CRC CARE
ARIC
ISSUE 17 2015

Remediation Australasia

ASIA SOIL CONTAMINATION SPECIAL

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References:

www.theworldcounts.com/counters/waste_pollution_facts/hazardous_waste_statistics | Modified from: Industry Canada (2005), Canadian Environmental Industries – Soil Remediation Technologies

EDITOR'S NOTE

Welcome to Issue 17 of Remediation Australasia.

You may have noticed that the magazine has had something of a hiatus over the past year. We're sorry that it hasn't been available as often as usual, but there have been major – and exciting – changes afoot at CRC CARE. Earlier this year, the CRC's head office moved to the University of Newcastle, NSW, where we will work closely with the flagship Newcastle Institute for Energy and Resources (NIER).

Since our launch a decade ago, our time at the University of South Australia has seen us flourish into an internationally recognised centre, with collaborative work reaching beyond our shores and across many continents. Establishing the CRC at UniSA laid the foundations for a decade of growth and achievement, with the early years paving the way for our successful (and unprecedented for a CRC) 9-year extension, which guarantees Commonwealth funding until 2020. Our expansion to NSW takes this growth to the next step, which will open up opportunities in what is arguably the busiest industry hub in Australia. Meanwhile, the CRC will retain a vibrant South Australian node, which will house our ongoing work around national clean-up regulations.

Even without the move to the east coast, 2015 was going to be a big year for CRC CARE. In September we're hosting the 6th International Contaminated Site Remediation Conference, or CleanUp 2015. At the time of publication, more than 550 scientists, engineers, regulators and other environmental specialists had registered to attend – around 100 more than at the same time in 2013, keeping us on track for over 700 delegates. Add to this a record number of exhibitors, and we have all the ingredients for the biggest and best CleanUp that CRC CARE has hosted to date. We'll bring you highlights in the next issue of Remediation Australasia.

This issue offers a special insight into contamination issues in Asia. Yes, 'Australasia' is part of the magazine's title, but it's increasingly impossible to work in industry or research here without engaging with Asia. Businesses ignore our four billion neighbours – more than half the planet's population – at their peril. What's more, Australasia certainly doesn't have a monopoly on contamination. Asia is home to an estimated 3 million potentially contaminated sites.

I believe strongly that as a developed economy, we have an obligation to work with Asian governments and industry to help clean up contamination in our neighbouring region. Despite impressive economic and social progress in Asia in recent decades, it remains home to a large proportion of the world's poor – people who bear a disproportionate burden of pollution problems. Australasian scientists, regulators and industry can make a great contribution to a safer environment in Asia, particularly through efforts to build capacity – in research, regulation and clean-up itself.

That said, some of the world's leading contamination science is coming out of Asia. This issue of the magazine looks at examples from Bangladesh, Japan, Korea, Taiwan and Thailand. In particular we examine soil contamination and its impact on crop quality.

Issue 17 includes an update on the National Remediation Framework, a CRC CARE-led initiative to harmonise Australia's guidance on the management of contaminated sites. We also look at issues around the concept of sustainable remediation and explore the importance of chemical reference materials in improving the accuracy and reliability of testing to ultimately allow better decisions on site remediation.

Prof Ravi Naidu
Managing Director and CEO, CRC CARE
Editor-in-chief, *Remediation Australasia*

Remediation Australasia is a quarterly industry magazine produced by the Australian Remediation Industry Cluster (ARIC) for the Australian remediation industry.

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COVER PHOTO
Children traverse rice fields in the Bicol Region of the Philippines, with Mayon Volcano in the background. Photo: International Rice Research Institute (www.irri.org)

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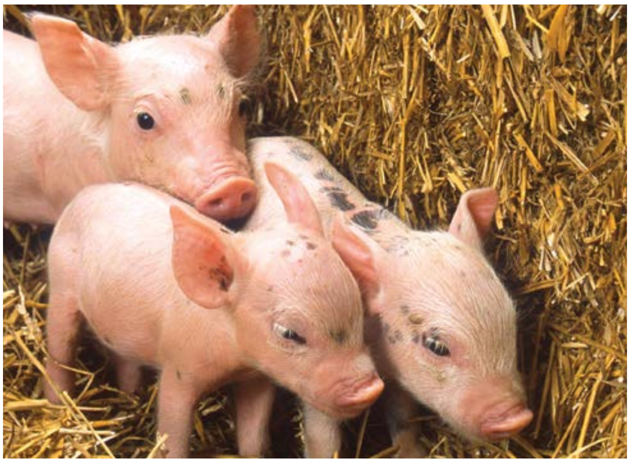


