Next Steps in the Development of Ecological Soil Clean-Up Values for Metals

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ABSTRACT

This special series in Integrated Environmental Assessment and Management presents the results from 6 workgroups that were formed at the workshop on Ecological Soil Levels—Next Steps in the Development of Metal Clean-Up Values (17–21 September 2012, Sundance, Utah). This introductory article presents an overview of the issues assessors face when conducting risk assessments for metals in soils, key US Environmental Protection Agency (USEPA) documents on metals risk assessment, and discusses the importance of leveraging from recent major terrestrial research projects, primarily to address Registration, Evaluation, Authorization and Restriction of Chemical Substances (REACH) requirements in Europe, that have significantly advanced our understanding of the behavior and toxicity of metals in soils. These projects developed large data sets that are useful for the risk assessment of metals in soil environments. The workshop attendees met to work toward developing a process for establishing ecological soil clean-up values (Eco-SCVs). The goal of the workshop was to progress from ecological soil screening values (Eco-SSLs) to final clean-up values by providing regulators with the methods and processes to incorporate bioavailability, normalize toxicity thresholds, address food-web issues, and incorporate background concentrations. The REACH data sets were used by workshop participants as case studies in the development of the ecological standards for soils. The workshop attendees discussed scientific advancements in bioavailability, soil biota and wildlife case studies, soil processes, and food-chain modeling. In addition, one of the workgroups discussed the processes needed to frame the topics to gain regulatory acceptance as a directive or guidance by Canada, the USEPA, or the United States. Integrated Environ Assess Manag 2014;10:342–345. © 2013 The Authors. Integrated Environmental Assessment and Management Published by SETAC

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INTRODUCTION

The clean up of metal-contaminated soils to protect ecological resources presents several significant challenges for risk assessors and site managers. Determination of background metal levels in soil and selection of appropriate ecological endpoints are known pieces of required information, and approaches to address these needs have been well described (USEPA 1996, 2003). However, other factors, often more complex, affect how biota respond to metals in soils, and these interactions require consideration when developing clean-up criteria for specific locations. These approaches may differ from those used to conduct the risk assessment. Site-specific factors include, for example, effects of local soil chemistry parameters on metal bioavailability and toxicity to soil biota and plants, and determination of the bioconcentration or biodilution of metals in the terrestrial food web. Further assessment of appropriate toxicity endpoints and threshold concentrations for wildlife receptors also provides appropriate site-related focus and ecological realism when setting clean-up goals.

Ecological risk assessors have relied on ecological soil screening levels (Eco-SSLs) developed by the US Environmental Protection Agency (USEPA) to standardize and facilitate initial screening of contaminated sites for the most common pollutants (USEPA 2005). These screening values are based on information about the toxicity to plants, soil invertebrates, and wildlife and are intended to provide a general level of protection for all species at any site. The Eco-SSLs develop toxicity thresholds for each of these 3 groups of organisms, and the lowest value for wildlife or the geomean of acceptable values for plants and invertebrates (whichever is lowest) then becomes the soil screening concentration for that chemical. The guidance requires that the data representing the most highly bioavailable form of the metal be used when deriving the screening values and includes all species tested, regardless of whether or not they are present at the site. This necessarily results in relatively conservative soil values, which are appropriate for an initial screening assessment of a contaminated site but should not be used when determining baseline risk or setting clean-up values (USEPA 2005). However, because of the lack of established methods for deriving Eco-SCVs, the toxicity values from the Eco-SSLs frequently are used in a decisional context (Mayfield and Fairbrother 2012).
USEPA’s Framework for Metals Risk Assessment (Fairbrother et al. 2007; USEPA 2007) put forward key principles for risk assessors to address when conducting metal assessments at specific locations or for setting clean-up values. These principles include that metals are naturally occurring, they occur in mixtures, some metals are essential for biota, environmental chemistry for metals needs to be considered, and the metal and its form are critical when assessing toxicokinetics and toxicodynamics issues. The Framework document provided risk assessors with issues that they needed to address, but the availability of methods or databases were limiting factors at the time, making it difficult to implement many of the recommendations.

