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Risk based land management requires focus beyond the target contaminants—A case study involving weathered hydrocarbon contaminated soils

Palanisami Thavamani [a,b,c,*], Euan Smith [a], Ramadass Kavitha [a], Grant Mathieson [a], Mallavarapu Megharaj [a,b,c], Prashant Srivastava [b], Ravi Naidu [a,b,c]

[a] Centre for Environmental Risk Assessment and Remediation (CERAR), University of South Australia, Mawson Lakes, SA 5095, Australia

[b] Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE), University of Newcastle, Callaghan, NSW, Australia

[c] Global Center for Environmental Remediation(GCER), University of Newcastle, Callaghan, New South Wales, Australia

HIGHLIGHTS

- Weathered hydrocarbons may not pose risk to environmental receptors.
- Multispecies ecotoxicity assessment should include site based local receptors.
- Field level application of Risk based land management is complicated using current methods.
- Risk based land management should focus beyond target contaminants.

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ABSTRACT

Irrespective of the nature of contamination, the use of total contaminant loading as a measure of risk together with conservative policy guidance is proving major stumbling block towards remediation of contaminated sites. The objective of this study was to investigate the use of risk based approach to manage contaminated sites at field scale. This study recognizes the presence of weathered hydrocarbon compounds in long-term total petroleum hydrocarbon (TPH) contaminated soils and that such compounds may not pose risk to local receptors. A multispecies ecotoxicological assessment was used to determine the potential risk from weathered hydrocarbons to the surrounding environment. The ecotoxicity of soil residual TPHs was evaluated using earthworm, water-flea, two native and two non-native Australian plants, and soil microbial activity. Plant germination was 100% in all soils but post germination, seedlings except Ryegrass failed to establish. Earthworm toxicity studies found that there was a negative impact on earthworm reproduction and mortality. Further investigation of the poor plant growth and earthworm mortality revealed that it was due to the elevated salinity that developed due to surface evaporation of the saturated calcium sulphate and not residual soil TPHs. Toxicity assessment of the soil leachate on the aquatic environment showed no effect on the survival of water-flea even though the TPH concentrations in the first year leachate were as high as 1.6 mg TPH L^{-1}. The study concluded that the residual TPHs in soils had little impact on a range of environmental receptors. Assessment of the residual TPH ecotoxicity was complicated by

* Correspondence to: Global Center for Environmental Remediation(GCER), University of Newcastle, Callaghan, New South Wales, Australia. Tel.: +61 2 40339411.

E-mail address: Thava.Palanisami@newcastle.edu.au (P. Thavamani).

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the elevated salinity of stockpile soils which impacted on the earthworm and phytotoxicity assessments. Therefore results of this study suggest that it is paramount to focus beyond target contaminants while implementing risk-based management approach. Indicators for risk based assessment are considered critical for regulatory decision making. The results of this study provide a valuable input in to the risk based management of contaminated sites.

1. Introduction

Currently, there are more than 3,000,000 potentially contaminated sites around the world which represent a lost economic opportunity and threat to the health and wellbeing of human as well as the environment (Singh and Naidu, 2012; Thavamani et al., 2011). Of the 160,000 contaminated sites in Australia (CEI, 2005), 60% comprise hydrocarbon-contaminated sites (NEPC, 1999). Ageing of hydrocarbon contaminated sites results in the loss of volatile hydrocarbons with residual weathered compounds remaining in soils (Tang et al., 2012). Land-farming has commonly been used for many years in the management and disposal of hydrocarbon contaminated soils (Theodore and Reynolds, 1987). It is one of the simplest and cheapest bioremediation treatment options for large volumes of hydrocarbon contaminated soils. Properly managed land-farming treatments often lead to a significant decline in total hydrocarbon concentration via volatilization of low molecular weight TPHs (e.g. gasoline range fractions). Biodegradation is more significant than evaporation in removing medium molecular weight range hydrocarbon products (e.g. diesel fuel, kerosene) (Atlas and Hazen, 2011). However, land-farming often leaves behind heavier complex and less bioavailable hydrocarbon fractions (e.g. lubricating oils) due to the fact that they are not volatile and take an extended time period to biodegrade (US EPA, 1994; Alexander, 2000; Thavamani et al., 2012a). The presence of residual petroleum hydrocarbons including weathered products has been of much concern to regulators and as a consequence, industry is left with stockpiles of land-farmed soils and stockpile management costs in excess of ∼AUD 5M per annum.