Features

SOIL CONTAMINATION IN ASIA

reMEDIAtion

Your guide to environmental contamination and remediation issues in the media

Chinese blast prompts contamination caution

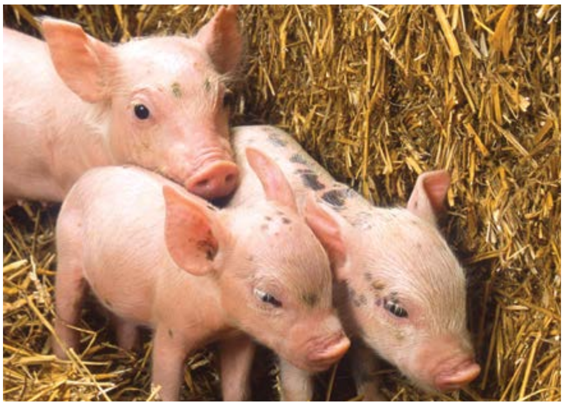
CRC CARE Managing Director Professor Ravi Naidu was quoted in a *TIME* report (ti.me/1g1n1hP) on the potential for contamination problems caused by the enormous factory explosion in the Chinese city of Tianjin in August. Prof. Naidu commented on the need for long-term monitoring, especially of soil and buildings in the surrounding area. He also cautioned that the blast was sufficiently powerful for particulate contaminants to be spread over a large area, in directions that would not be expected following a smaller blast given the land contours and prevailing winds.

Coal gasification causing environmental harm?

In August, the ABC obtained a confidential report commissioned by Queensland's environment department. According to the ABC (ab.co/1gruOWH), the report suggests an underground coal gasification plant operated by mining company Linc Energy at Chinchilla, Queensland, has caused permanent damage to agricultural land through acidification of the soil near the site. Linc Energy has rejected the allegations, asserting in a statement (ab.co/1KT7f5C) that the findings lacked evidence.

Fire-training centres to be investigated

In light of the perfluorochemical (PFC) contamination seen around the Fiskville Country Fire Authority (CFA), Environment Protection Authority (EPA) Victoria is investigating potential environmental contamination at CFA training centres across the state, reports *PSnews* (bit.ly/1LRAdRZ). PFOS and PFOA, two PFCs found in some fire-fighting foams, are known to persist in the environment and have been linked to health problems (the chemicals have been outlawed in current-generation foams). Waterways, drains and groundwater around fire training facilities will be tested at Penshurst, Wangaratta, Longerenong (Horsham), Huntly (Bendigo), Fulham (Sale) and Bangholme (Dandenong/Carrum) CFAs. EPA Victoria, which has stated that the environmental and human health risks remain very low, is providing information at www.epa.vic.gov.au/cfa.



Stronger laws means fewer pigs

Recently tightened environmental laws in China have prompted a reduction in the number of pigs slaughtered, according to *Pig Progress* magazine (bit.ly/1fBiAKl). June 2015 saw a drop of over 6% compared with the previous month, while the decline was almost 15% from the year before (China remains easily the world's largest pork producer, with 15.9 million pigs slaughtered in June). The stricter new laws, related to waste disposal, have forced some pig farmers to abandon their farms. The management of piggery waste is a major issue in China, home to an estimated 700 million pigs.

Valuing contaminated sites

Challenger Listed Investments Ltd has had the value of a property it owns halved by the NSW Valuer-General, reports the online news service CE Daily (bit.ly/1LR9AMY; subscription only). The contaminated site in Yennora, Sydney, was originally valued at $7 million. The Valuer-General asserted that remediation costs should not be factored into the valuation, based on the idea that the site could continue to be used for its current purpose. After successfully arguing to the Land and Environment Court that the Valuer-General misinterpreted s6A of the Valuation of Land Act, Challenger had the value reduced to $3.5 million, meaning that that council rates and land tax will be reduced accordingly. The judgement can be viewed at bit.ly/1Qh4NG4. After the Court initially determined in April that remediation costs should be considered, the Clayton Utz Insights blog discussed the implications for valuation of contaminated sites generally (bit.ly/1NiwX5m).

