NATIONAL STANDARDS FOR SOIL AND GROUNDWATER

WHY DO THEY DIFFER SO MUCH BETWEEN COUNTRIES?

Drs. Ben Keet, Geo & Hydro – K8 Ltd, e-mail: ben@benkeet.com

Abstract

National standards for soil and groundwater of over 30 countries have been evaluated. Differences of up to seven orders of magnitude exist. The cause of these variations is complex. The national standards often fit in a country specific legislative framework. The various threshold levels have different definitions and the methods of analysis influence the guideline levels set.

Using the Ministry for the Environment Contaminated Land Guideline no. 2, "Hierarchy and Application in New Zealand of Environmental Guideline Values" is complicated by these different approaches. This paper analyses these differences, which will provide insight into some of the background issues in this complex matter. DDT is used in a case demonstrating the difficulties using the MfE guidelines database. Some recommendations for alternatives are provided.

Introduction

Since 2005 efforts to harmonize human health and ecological risk assessment for contaminated land in member states of the EU has been undertaken as project HERACLES[1]. In 2007, a report was produced including the country surveys of 15 EU member states[2]. Following a seminar held in Napier[3] discussions with several Regional Council staff made clear the urgent need for a set of guidelines for New Zealand which address eco-toxicological risks (important for Regional Councils) as well as human health risk (important for TA's). These should address various land uses and specify which environments they protect (i.e. fresh water, groundwater).Using this wish list a new website has been established[4] providing information on the national standards of many countries specific to the environments they protect. In researching this type of information from over 30 countries, many variations in derivation of guidelines have been encountered and these have been discussed by e-mails and by personal visits to people involved in the development and application of these standards.

Starting point and evaluation

During a discussion after the seminar "Financial risks and opportunities of contaminated land" held on 18 February 2008 in Napier[3] between some members of the Ministry for the Environment and staff from several Regional Councils, it became clear New Zealand would

1 http://eusoils.jrc.ec.europa.eu/library/Themes/Contamination/Workshop_Feb2005/Presentations/Carlon_HERACLES.pdf
2 http://ies.jrc.cec.eu.int/fileadmin/Documentation/Reports/RWER/EUR_2006-2007/EUR22805-EN.pdf
3 http://www.benkeet.com/DVDContents.pdf
4 http://www.epa.org.nz/index.html

not have any National Standards focussed on the protection of the ecological aspects of our environment for a long time to come. As New Zealand's 'Clean and Green' image is based on its special flora and fauna, our environment, all present agreed knowledge of the eco-toxicity of all of the chemicals we use in our daily home, commercial and industrial life is very important. However, very little guidance by central government can be provided. Regional Councils are responsible for the environmental effects of contaminants. Staff of councils with less knowledge appear to request guidance from other councils where, at that time, a specific staff member has more knowledge. Due to staff changes, this can be a difficult process.

A web-based data system is more readily available even to remote council staff. The Environmental Protection Association is incorporated in April 2008 with the aim to care for our environment and bring data together on its website www.EPA.org.nz . Its primary role is to provide information on human- and eco-toxicity in easy accessible formats. In many, if not all cases, working towards eco-toxicological guidelines will protect human health as well.

One of the initial key points chosen to focus on was a land-use specific eco-toxicological guidelines for soil, water and air. The web-based database associated with the Ministry for the Environments updated Guideline no. 2 does provide some of this data, however; no relation with land use, soil type, aquifer protection or the effects of the presence of combinations of contaminants is provided. The goal of the EPA website is to address these issues.

This paper focuses on soil and therefore soil quality standards of the countries investigated . The term 'soil quality standards' is equivalent to 'soil screening values', 'soil guideline values' or 'national standards for soil quality'.
As will be seen in the next paragraph soil quality standards are *less standardised* than the term implies.

Soil quality standards

The first major difference is the nomenclature. What is called 'unacceptable risk level' in one country or group of countries (EU) is called 'investigation or regulatory level' in others (Australia and Korea resp.) or 'preliminary remediation goals' in another (US - Region 9, the Pacific Southwest, serving Arizona, California, Hawaii, Nevada, the Pacific Islands, and Tribal Nations).

This makes country-to-country comparisons difficult for people with a fair level of knowledge but perilous for the layperson or someone only occasionally dealing with these matters.

Despite the various names used, more countries appear to agree on 'background' and 'no-action' levels. Comparisons of these are disturbed by the various definitions of 'background'. In some countries, this is 'detection limit' for most contaminants, in others the concentrations found in nature areas or large national parks. Both of these seem to make sense, even though the first will be a moving target with ever more sophisticated analytical techniques.