In the years since the Eco-SSLs were developed and the Framework was published, the available methods for determining effects in different types of soils have seen significant improvements that make it possible to more accurately predict the consequences of metal enrichment at particular sites. Consideration of total metal concentrations in soils takes little account of the substantial effects of soil properties on metal bioavailability and toxicity. This leads to both overprotective and underprotective guidelines, depending on the soil conditions encountered. In particular, test methods used to develop soil toxicity data, particularly for plants and soil invertebrates, have evolved to include consideration of the form of the metal used, the amount of time the metal has been in the soil, and the soil chemistry. This research was conducted in support of regulatory requirements of the European chemical registration program known as the Registration, Evaluation, Authorization and Restriction of Chemical Substances (REACH) (EEC 2008a, 2008b), and accounts for differences in bioavailability and organism response as a function of both test methods and local soil parameters. Additionally, new approaches to setting toxicity threshold values (e.g., use of the species sensitivity distribution approach and concentration response functions instead of no-observable-adverse-effect concentrations) have gained acceptance, resulting in more accurate predictions (NEPC 2011a, 2011b). A 2008 Pellston workshop resulted in a recent publication that addressed these issues and provides the scientific rationale for their use in setting soil quality standards (Merrington and Schoeters 2010). A recent Organisation for Economic Co-operation and Development (OECD) workshop on metal-specific issues in environmental risk assessment held in Paris, France, 7–8 September, 2011, supported the use of these approaches among the regulatory community and highlighted recent research on metals to support of REACH requirements. Additionally, both Canada and Australia recently published updated approaches for setting soil clean-up criteria that incorporate some of these newly developed methods.

Given that there are now new data and approaches for more accurately predicting ecological risks as a function of soil chemistry, it is a propitious time to revisit how ecological soil clean-up values (Eco-SCVs) can be derived for remediation of contaminated sites within North America to levels that are appropriately protective of ecological resources. A workshop titled, Ecological Soil Levels—Next Steps in the Development of Metal Clean-Up Values, was held 17–21 September, 2012, in Sundance, Utah, to address these issues and provide a suitable framework for their application by ecological risk assessors and decision makers. The workshop focused on metals and other inorganic contaminants because of their ubiquity at contaminated sites and because their natural occurrence makes it difficult to determine adverse-effect levels. The goals for the workshop were:

- Move from ecological soil screening values to development of soil clean-up criteria for metals
- Communicate the application of recent methods and processes from around the world
- Develop methods appropriate for the United States and Canada
- Selected topics
- Incorporating bioavailability
- Tools for normalizing soil organism toxicity thresholds under variable soil conditions
- Establishing wildlife toxicity reference values (TRVs), including site specificity and consistency
- Addressing food-web issues and bioaccumulation
- Incorporating background
- Stimulate discussion
- Within the scientific community
- Regulatory agency acceptance and development of ecological soil criteria.

Approaches for developing Eco-SCVs build on the Eco-SSL methods and data sets and incorporate new knowledge and methods for soil toxicity testing. The workshop workgroups used case studies to present approaches to moving from Eco-SSLs to Eco-SCVs. The following issues were discussed by the workshop attendees:

- Bioavailability of metals for soil microbes, invertebrates, plants, and wildlife as a function of both soil type and form of metal
- Methods to normalize toxicity thresholds for soil microbes, invertebrates, and plants across different soil types and their use in determining soil clean-up values
- Methods to incorporate background concentrations for metals into soil clean-up values
- Food-web issues related to secondary toxicity, bioconcentration, and biodilution
- Evaluation of the variability in the use of wildlife TRVs by regulatory agencies, and methods for consistent selection of site-specific TRVs
- Development of an approach that can be used by regulatory agencies to communicate the methods for generating site-specific Eco-SCVs (e.g., a directive, draft guidance, training modules)

This special publication series consists of 6 manuscripts that are the products of the workgroup discussions at the workshop. The manuscripts discuss the bioavailability characterization and fate of metals, effects issues of metals for the various ecological endpoints, and a regulatory applications article that discusses a path toward regulatory use of methods and data that have been generated over the last 10 years. The sections below provide brief overviews of the articles in this journal issue that follow this introductory material.

**OVERVIEWS OF ARTICLES IN THE SERIES**

**Soil invertebrates and plants**

Chetkai et al. (2013) explain and evaluate the methods to derive soil limits under REACH in the European Union and
NEPC in Australia. A combination of these methods is proposed for derivation of site-specific Eco-SCVs. A range of levels of protection is proposed, from which site managers can choose the one, or ones, most appropriate for meeting the remedial goals at their site. The workgroup suggested that resulting site-specific Eco-SCVs that account for bioavailability may permit a greater residual concentration in soil when compared to generic screening-limit concentrations (e.g., EcoSSL values). Two choices for selecting the level of protection are compared (i.e., allowing higher effect levels per species, or allowing a higher percentile of species that are potentially unprotected). A case study for molybdate is presented that shows the large effect of bioavailability corrections, but a smaller effect of choice of protection level when deriving Eco-SCVs.