Harmonising Australia's approach to remediation

A national framework for remediation and management of contaminated sites in Australia, currently being developed through CRC CARE to provide practical guidance to regulators and practitioners, is now seeking input from industry and the broader public.

In 2010, the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE), along with other industry experts, identified a need for a national framework for the remediation and management of contaminated site. Following widespread consultation, the CRC committed to the development of the National Remediation Framework that complements the National Environment Protection (Assessment of Site Contamination) Measure (ASC NEPM).

The National Remediation Framework has strong support from site contamination assessors and remediation practitioners, and will be a significant boon to the site contamination remediation profession and community, including regulators.

The purpose of the Framework is to:

- establish a nationally consistent approach to remediating and managing contaminated sites
- provide practical procedural guidance to people cleaning up and managing sites
- educate and inform government, industry and the community about the issues.

The Framework will harmonise existing Australian practice and documentation to facilitate:

- ready transfer of best practice between jurisdictions
- use of national expertise across jurisdictions, thereby improving overall standards over time
- cost efficiencies for remediation
- a common 'remediation language' across jurisdictions
- training efficiencies, including enhanced workforce mobility, mutual recognition of skills, and the ability to ensure that all practitioners meet a recognised professional standard
- improved confidence and certainty in the profession and the community regarding site clean-up.

The Framework is compatible with the concept of seamless environmental regulation.

The foundation work for designing the Framework has been completed, and is encompassed in three reports, all of which are available on the CRC CARE website (www.crccare.com):

1. **Survey of state, territory and international frameworks for the remediation and management of site contamination, including their legal basis**

   [CRC CARE Technical Report 22: Developing a national guidance framework for Australian remediation and management of site contamination - Review of Australian and international frameworks for remediation]

2. **Defining the context, philosophy and principles for the Framework**

   [CRC CARE Technical Report 27: Defining the philosophy, context and principles of the National Framework for remediation and management of contaminated sites in Australia]

3. **Identifying existing guidance and determining gaps in that guidance**

   [CRC CARE Technical Report 28: Identification of existing guidance for a National Remediation Framework].

The Framework's modular structure will allow guidelines to be updated and added as requirements change over time, thus ensuring currency. Each module comprises one or more guidelines, each of which provides practical guidance for practitioners and regulators.

Guidelines will harmonise existing guidance and document existing Australian practice. Each guideline will be compatible with the principles espoused in CRC CARE Technical Report 27 and with any related requirements in the ASC NEPM.

As guidelines are drafted, stakeholder consultation is being used to both inform stakeholders of their availability and to refine and improve the documents. Stakeholders include industry (e.g. site owners, consultants and auditors, as well as the financial and planning sectors) and regulators, as well as the public. Consultation on the initial draft guidelines has commenced.

Readers are encouraged to review the consultation documents and submit feedback to help CRC CARE develop this important body of work.

Consultation timetable

Topic	**Expected release date**
• Framework report (CRC CARE Technical Report 22) • Principles report (CRC CARE Technical Report 27) • Identification of existing guidance (CRC CARE Technical Report 28) • Framework structure (schematic)	Currently available on CRC CARE website (www.crccare.com)
Draft guidelines	
• Health and safety (worker/onsite) • Documentation, record-keeping and reporting • Stakeholder engagement	Currently available on CRC CARE website (www.crccare.com)
• Identifying remedial options • Selecting technologies • Treatability studies	November 2015
• Cost benefit and sustainability analysis • Site specific remediation objectives	November 2015
• Remediation validation and closure • Long term monitoring • Auditing/third party review • Institutional controls • Regulatory considerations	March 2016
Final draft Framework	
• Context • Principles • Guidance	February 2017

Chemical reference materials – ensuring better remediation decisions

David Saxby, National Measurement Institute

The decision about whether site remediation is necessary relies on chemical measurements of the contaminant of concern. The use of chemical reference materials is one way to improve the accuracy and reliability of chemical testing results and hence improve decisions on how to remediate contaminated sites.