Risk-based land management (RBLM) is increasingly being adopted by regulators as a means of managing contaminated sites. RBLM works on the underlying basis of demonstrating no or negligible risk from exposure to contaminants to both humans and environmental receptors (Naidu et al., 2008). RBLM involves diverse approaches including an assessment of the concentration and nature of contamination, potential risk that these contaminants pose to environmental and human health, the planned use of the soil and the impact on surrounding ecosystems. RBLM can be applied at various stages as appropriate to manage contaminated soils (Kwame, 2006; Luo et al., 2009; Naidu et al., 2008). It represents a mature and sustainable approach in management of increasing numbers of contaminated sites and associated costs in remediation (Naidu et al., 2013; Nathanail, 2009). RBLM, in particular, can be applied in setting an overall sustainable development strategy for management of contaminated land in a particular region (Naidu et al., 2008; Kwame, 2006). However, there are limited field based studies demonstrating the application of RBLM to management of long-term hydrocarbon contaminated soils. The presence of approximately 10,000 tonnes of post-land farm soils stockpiled at an industrial site at Newman, Western Australia provides an excellent opportunity to demonstrate application of such a strategy. Analysis of composite stockpile samples indicated that the total petroleum hydrocarbon (TPH) concentrations in the stockpile soils are lower than the locally applicable Soil Ecological Investigation Levels (EILs) (WA DEC, 2010) but did not achieve the target TPH concentrations stated in the remediation licence. The TPH residual fraction comprises mainly the C29–C36 fractions and the presence of these fractions limits further bioremediation of the stockpile soils. The presence of large volumes of land-farmed soils therefore presents an opportunity to test risk-based approach and especially its acceptance by regulators. Clearly from regulatory perspectives, risk based frameworks are not always supported by suitable and robust indicators for risk assessment, especially in the case of matrices contaminated with weathered hydrocarbons. Such indicators for risk based assessment are considered critical for regulatory decision making.

There are a number of approaches that may be adopted when considering environmental ecotoxicity testing but there is increasing interest to incorporate a range of tests (with a battery of different assays) that integrate contaminant exposure, and on a range of bioassays (O'Halloran, 2006; Chapman et al., 2012). Standardized bioassays can be used for path-related, toxicological characterization of soils and soil materials, taking into account possible transfer of pollutants to groundwater and potential effects on soil micro-organisms, earthworms and plants (Hatcher, 2002). In recent years, ecotoxicological tests have also been used as supplementary tools to monitor bioremediation of hydrocarbons, both in laboratory and field studies (Wang and Bartha, 1990; Salanitro et al., 1997; Saterbak et al., 1999; Megharaj et al., 2000, 2011; Sinnett et al., 2011). Various bioassays representing different trophic levels have been used for screening soil toxicity (Juvonen et al., 2000; Spurgeon et al., 2005). Soil quality tests using bacteria, plants and invertebrates are all promising tools for risk-based corrective action (Płaza et al., 2005). Utilization of standard ecological receptors facilitates the standardization of ecotoxicological endpoints to assess the environmental impact of the contaminant when undertaking risk-based ecotoxicity assessments (Alexander, 2000).

The objective of this study was to develop the underlying scientific basis for the risk based assessment of long-term TPH contaminated sites. In particular, the study focuses on an evaluation of the residual toxicity of stockpiled long-term