Problems with comparison arise when on a national or regional scale the background levels are adjusted to naturally (volcanic, geothermal) or anthropogenically (mining, smelting) elevated levels of certain contaminants [often metals]. Background levels are also at times adjusted over a certain industry group. For example, hydrocarbon levels at the refinery areas in Holland, which given the land-use is not likely to impact on human or ecological health as long as the migration streams from such areas is well monitored *and controlled*.

More problematic are raised background levels due to irreversible activities in the past which have resulted in elevated wide scale contamination like arsenic, cadmium or DDT on agricultural land, or PAH and metals in inner city areas. Needless to say these deviations from the true background levels are mainly political (see also in 'Methodology' below).

Therefore, it is important to make comparisons with guidelines from several other countries, as soils and parent rock materials over the world show less difference than political views. There will always be a few countries that have 'true' background levels and action levels that provide adequate protection of human health and the environment to compare with.

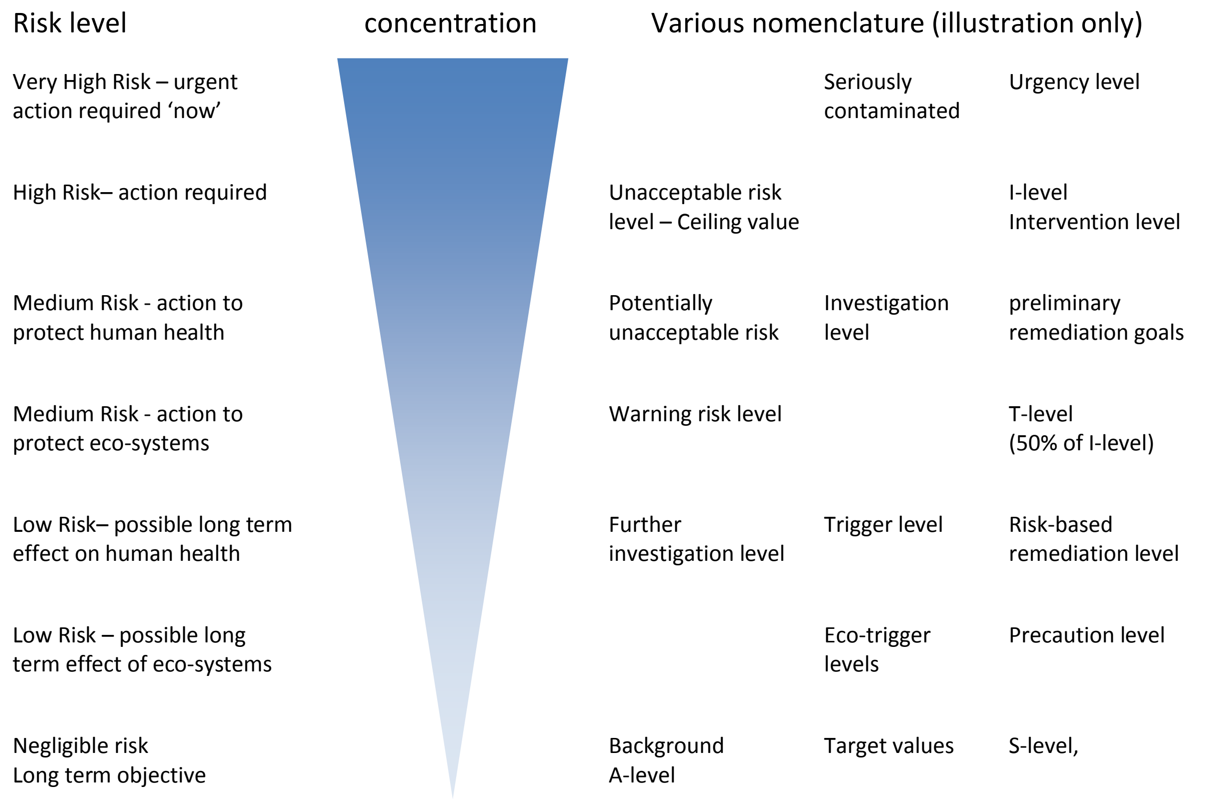

Figure 1 Nomenclature of Soil Quality Standards varies significantly in meaning and levels

Except background levels, most other health based investigation, trigger, action, intervention etc. levels will be linked to the current or future land-use. Even the eco-toxicological levels can be differentiated, and in areas where the contamination is above the true background level some arguments can be used to create zones with varying contaminant threshold levels:

- Distance to receptors (often water course),
- Connection of surface soils to groundwater (aquifer type: confined or unconfined)
- Soil type (highly adsorbent (peat, clay) or not (sand, silt)

In many countries and regions the movement of soil is strictly controlled. With 'clean' fill being readily accepted free of charge while contaminated soil costing \$ 100 – \$450 /ton to dispose of, plus often huge trucking costs to reach the nearest hazardous waste facility, there is a clear incentive to cart away soil as clean fill, even before the first (official) investigation is carried out.