Since contaminated site remediation is an expensive and time-consuming process, the best possible outcome is if remediation work is only carried out when there is a genuine need. This places an obligation upon site assessors to make 'the right decision,' avoiding the waste of remediating where it is not actually needed and avoiding the risk of not remediating where it actually is needed. One key input into site assessment and the decision making process is chemical measurement results. Correct decisions can only be made when chemical measurement results are reliable. This article will outline how to use chemical reference materials as a tool to help ensure that decision making is based on accurate measurement results.

Chemical measurement is a complicated business, much more complicated than is apparent in a one page Report of Analysis for a contaminant of interest. Regulatory limits require accurate measurement of chemical elements and compounds at nanogram per gram levels and even lower. The decision to remediate a site might depend on measurements of one particular chemical (e.g. cadmium) but the testing laboratory is most likely concerned with hundreds of chemicals and dozens of different sample types. A screening method for pesticides can analyse over 250 chemical compounds at a time. A quantitative trace elements analysis will give the concentrations for 60 elements in less than 5 minutes with laboratories making automated measurements in this way 24 hours per day. The variety of sample types, analytes and analytical procedures creates a significant challenge for ensuring that all measurement results are reliable.

The quality of these results depends upon many things: accurate calibration standards, rigorous method validation, detailed method documentation, well-trained staff, well-maintained instrumentation, continual quality control. Laboratory accreditation provides verification that the systems required for reliable measurements are in place. Even so, laboratory testing is susceptible to numerous possible technical and human errors. Previously in *Remediation Australasia* (Issue 13), Ray Correll documented some the difficulties faced by commercial testing labs for reporting reliable results. He concluded saying, "it is important to incorporate sufficient control and reference samples to ensure the accuracy of analyses."

Chemical reference materials are a valuable tool that helps to ensure the accuracy of results and therefore also the correctness of decisions based on those results. Reference materials act as a benchmark for measurement, either calibrating the measurement result or evaluating the accuracy of a measurement method. A result in agreement with the reference value gives confidence that the measurement of an unknown sample is also accurate. Consequently reference materials are very important in validating the accuracy of an analytical method and demonstrating the ongoing performance of the method.

'Reference material' is a fairly general term that requires some explanation. An internationally recognised definition is a "material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties."[1] The key requirements are stability, homogeneity and suitability for the intended use. Stability and homogeneity are needed for comparison of measurements in different locations and at different times, essential in contaminated site assessments. The intended use is given be the manufacturer and describes the valid use of the reference material. For example, a reference material intended for analysis of total metal content is not suitable for an analytical method measuring acid-extractable metals.

Reference materials can range from a simple batch of homogenous material used within a laboratory for on-going quality control, to a Certified Reference Material (CRM) used to provide certainty about the accuracy of results. "Certified" does not simply mean that it's a reference material that comes with a "certificate." A CRM is a "reference material, accompanied by documentation issued by an authoritative body and providing one or more specified property values with associated uncertainties and traceabilities, using valid procedures."[2] This specification means that CRMs provide the highest level measurement benchmark.

