Bioavailability—the underlying basis for risk-based land management

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Contaminated sites represent a growing challenge. Globally, there are more than 3,000,000 potentially contaminated sites which represent a lost economic opportunity and threat to the health and wellbeing of humans and the environment. Environmental contamination is the legacy of industrialization and insufficient environmental legislation and enforcement. At the biennial International Committee on Contaminated Land,

the World Bank reported that it had integrated contamination in its “Greening Development and Sustainable Urban Development” Agenda. The potential impact of industrial pollutants on human health was only recognised following mass poisoning of people via ingestion of toxic metals including cadmium (Cd), arsenic (As) and lead (Pb) (Naidu et al. 1996). Although site contamination was recognised as early as the 1960s, less than a tenth of potentially contaminated sites have been remediated due to the complex and challenging nature of both surface and subsurface contamination. These challenges are further exacerbated by cost and technical impracticability associated with contaminants present in mixtures and those that are recalcitrant and persist. Common contaminants include petroleum hydrocarbons, chlorinated solvents, pesticides, inorganics, heavy metals and radioactive wastes. These can be found in a variety of sites such as oil and gas operations, mines, industrial complexes, landfills, waterways and harbours.

However, in most countries, the scale of the problem is difficult to assess, as the definition of “contaminated land” or “site contamination” has often been subjective or poorly defined, even in statute. Only limited efforts have been made to develop an inventory of contaminated sites in developing countries although industrial practices and the societal drive for economic growth continues to increase environmental contamination due to disposal of wastes into land and water bodies. Although, most developing countries have stringent regulatory guidelines, adherence to and regulation of these is a major problem. The rapid expansion of the urban fringe due to mass migration of people from rural into urban areas is causing significant pressure on available land for residential properties. Thus, expansion is being driven onto disused former industrial zones. Such expansion has led to a significant demand for remediation and indeed cost-effective and sustainable techniques for managing

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environmental contamination to ensure the land is suitable for its new, more sensitive use.

Contaminated site remediation technologies fall into two principal approaches: *in situ* (soil and water are treated in the ground) or *ex situ* (treatment is carried out above ground). While *in situ* remediation deals with contamination without removing soil or water from the ground, *ex situ* remediation requires the excavation of contaminated soil or abstraction of polluted water for treatment or landfilling. The techniques available for *in situ* or *ex situ* remediation can be prohibitively expensive, resulting in poor adoption in most countries. This is one reason for the introduction of risk-based management as a strategy to assess and manage long-term contaminated sites. Risk-based land management aims to manage the risks posed by historic contamination and to mitigate those risks deemed unacceptable. The decision of what level of risk is unacceptable has a socioeconomic dimension but is based on robust scientific estimates of the level of risk.

Policymakers and regulators have grappled with the decision criteria to trigger remediation over decades. A central theme has been the distinction between hazard and risk. The presence of chemical substances in soils and groundwater (the hazard) is of concern, but harm to the environment, human health and/or ecosystems require exposure. For there to be risk, there have to be pathways connecting sources of contamination and receptors that can be harmed.

Two policy shifts have been notable over the last 30 years—firstly, recognition that it is the management of the risks posed by historically released chemicals that should drive remedial action; and secondly, that the risk is a function of the dose-response relationship for each chemical substances (Naidu and Bolan 2008). This means that a chemical substance must be present in a form and at levels that pose risk to the receptor. Hence, contaminant bioavailability modifies effective intake and hence the level of risk posed: a critical parameter in risk-based land management. Sites with high contaminant bioavailability may be managed by imposing treatments that demonstrably reduce bioavailability in the long term.

The assessment and management of site contamination is dependent upon the current or proposed land use, community and governmental expectations and the resources available for the task. Social, financial and environmental factors must all be taken into account in decision making. Together, these concepts form the basis of risk-based land management (RBLM), which represents a mature, sustainable approach to the challenges of contamination (Ferguson et al. 1998; Naidu et al. 2008a; Nathanail 2009, 2013).

The bioavailable fraction of a soil contaminant is that fraction that is taken up and able to reach the target organs where the chemical can do harm (Naidu et al. 2008b). The non-bioavailable fraction passes through the organism and is not able to cause harm. For many chemical substances,

bioavailability decreases with ageing, such that the toxic effects of substance may eventually decrease to concentrations below concern for human and environmental health (Nathanail and Smith 2007). Thus, through this approach, it may not be a requirement to secure the full removal of all contamination. In practice, recognition of this reduced likelihood of effective intake and adoption of this approach has already avoided enormous remediation costs (DTZ 2010).

In the case of some of the largest contaminated sites in Australia, such as those in the Homebush Bay area (the Sydney Olympic site) and where large industrial operations have taken place (such as steel making and gas manufacture), adopting risk-based remediation strategies have resulted in cost savings of tens of millions of dollars for each site. However, the risk-based approach to remediation is an area that remains contested.