Truck dockets are in use in most countries, even for loads of clean fill, indicating where the soil was loaded and its destination. In, for example Hawkes Bay, such a system is being proposed and figure 2 below shows one way how the contaminant and land-use levels can be integrated in ‘contaminant specific’ soil use charts.

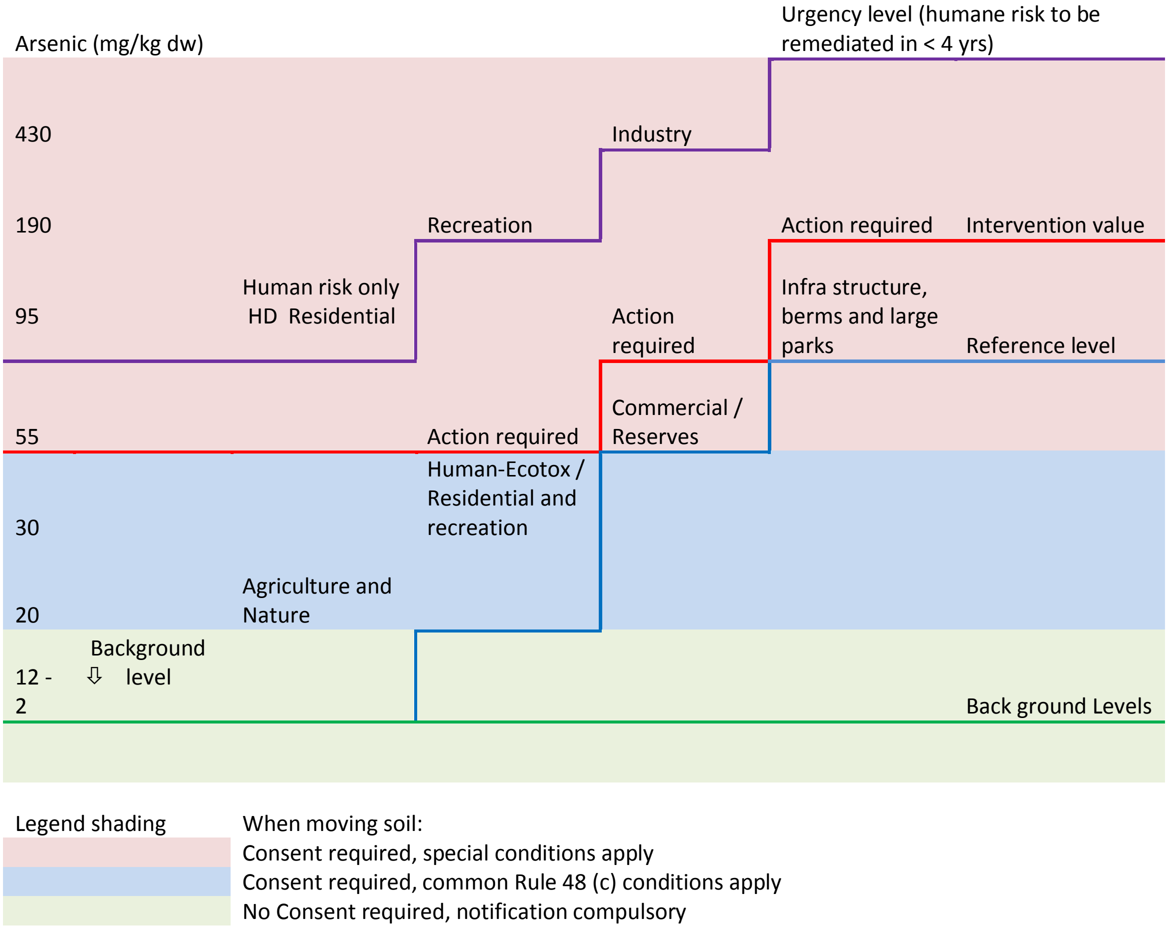

Figure 2 Example of a hybrid classification system showing Reference, Intervention and Urgency levels as well as consent requirements for moving soil on and off site (source B. Keet).