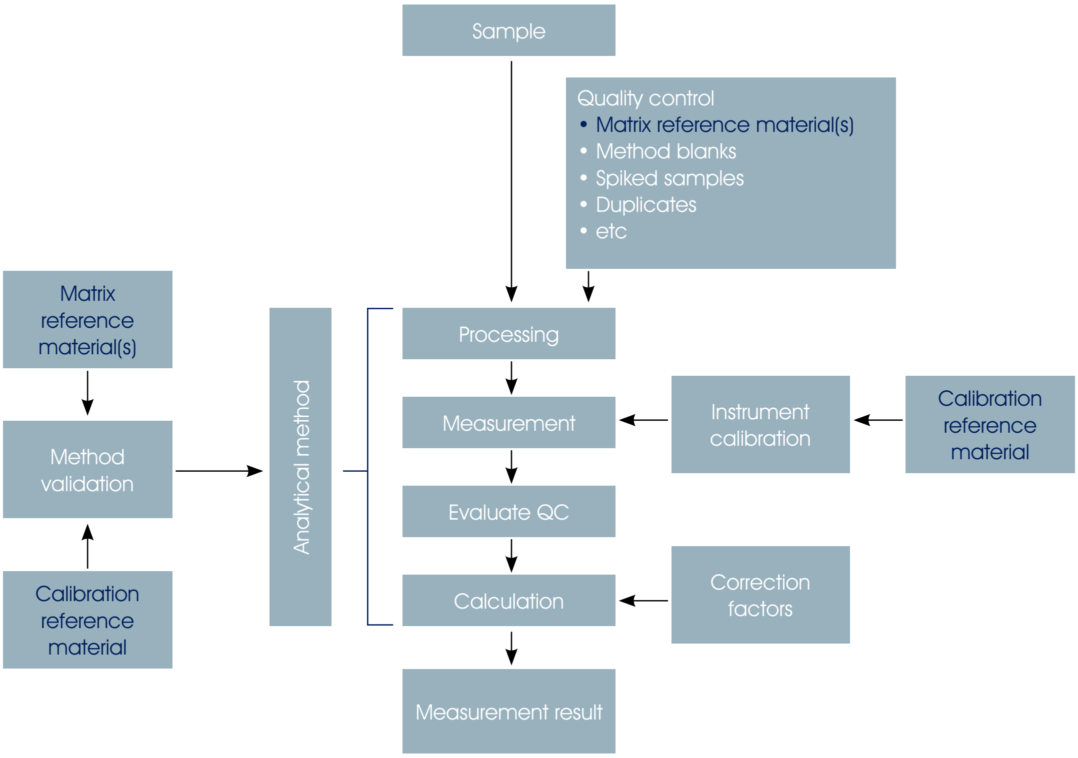
CRM property values are determined in accordance with measurement principles that use established international best practice protocols.[3] Assessment of measurement uncertainty gives a quantitative evaluation of accuracy. Metrological traceability to recognised standards enables meaningful comparisons of results to be made – independent of the time and place at which the measurements are made.

The use of chemical reference materials falls into two broad categories: calibration and quality control. Reference materials for calibration are usually highly

Certified reference materials. Top: Ampouled organic compound with certified purity. Used for calibration. Bottom: Matrix reference material with certified values for trace constituents. Used for method validation and quality control. *NMI*

purified organic compounds, highly purified metals or metal compounds, or simple solutions of the analyte(s) of interest. When such standards are used to calibrate measurement results, it is essential that they are accurate.

Investigations into the accuracy and comparability of commercially available calibration standards have given some cause for concern. When a high accuracy measurement technique was applied to a selection of commercially available single element calibration solutions, it was shown that some products did not match the certificate concentration and stated measurement uncertainty range.[4] For some purified organic compounds, the purity value may not be derived from comprehensive testing. For example,



Schematic of chemical measurement showing the role of reference materials

some calibration materials for organic compounds are characterised by organic purity, which does not include the impurity contribution water or insoluble components. Similarly, calibration materials for elemental analysis need to evaluate all possible impurities present (e.g. metals, non-metals, water, etc). Personal experience with calibration materials for organic compounds has shown that occasionally the chemical identity is not even the same as the manufacturer's specification! Because measurement results can never be more accurate than the calibration materials used, it is important to inspect the credentials of calibration material suppliers and their products.

Additional difficulty often comes with less common measurements. For example, organometallic contaminants (e.g. organotin, organolead, organomercury compounds) may only be available from a limited number of suppliers without the rigour of a CRM characterisation. It may also be hard to find suppliers of calibration standards for contaminants of emerging concern (see *Remediation Australasia*, Issue 15) when measurements are not yet widely performed. In such cases, laboratories need to take extra care in assessing the quality of the materials they choose.

Calibration reference materials provide the basis for quantification, but generally do not account for any of the processes required for transforming the sample into a measureable form. This creates the need for reference materials for quality control which match the analyte level and sample matrix as closely as possible. The matrix reference material is taken through every process in the same way as the sample. For example, a sea water matrix CRM with a certified value for Hg, such as NMIA MX014, allows laboratories to assess and quantify the efficiency of mercury extraction and the matrix suppression for mercury quantification. In this way, accurate analysis of the known mercury level in the CRM gives confidence for measurement of seawater samples with unknown mercury content.