Regulators throughout the world are quite rightly demanding evidence that contaminants left behind in the soil do not pose a risk under changing conditions of exposure through the following:

- The introduction of new receptors (change of land use), for example, or of new pathways for exposure (new basements being built) or
- The introduction of a new source of contamination (solubilising solvents, for example).

Under these scenarios, there are changes to the likelihood of exposure and these may dramatically affect the risk of harm being realised. In the UK, the above circumstances are covered under the planning regime and contaminated land regime, respectively.

In 1996, CleanUp conference series initiated in Adelaide was held under the original banner Soil Contamination Research Australasia Pacific (SCRAP) when contaminant source, assessment, risk and remediation were the focus of the meeting attended by more than 250 delegates. This conference that is now held every 2 years under the CleanUp banner has grown in size with delegates from all over the world with the last meeting being held in Adelaide in 2011 and the next scheduled for 2013. The 2011 conference incorporated the 6th International Workshop on Chemical Bioavailability in the Terrestrial Environment. More than 30 invited speakers from USA, Canada, UK, Germany, Belgium, Italy, Spain, Switzerland, New Zealand, Hong Kong, China, India and other developing countries from Southeast Asia made significant contributions towards the discussions held at the workshop. Invited speakers brought significant expertise including contaminant assessment, bioavailability methods, exposure assessment and modelling, risk characterisation and risk-based management of contaminated sites. Both the workshop and main conference identified major knowledge gaps, challenges and research needs associated

with bioavailability of hazardous substances and implications to risk-based management of contaminated sites. Priority areas for future work identified by the participants include:

1. Emergent contaminants—analytical methods, risks and management
2. Bioavailability—in vivo and in vitro methods
3. Measurement tools for real-time assessment of chemical bioavailability
4. Mixtures vs. single contaminants—policy implications including liability
5. Mixtures and effect on contaminant bioavailability
6. Incorporating bioavailability into guidelines
7. Bioavailability-based soil guidelines
8. Science underpinning policy
9. Incorporating bioavailability into risk assessment models
10. In situ management vs. residual liability

In this special issue of ESPR, selected contributions from workshop participants that highlight the current scientific knowledge of bioavailability and the implementation of this to risk-based land management is published. The bioavailability workshop that is often held alongside CleanUp conference series aims to highlight the role that contaminant bioavailability plays in risk characterisation and in situ as well as ex situ management of contaminated sites. The workshop also aims to enhance discussions on breakthrough research focussing on contaminant bioavailability—including tools for monitoring bioavailable fraction in terrestrial and aquatic environment. The next workshop is scheduled for November 2013, in Nottingham, UK.

Of the 70 papers presented at the workshop, 20 focussing on risk-based land management were selected for publication in this special issue. Of these, 18 were accepted and included in this review. One of the papers jointly written by delegates from UK, USA, Europe and Australia outlines the need for bioavailability-based soil guidelines. Clearly, there is a need for better and more coordinated effort involving scientists, engineers and mathematical modellers in order to develop reliable tools for predicting contaminant bioavailability in both terrestrial and aquatic ecosystems. Not forgetting the need to delineate the effect of mixtures. All in all, this special issue typifies the need for the following:

- (a) Policy that takes into consideration chemical bioavailability
- (b) More concerted effort towards contaminants research
- (c) Multidisciplinary approach to assess, characterise and manage contaminated sites
- (d) Recognition by appropriate authorities that humans and our delicate environment are exposed to in excess of 75,000 different chemicals that are slowly but with certainty adversely impacting on our systems.

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Prof. Naidu is an expert in environmental contaminants, toxicology, bioavailability and remediation. He has co-authored over 500 technical publications (355 journal publications) and co-

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In 2013, Prof. Naidu was elected as Fellow of the American Association for the Advancement of Science and, in 2012, won the Soil Science Society of America (SSSA) International Soil Science Award. Other awards conferred on Prof. Naidu include the following: Fellow of Agronomy Society of America (2006), Fellow of the Soil Science Society of New Zealand (2004), Fellow of the Soil Science Society of America (2000), and a Tamil Nadu Agricultural University's gold medal in environmental science (1998).

Prof. Naidu has been Chair of the International Union of Soil Sciences Commission for Soil Degradation Control, Remediation and Reclamation (2002–2010) and President of the International Society on Trace Element Biogeochemistry (2005–2007).

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support tools for site prioritisation, site investigation design, human health risk assessment and remediation strategy selection. Paul’s research and consultancy practices have resulted in the introduction into the mainstream practice of risk-based contaminated land management in the UK of several technologies including the use of bioaccessibility testing for DQRA, stochastic modelling for DQRA, bespoke software for conceptual site modelling. He also pioneered the development of industry standard generic assessment criteria produced by the sector for the sector which has since become mainstream. His most recent innovation is the Dose-response Roadmap to inform decisions on the unacceptability of contaminant intake under UK contaminated land legislation. He currently runs a unique online masters programme in contaminated land management and was at the forefront of webinars to assist in awareness raising among the UK contaminated land sector. He has appreciated the opportunity to contribute to several CleanUp conferences and Bioavailability workshops in Adelaide over the past 7 years.