Wildlife effects

This article by Mayfield et al. (2014) discusses the development and derivation of TRVs for terrestrial wildlife. Topics examined include methods for toxicological endpoint selection, techniques for dose–response assessment, approaches for cross-species extrapolation, and tools to incorporate environmental factors (e.g., metal bioavailability and chemistry) into a reference value. The workgroup also makes recommendations to risk assessors and regulators on how to incorporate site-specific wildlife life history and toxicity information into the derivation of TRVs to be used in the further development of soil cleanup levels. Because of the complexity and time-intensive nature of TRV development when considering remedial goals, the authors recommend instituting a national forum for data storage and wildlife TRV development—an “Eco-IRIS” following the model of USEPA’s Integrated Risk Information System (IRIS) for setting reference doses and cancer slope factors for protection of human health.

Food-web and exposure

Sample et al. (2014) review and evaluate methods for quantifying exposure of wildlife to soil-associated metals through soil and food consumption, and provide recommendations for the development of site-specific estimates that can be used in determining Eco-SCVs. Topics addressed include bioaccumulation and trophic transfer to identify potential opportunities for refining and improving exposure estimates. The authors conclude that existing exposure estimation models are generally appropriate when fully expanded, and that methods are available to develop more robust site-specific exposure estimates. Improved realism in site-specific wildlife Eco-SCVs could be achieved by obtaining realistic estimates for local wildlife on diet composition, bioaccumulation, bioavailability, soil ingestion, spatial aspects of exposure, and target organ exposure. Although the focus is on metals contamination, many of the methods and tools discussed are also applicable to organic contaminants.

Soil microbial processes

Approaches for soil criteria development that use soil microbial processes and an evaluation of how the 5% hazard concentration (HCS) from the species sensitivity distribution would change if soil microbes are included are discussed by Siciliano et al. (2013). The concerns about including soil microbial processes into ecological risk assessments that were expressed during the Eco-SSL derivation process have now been addressed, and a robust, international protocol for adjusting soil microbial toxicity to site-specific soil chemistry is available. Siciliano et al. (2013) point out that microorganisms are essential for sustaining soil fertility, structure, nutrient cycling, and groundwater purification, and therefore deserve protection. For several metals, the range of effective concentration values for plants, invertebrates, and soil microbial processes overlap, and the inclusion of soil microbial processes does not substantially change the HCS; however, it makes the HC5 more robust. Soil microbial processes have been incorporated successfully into soil risk assessment in other national and international regulatory schemes, and the workgroup recommends their application to Eco-SCV development and clean up of contaminated sites in North America.

Regulatory applications

Greenberg et al. (2014) note that, because of the great potential for more immediate and widespread use of normalizing factors to adjust soil values to site-specific soil chemistry, an easily accessible compendium of approaches and normalizing factors is needed. They also noted that this approach depends on collecting the required information during soil analyses conducted in support of the risk assessment. Additionally, Greenberg et al. (2014) point out that the variability in standardized toxicity tests for soil biota makes it difficult to calculate precisely low-effect values (such as the concentration where 10% of the test population would be affected). Therefore, an effect concentration between 25% and 50% is recommended for all endpoints when setting Eco-SCVs. This could lead to a change in the way that risk assessors and managers evaluate the use of EC20 and EC50 values as substitutes for the no-observed-adverse-effect concentration (NOAEC) and maximum acceptable toxicant concentration (MATC), respectively. Differences in protection levels related to proposed land use were not considered feasible for contaminated sites in the United States, because legal restrictions on postclean-up use are difficult.

CONCLUSION

The success of this workshop will be measured not only by the frequency with which the resulting manuscripts are cited in new research, but also by their success in initiating regulatory outcomes that more fully reflect the unique properties and environmental chemistry of metals in soils. If ecological risk assessors and site managers incorporate the approaches discussed in these manuscripts when determining Eco-SCVs, the resulting management decisions will have a sounder scientific basis, and site clean-up will be appropriately protective while minimizing disturbance of established habitats.

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