Matrix certified reference materials require property values with low measurement uncertainty from high accuracy analysis to enable the best assessment of method and laboratory performance. Additionally, matrix CRMs must undergo homogeneity assessment and stability assessment for a stated shelf-life.[5] These requirements necessarily mean that production is an expensive and time-consuming task.

The cost is due to the time and care that must be taken in sourcing, preparing, characterising, storing and delivering the CRM. Method development and implementation of high-accuracy reference measurements often requires specialised instrumentation or reagents (e.g. mass spectrometry and isotope dilution techniques). Traceability of measurement results must be confidently established and ongoing testing is required to verify the stability of the certified values. Such effort is essential because a CRM acts as benchmark for assessing accuracy. Consequently, many of the respected CRM producers world-wide are government agencies that choose to subsidise CRM production costs in the interests of safeguarding trade, environmental protection, human health, and other public interest considerations.

Due to the cost of production, certification and maintenance, matrix CRMs are not always available for the particular measurement needs of a laboratory or contaminated site assessment. In such a case, it can become difficult for a laboratory to validate the accuracy of measurements, particularly for complicated measurements. If reference materials are not available for validation and quality control, this places extra importance on expert knowledge of the sample, analyte and analytical procedures which are demonstrated through a history of proficiency testing. However, whereas proficiency testing results demonstrate comparability, certified reference materials have a unique role in demonstrating accuracy because of their well-defined metrological traceability. There is already a considerable range of reference materials and CRMs available from national metrology institutes and commercial suppliers and it is growing every year, making the use of reference materials much more a necessity than simply a possibility.

In conclusion, here are a few practical suggestions for improving the reliability of chemical measurement results, including use of reference materials.

When submitting samples for testing:

- Specify clearly the measurement that the laboratory needs to make. For example, measurements of contaminants in soil can vary depending on whether the measurement is for extractable, labile, water-soluble or total content.
- Ask what reference materials and acceptance criteria the laboratory uses.
- Submit a reference material as a blind check sample.
- Ask for the measurement uncertainty associated with the analytical method.
- Speak to reference material producers about what reference materials are needed for your industry.

When making chemical measurements:

- Include the best available reference materials (CRMs wherever possible) in calibration, method validation and quality control.
- Check the quality of reference materials and use those with the most information about homogeneity, stability, shelf-life, measurement uncertainty and metrological traceability.
- Include the measurement uncertainty associated with both the reference material and the analytical method when estimating the measurement uncertainty of results.
- Speak to reference material producers about what reference materials are needed for your industry.

Chemical reference materials are an important tool for better measurement and better decision making. In calibration and quality control, reference materials act as the benchmark for measurement accuracy. The quality of decisions based on measurement can never be better than the quality of the reference materials that the results are based upon.

David Saxby (david.saxby@measurement.gov.au) has worked at the National Measurement Institute for over ten years, specialising in high-accuracy chemical analysis for producing reference values for proficiency testing schemes and certified reference materials. Information about NMI's Chemical Reference Materials can be obtained from www.measurement.gov.au/chemref and chemref@measurement.gov.au.

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1. International Vocabulary of Metrology — Basic and general concepts and associated terms, JCGM 200:2008.
2. JCGM 200:2008.
3. For example ISO Guides 34 and 35 for reference material certification and JCGM 100:2008 for estimation of measurement uncertainty.
4. Primary Standards for Challenging Elements, European Metrology Research Program project SIB09 (2011).
5. Requirements are documented in ISO Guides 34 and 35.

Meet SA EPA's chief executive

The South Australian Environment Protection Authority's new Chief Executive, Tony Circelli, is now into his second year at the helm of the EPA.

Mr Circelli was appointed following the resignation in April 2014 of former Chief Executive Campbell Gemmell, who returned to Scotland after two years at the helm of the independent regulator.

Mr Circelli is well-known to industry and environmental groups in South Australia, having worked in the EPA since its establishment in 1995.

He has held a variety of senior executive positions, including leading national and state policy and strategy development, operations, and corporate governance functions.