Other Differences in National Standards

By researching national standards of over 30 countries, the significant differences soon became clear. Many government agencies have decided to ‘invent their own wheel’. Only some new European member states, under pressure to ‘get their house in order before entering the EU’ have adopted the guideline system developed in other countries. Discussions with some staff working in the “EPA’s” of these countries revealed this to be generally seen as a good step forward, despite the need for some local alterations based on specific conditions found in their countries. It should be noted that the ‘special conditions’ are often more political than technical.

Even the more developed national standards show large differences. In the figure 3 below, the screening values for potentially unacceptable risk (residential soil-use), using only a health based investigation thresholds and/or final remediation goals for the most relevant organic contaminants is shown. For dioxins the variation is 7 orders of magnitude. For most contaminants the differences of these soil quality standards ranges between 2 and 5 orders of magnitude.

Acceptance of very high contaminant concentrations are deemed protective for the sturdy people and their rugged environment in Australia and the US - region 9; maximum soil quality standards there are between 5 – 100 times higher than any other country included in this survey. Other countries where high contaminant levels are an acceptable risk are Spain and Czechoslovakia. The Netherlands also displays a few moderately high concentrations for their Intervention level, however it should be noted that if this level is exceeded remediation to below 50% of this level is often required. Austria and Switzerland (not in figure) share the top concentration for Dioxins (100 ng I-TEQ/kg), however when direct soil contact is possible this is reduced in Switzerland to 20 ng I-TEQ/kg[5]. The bulk of the soil quality standards are within 2 orders of magnitude from each other, with lower (more stringent) soil quality standards are found in Italy, Canada and Finland.

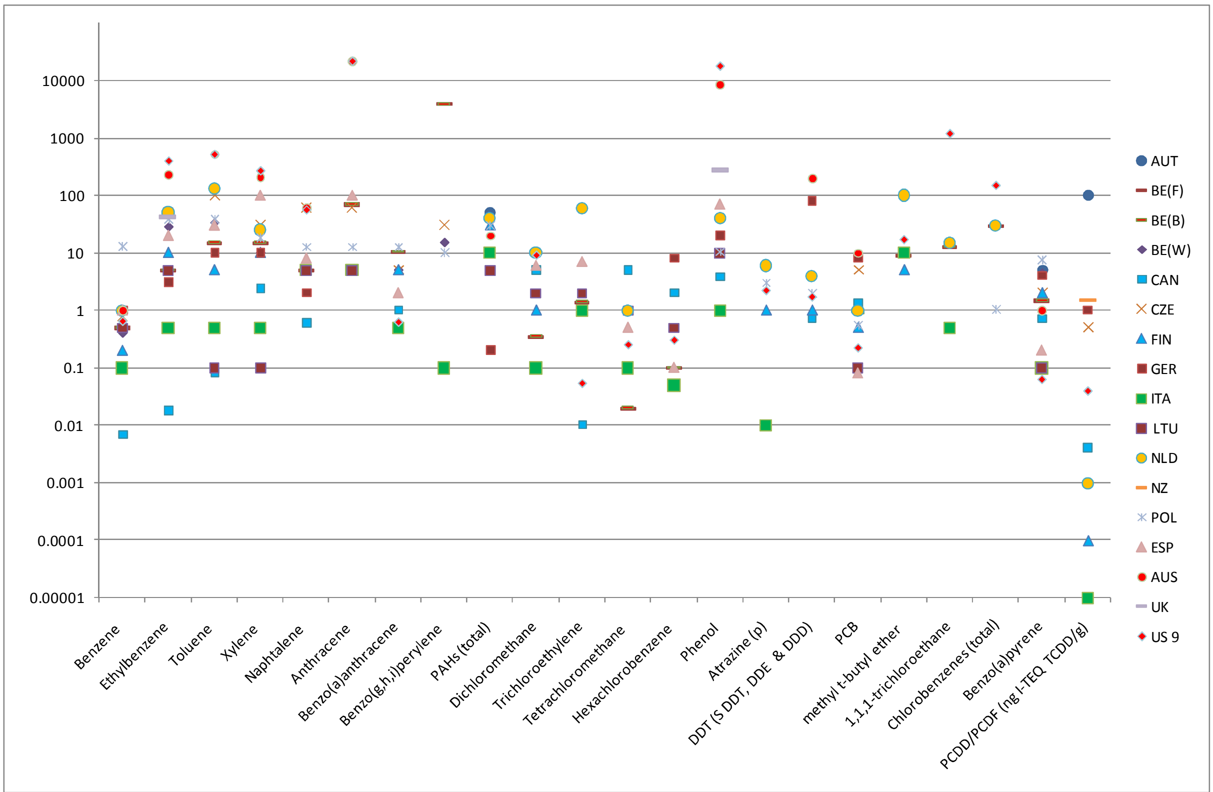

Figure 3 Screening values for potentially unacceptable risk (residential soil-use) and/or final remediation goals

