameters. This enables an easier evaluation of inter-elemental interactions in uptake;
c) various nutrients and metals are measured in a single extract, so that interpretation can also include concentration ratios between the elements;
d) the divalent cation causes good coagulation in the suspension, making high concentrations unnecessary, as would be the case with some monovalent cations such as Na^+;
e) the relatively low salt and especially chloride concentration facilitates strongly the final determination of metals;
f) the $CaCl_2$ extract allows the determination of all the important nutrients (including N) besides the various heavy metals;
g) measurements can be taken simultaneously, making automation an attractive option;
h) the amount of chemical used for extraction and the amount of waste from harmful solutions is minimal; and
i) the cost of reagents is minimal compared to many other methods.

Calcium chloride extractable cadmium was a good predictor of cadmium uptake by subterraneum clover in Australia (Whitten and Ritchie, 1991) and for both zinc and cadmium in maize in The Netherlands (Smilde, van Luit and van Driel, 1992). In Switzerland, critical threshold concentrations for plant-available heavy metals in soil were established by Gupta and Hani (cited in Pepels and Lagas, 1993), using 0.1 M $NaNO_3$ as the extractant solution. These were valid for soils ranging in pH from 3 to 8, and in cation exchange capacity from 10 to 50 *mmol/100g* soil.

Conclusion

EPAV has made a significant conceptual contribution in making a distinction between environmental pollution from environmental contamination.

The Dutch B-values were investigation levels in a preliminary contamination assessment scheme, and have, illogically, become criteria for soil disposal in Victoria, and unfortunately tend to be used blindly as default criteria.

At a national level, in a country with as varied a lithology as exists in Australia, the emphasis on single value background values for heavy metal concentration and the use of the TCLP leaching procedure should be abandoned. The present EPAV classification system of soil material acts as a stick with which Victorians belabour their own backs, and the ANZECC/NHMRC environmental investigation guidelines do the same for Australians in general.

Greater weight should be given to a first stage recognition of undisturbed and unmodified soil or rock profiles, where there is no history of land use capable of polluting the environment, and no history of adverse biological impacts at a specified site. Soil scientists rather than engineers should be involved in this judgement.

The suggested proforma below portrays a decision making system that may assist in developing a more realistic and cheaper scheme for classifying earth materials in terms of pollution rather than contamination.

A 0.01 M $CaCl_2$ extracting solution is generally recommended for site specific leaching tests.

Acknowledgements

FLOW DIAGRAM FOR CLASSIFICATION OF NATURAL EARTH MATERIALS

(A) Does the material consist of fill or is it natural soil with an undisturbed profile or undisturbed country rock (bedrock)?	*Fill* →	Treat as potentially contaminated and follow appropriate protocol	Collect a small number of strategic samples, consider composited samples
Natural soil/rock ↓			
(B) Does site land use history suggest a man-made source?	*Yes* →	Use normal protocol for potentially contaminated sites	Total Concentrations plus Plant-available concentrations. **Classify degree of contamination and treat or dispose as required.**
No ↓			
(C) Assume materials and site are safe *Go to (D), but may do:* Optional low density sampling to confirm diagnosis			Preliminary sampling: Only Total Concentrations determined ↓
			Some samples return somewhat elevated concentrations *Go to (D); If not go to (F)*
(D) Soil judged to contain a surplus of materials active in immobilising the trace element	*No* →	Investigate if trace elements have arrived in seepage or runoff from any adjacent contaminated site	Analyse for % Fe, Al and Mn; also %CaCO3 if soil pH > 7.5; estimate % clay and determine % Organic Matter *If immobilisation likely, go to (E)*
Yes ↓			
(E) Soil aerobic and well oxidised judging by colours, iron minerals, and landscape position? Likely to remain so?	*No* →	(a) Exposure of soil may oxidise the material and block trace elements; or (b) Exposure may oxidise sulphides and create very low pH (c) Burial of organic-rich material may create low redox potential and toxic gases (H_2S, CH_4)	**(a) If remaining oxidised in future and no low pH, treat as clean fill (b & c)** Determine Acid forming potential and predict future pH and solubility of metals **If low pH or low redox in fill site are likely to develop, classify as potentially hazardous, treat or dispose as required;**
Yes ↓			
(F) Classify as potential clean fill; Confirm classification with determinations of plant-available trace elements using neutral salt extractants	*Confir-mation nega-tive* →	Start new intensive sampling and analysis program; or Treat soil as contaminated	Re-consider land use history and investigate reasons for wrong preliminary diagnosis. or **Dispose as per appropriate protocol**
Confirmation positive	→	**Dispose as clean fill**	

Australian Soil Science Society Inc.
National Soils Conference – Environmental benefits of soil management. Brisbane 27-29 April 1998

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