Very different systems are found in Japan and Denmark. Soil quality standards in Japan relate to the maximum concentration found in the water phase after equilibrium with the soil has been reached in a laboratory test. This is similar to a TCLP[6] test only using distilled

[5] Der Schweizerische Bundesrat, 1 July 2008, Verortnung über Belastingen des Bodens (VBBo) 814.12
[6] Toxicity Characteristic Leaching Procedure, ref:
http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1311.pdf

water (conductivity less than 5 μS/m). An advantage is that the several soil characteristics for which other countries (Holland, UK, Germany, Switzerland and Belgium) make correction for are 'filtered out'. A disadvantage is that the contaminant 'reservoir' is eliminated from the evaluation.

Denmark uses a Triad approach were individual Lines of Evidence are used with differential weighting of tests based on the ecological conceptual model (ECM) used for a specific site, or type of site. This influences the weighting, or the range of variations expected, or when bias in measured and calculated effect is expected (for example in highly dynamic systems where full sampling may exceed the allocated budget). As a result, very few numerical soil quality criteria are in use that impedes the comparison with guideline systems in other countries. Using this system some practitioners in Denmark find that in general more emphasis is placed on the assessment phase which is favourable when larger receptor areas are considered (river sections, recharge areas and reserves), however for smaller sites (residential, commercial) often some form of numerical standard (Swedish) is used as a short cut due to limited funds.

Further causes of variations

Legal framework

Soil quality standards are incorporated in different types of legislation. While most countries have special laws for contaminated land, some work with laws to protect soil and groundwater and in others contaminated land is part of their waste management laws. The contaminated land laws are often set by national government, however regionally different laws (Germany and Spain) and/or soil quality standards may exist, like in Belgium, Canada and in the United States.

The different types of legislation refer to background (or non-detectable) levels, trigger levels (triggering some form of action) or intervention levels (enforcing action, given a certain time frame). Some countries use only one level where soils with concentrations higher than this level will be classed as contaminated (black – white system). The one level system creates problems when the single guideline given is only to protect a certain segment of the environment (for example humans, see below) in that more sensitive receptors will remain unprotected. Grey-zone systems exist where the investigation thresholds differ from the remediation thresholds the latter often being lower. In some countries the legislation may vary between historical contamination and recent contamination.   Overall, the variability due to regulatory and political differences is very high.

Methodology

The methodology to derive the various levels (background, trigger, etc.) varies between countries. Some have detailed information on their regional background levels, while others use detection limits but whichever is used can often not be found in the guideline documents. Very little use is made of outcomes of studies in the interaction between contaminant concentration, their speciation and effects on ecological processes (bioaccumulation). Certainly the more recent and 'low budget' standards do not incorporate any of these elements.

The methodology to derive trigger or intervention levels is even less transparent. Acceptable risk levels for example to get ill / develop cancer vary from 10^{+4} – 10^{+6} the latter being used in

Canada[7] and most NW EU countries while depending on the contaminant the US uses the full range (10^{+4} – 10^{+6}) while 10^{+5} is common in Australia and NZ, with 10^{+4} used for an aggregate of contaminants[8]. In some countries political interest has led to sound technical programs to support long-term environmental policies (Holland, Belgium, Canada). However similar programs are used in other countries to adjust the soil quality standards to favour some political outcome (raising Cadmium standards for agricultural land, or PAH standards for inner city garden soils). The local research institutes or in absence of these a local or international consulting firm derives national standards which are suitable to the politicians of that country. For these and other reasons the methodologies applied are often not transparent and the variability is high.

Protection of what?

All environmental legislations address the protection of human health. The majority also protect some ecological receptors (about 17 of the 22 countries where this was clear in their methodology documents), however not in all these countries has this been incorporated into the national legislation. In addition, the differentiation between protecting groundwater for drinking water or for surface water quality (aquatic ecosystems) is often more than just fuzzy. The quantification of bioavailability varies a lot and short-term limited population studies can prove a totally different outcome compared to a long-term multi-species study. Some studies appear to be plainly wrong[9], like measuring dissolved oxygen (DO) in rivers only in daytime when oxygen is produced by aquatic plants, while at night the DO may drop to the point most species in the river die. It is like measuring the sun light intensity only during office hours and concluding the sun always shines.
Reasons for not adopting results of internationally recognised studies are; 'not proven locally' or 'we have different species', etc. When guidelines are open for interpretation their application is different per region and adjusted 'temporary' for example, allowing (consenting) discharges to protect employment.

Just under 50% of the countries address the soil – groundwater connection, while only in Spain, Sweden and Canada the quality standards of surface water is nationally legislated. Drinking (tap) water standards are present in most countries. However also here large variations exist, some using outdated WHO standards while others have incorporated the latest research on combinations of contaminants. Very few report specifically where the standards apply for example , at the tap (after circulating through the network) or at the exit of the treatment plant.

The differences between the water (ground-, surface- and drinking-) guidelines is very significant and originate from a combination of regional setting (geological, soil micro-biological), reliance on groundwater as drinking water resource, climate, social and cultural factors. Scale factors play a role; in countries where population is denser, a higher level of attention is given to ecological values. Even within countries this is apparent on a regional scale. For example, comparison of staff numbers and size of budget of the regional councils of Auckland (6,059 km^2 – rates $ 132m – 519 staff) with Westland (23,627 km^2 – rates $3.3m – 50 staff).

---

7 http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/part-partie_i/appendix-b-annexe-eng.php
8 http://www.ghd.com.au/aptrixpublishing.nsf/AttachmentsByTitle/PP+RemediationCriteria+PDF/$FILE/e4078.pdf
9 Page 290 MfE (2007) New Zealand Environment : note national monitoring network consists mainly out of manual (day-time) observation 'network', pers. ref. Dr. M. Joy Massey University

Methods of analysis

On a technical level differences in guideline levels are a result of the methods of analysis used. To illustrate this let us look at the analysis of metals. For metals the extraction using a strong acid (even though variable) is used most often, technically leading to similar results. For example making extracts by boiling the sample in aqua regia (mixture of HCl and HNO_3 sometimes with H_2O_2) or in 2M HNO_3 provides a roughly similar basis for the analysis of all extractable metals. The results obtained by both methods show a good correlation. However, several countries use other extraction methods. In Germany for example, extraction is carried out with Ammonium nitrate, which only extracts the more mobile forms of the metals. When the soil contains substantial amounts of mineral rich parent rock material, this method provides a more relevant measure of contamination.

Other extractions methods include ammonium acetate (at pH 7 and 4.8), 0.1M HCl and 0.05M NH_4–EDTA (pH 7). The ammonium salt solutions result in the lowest concentrations. The content of heavy metals extracted with ammonium acetate (pH 4.8) is higher than that extracted with ammonium acetate (pH 7). Even greater contents of heavy metals are the result when using 0.1 M HCl. A solution of 0.05 M NH_4–EDTA (pH 7) is capable of extracting not only the heavy metals participating in the exchange processes from the soil, but also the heavy metals in carbonates and organic complexes (bound)[10].

Clearly the concentration of metals found in soil is very dependent on the extraction method used. Using the above extraction fluids the percentage of metals found in soil compared to the aqua regia extraction varied between < 1 to over 60 %[10].

Case study DDT:

A brief history[11] of DDT (Dichloro-diphenyl-trichloroethane) reveals the German chemist, Otmar Tsaildler, first synthesized it in 1874. Its effectiveness as an insecticide, however, was only discovered in 1939. Shortly thereafter, particularly during World War II, the U.S. began producing large quantities of DDT for control of insect borne diseases such as typhus and malaria abroad. After 1945, agricultural and commercial usage of DDT became widespread in the world. The early popularity of DDT was due to its reasonable cost, effectiveness (insoluble), persistence, and versatility. During the 30 years prior to its cancellation, a total of approximately 600,000 ton of DDT was used in the US. From 1950 to 1970, 20,000 ton was used in the USSR annually (400,000 tons over these 20 years)[12].
After 1959, DDT usage declined greatly in the western world, dropping in the US from a peak of approximately 40,000 tons in that year to just under 6,000 tons in the early 1970s. Of the quantity of the pesticide used in 1970-72, over 80 percent was applied to cotton crops, with the remainder being used predominantly on peanut and soybean crops. The decline in DDT usage was the result of (1) increased insect resistance; (2) the development of more effective alternative pesticides; (3) growing public concern over adverse environmental side effects; and (4) increasing government restrictions on DDT use.

---

10 N. Sabienë (2004) Determination of heavy metal mobile forms by different extraction methods, EKOLOGIJA. 2004. Nr. 1. P. 36–41

11 A Review of Scientific and Economic Aspects of the Decision To Ban Its Use as a Pesticide, prepared for the Committee on Appropriations of the U.S. House of Representatives by EPA, July 1975, EPA-540/1-75-022

12 Officially banned-unofficially used: DDT use in the Soviet Union, PANUPS, Pesticide Action Network North America, San Francisco, US, 1997

Despite this new insight, large quantities of DDT have been purchased by the Agency for International Development and the United Nations and exported for malaria control. In the US DDT exports increased from 12 percent of the total production in 1950 to 67 percent in 1969. However, exports have shown a marked decrease in following years dropping from approximately 35,000 tons 1970 to 16,000 tons in 1972.

Although scientists voiced warnings against health and ecological hazards as early as the mid-1940s, it was the publication of Rachel Carson's book Silent Spring in 1962 that stimulated widespread public concern over use of the chemical.

The period of use in New Zealand is similar to that in the US. DDT was produced locally. The Mapua Fruitgrowers' Chemical Company is now the best known but others (Challenge) also produced DDT and DDT mixtures. DDT was used extensively for agricultural use in the 1950s and 1960s to control grass grub and porina moth. It was also used on lawns and for market gardens. Some 500 tons was being applied annually in 1959[13]. Use of DDT was prohibited on New Zealand farmland in 1970, and its sale for all other purposes (e.g. borer bombs) was banned and was deregistered in 1989[14].

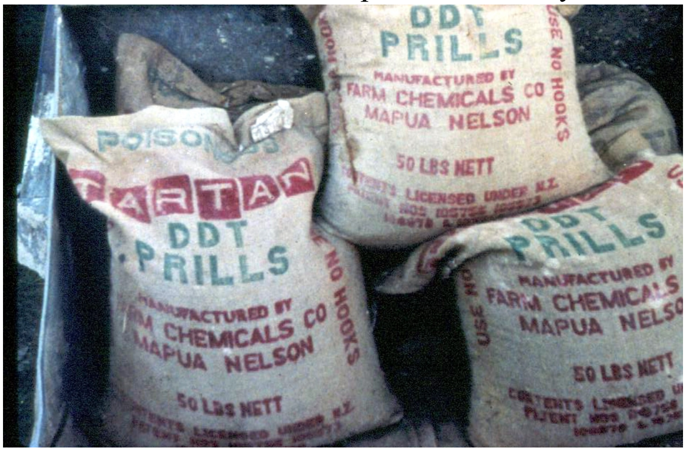

Figure 4 DDT Prills made in Mapua, Super with DDT (Photo Graham McBride)

Figure 5 The Maori Magazine, Te Ao Hou

These dates fall in the same period as the first ban of DDT in the world in Hungary in 1968 followed by Norway and Sweden in 1970, the US in 1972 and the United Kingdom in 1984[15]. DDT bio-accumulates in higher species and grazing on DDT rich pastures in dry summer months creates elevated DDT levels in livestock. In the 1980s 40% of the lambs in Canterbury, a region with low rainfall and occasional droughts, had DDT levels that were above the European Union's permitted limit but still acceptable under 'safe tolerance limits' for New Zealand[16] (!).

In the year of the introduction of the Agricultural chemicals Act (1959), more than 150,000 agricultural chemicals were registered in New Zealand[17].

---

[13] Salmon,, J. T. (1959). "Report of Conservation Committee to The Royal Society of New Zealand on The Use and Effects of Modern Insecticides.". *Transactions and Proceedings of the Royal Society of New Zealand 1868-1961* 86. Royal Society of New Zealand.

[14] H. Ellis, MfE(NZ) http://www.chem.unep.ch/pops/indxhtms/NZBrochure.html

[15] http://en.wikipedia.org/wiki/DDT_in_New_Zealand

[16] Taylor, Rowan; New Zealand (1997). *The State of New Zealand's Environment 1997*. Wellington, N.Z: Ministry for the Environment. ISBN 0478090005.

[17] L.Hunt (2004) The rise and fall of DDT in New Zealand, New Zealand Sociology, Vo. 19, No. 2, p240 – 259.

In 1969 between 0.4 and 1.9 mg/kg ΣDDT was found in fish in lakes around Rotorua. The lower value in fish from lakes surrounded by native forest and the higher in top dressed areas (2 kg DDT/ha, for multiple years)[18]. This was reported to be 10,000 times the concentration found of dissolved DDT in the lake waters[19].

As the worry about DDT in export meat was growing, NZ research focussed on forms of DDT application that did not increase the DDT levels in meat. One way found was the granulation of DDT, which allowed it to fall to the soil surface through the grass quicker. The jubilant advertising at that time[20] (see figure 5) did not reckon with the counter-effect: much reduced breakdown speed of the DDT 'nodules'.

The legacy goes on as we can see when we compare the current guidelines for soil on residential subdivisions in the Hastings District which is 25 mg/kg dw for ΣDDT, with the guidelines for ΣDDT in other countries as shown in figure 3. Most of the 16 countries shown in the figure have set their 'potential unacceptable risk' level between 0.5 and 4 mg/kg. Many of the Hastings soils are well above the maximum of these levels, however below the locally acceptable level. Exceptions are Germany (80 mg/kg, note again specific extraction method) and Australia (200 mg/kg). However when a pathway soil – groundwater exists the German investigations threshold is reduced to 0.1 mg/kg dw.

The New Zealand Ministry for the Environments guideline value database list has as its first entry for DDT:

Contaminated sites NEPC	'International Risk-based'	200 mg/kg	residential sites.

This is in fact the Australian guideline value, which can be found by clicking on 'Contaminated sites NEPM'. The third entry is:

Dutch 2000	'International Risk-based'	0.01 mg/kg	residential sites

This is the Dutch Target value. The fourth entry is the intervention value[21] from Holland with a guideline concentration of 4 mg/kg.

To copy the statement from page 2: "*This makes country to country comparisons difficult for people with a fair level of knowledge however perilous for the lay person or someone only occasionally dealing with these matters.*"

Clearly the 0.01 and 200 mg/kg (both 'residential') are not only geographically but also ideologically and methodologically 'a world apart'.

Using figure 3 while observing which countries fall in the middle of the data spread while recognising which of these have spent millions establishing their national standards will give even the lay person a better idea what 'on average' a safe level will be. Using the data sheets such as provided on www.EPA.org.nz will even provide this for specific land uses.

[18] S.R.B. Solly and V. Shanks (1969) Organochlorine insecticides in rainbow trout from three North Island lakes, N.Z. Journal of Marine and freshwater Research, Vol. 3: p 585-590.
[19] M.B. Ettinger and D.O. Scott (1967) A wild fish should be safe to eat, Journal Environment and Technology Vol. 1: p 203 – 205.
[20] Advertisement in The Maori Magazine, Te Ao Hou, No.56 (1966) p 54.
[21] This is more or less synonymous with 'potential unacceptable risk' see figure 3

Conclusions

Soil quality standards are far less standardised than would be expected from this expression.

Comparison of acceptable contaminant levels in soil show large variations between countries.

Many soil guideline or national standard systems have been developed over two or more decennia at a cost of tens of millions of dollars. The result is that a number of these systems show comparative data for most contaminants, or have sound arguments for extremes (high and low) for some contaminants.

Regional guidelines and guidelines of more rapidly developed 'low budget' systems deviate further from the 'mean'. Especially the US region 9 preliminary remediation goal and the Australian 'health based' standard look particularly 'unhealthy'.

At present, there is very little guidance to set ecological standards in New Zealand, a country internationally seen as an Eco Tourist destination, however by the OECD reported as one of the highest fertiliser and pesticide users in the world.

Relying on the *guideline database*, a part of MfE Guideline no.2 is likely to give most users more confusion than guidance. Land use specific, country-by-country comparison of guideline levels as provided on the website of the Environmental Protection Association (Te Rōpū Tiaki Taiao) [22] provides a quick overview of international guideline levels which allows the user to make informed decisions.

Recommendation

For New Zealand to protect its people, its environment and its fast eroding 'Clean and Green' image, urgent action is required to implement National Standards, which protects its people and its environment.

To avoid the 'number crunch' the Ministry for the Environment may wish to adopt a system like the Danish have done, using toxicity testing, rather than guidelines for individual chemicals to assess the suitability of site for their future use. This system immediately incorporates the multiplying effect of combinations of chemicals and is thus instantly a step ahead of the more ridged, however continuously evolving, tables with soil quality standards.

The Triad approach, discussed elsewhere in this conference, and in use since 2000[23] using fast on-site analysis, immuno-assays, (eco-) toxicity testing are all much more geared towards ensuring a truly quality environment, than spending huge amounts of time and energy in establishing 'The National Standard' which is likely to be amended from the day it is published.

A Triad approach pleases every one and protects our environment and therefore us at the same time.

Whichever 'National Standard' is developed, it has to stand up to other international standards especially for a country that boosts its **'Clean and Green'** image.

[22] www.EPA.org.nz

[23] Keet, B. (2008) The Triad Approach to make contaminated sites cleanup projects better and more cost-effective. Case: Complementary laboratory (ICP, etc) and field XRF analysis http://www.tracenz.lab-initio.com/conference2008/papers/NZTEG_2008_026_Keet_paper.pdf