He has significant knowledge of regulatory science and practice, is the current chair of the Australasian Environmental Law Enforcement and Regulators Network (AELERT), and is the presiding member of the SA Radiation Protection Committee.

Mr Circelli said he is continuing to drive the EPA's reform agenda, focussing on furthering risk-based regulation and seeking better ways to apply regulation. He has been active in encouraging the craft of better regulation through connecting with international centres of excellence as well as leading on national networks including the heads of EPA and through his leadership role with AELERT. He has also driven internal reforms in the SA EPA such as improved transparency and online accessibility of information – moving from paper based to electronic waste tracking and integration of online licensing systems.

"We have significantly improved our regulatory approach in recent years, and I want to ensure that we continue to focus on outcomes based on risk, on identifying and fixing the right problems," Mr Circelli said.

"To do that, we need to be good listeners, engaging with the community, industry and our peers, and be open to doing things differently and better," he said.

"We also need to be consistent in our regulation and practice, in promoting and pursuing a level playing field and certainty for business."

Mr Circelli said the EPA had been working to streamline red and green tape to produce better regulation, with recent examples including aquaculture reform, reducing duplication of regulation of the tuna industry with estimated savings to industry of $775,000, risk-based reform of the Water Quality Environment Protection Policy and the exploration of new innovative cost-effective regulatory tools such as civil penalties.

"It's not about lessening environmental standards, but ensuring that the standards are appropriate, streamlined and being well applied to protect communities and safeguard resources," he said.

"It's also important that we continue to ensure our decisions are based on good science, which means we want to continue to work with co-regulators and the environmental and tertiary sectors to collaborate and share our expertise and knowledge."

"We're continuing to work on making our data more accessible and available. We're increasingly providing more via our website, while at the same time working to improve environmental data at a broader level, particularly in the area of State of the Environment reporting."

"This means we can be confident that we understand the key issues and harms facing our community and our way of life, and also provides the means of knowing if we are effectively dealing with issues over time," he said.

These initiatives have been particularly effective in areas such as site contamination, with the EPA providing better and more detailed information to the community around the location of historically polluted sites.

Mr Circelli has an honours degree in Mechanical Engineering from the University of Adelaide and a Master of Business Administration from Deakin University. He is a member of the Australian Institute of Company Directors and Fellow of the Governor's Leadership Foundation.

NSW: cost recovery and update on UPSS regulation

Cost Recovery provisions under the Contaminated Land Management Regulation 2013

Under section 34 of the *Contaminated Land Management Act 1997* (CLM Act) (NSW), the NSW EPA may recover costs associated with:

- preparation and serving, monitoring action and seeking compliance of an order under Part 3 of the CLM Act; or
- the assessing and settling of terms, monitoring action and seeking compliance of any approved voluntary management proposal; or
- any other matters associated with, or incidental to, an order or approved voluntary management proposal.

The rate of cost recovery is prescribed under clause 4 of the Contaminated Land Management Regulation 2013 (http://bit.ly/1JAYLxG). As per the Contaminated Land Management (Adjustable Amounts) Notice 2014 (http://bit.ly/1II0Xj1) from 1 September 2014, the rate became $83 per hour.

Revision of the *Duty to Report* Guidelines

The NSW EPA's *Guidelines on the Duty to Report Contamination under the Contaminated Land Management Act 1997* (the Guidelines) were recently revised to ensure consistency with the amended *National Environment Protection (Assessment of Site Contamination) Measure 1999* and to account for other updates since the previous version was published.

The Guidelines are now available for downloading from the EPA website (www.epa.nsw.gov.au/clm/150164-land-contamination.htm).

The Guidelines were available for public consultation in July/August 2014, during which time submissions were received from a variety of stakeholders. NSW EPA considered the 18 submissions which are available on the, along with the EPA's responses.

Amendment of the UPSS Regulation

The Protection of the Environment Operations (Underground Petroleum Storage Systems) Regulation 2014 (the Regulation) commenced on 1 September 2014 and replaces the Protection of the Environment Operations (Underground Petroleum Storage Systems) Regulation 2008 (see http://bit.ly/1II15z2).

The object of the Regulation is to regulate the storage of petroleum in underground storage systems so as to minimise the risk of the discharge of substances that cause significant damage to the environment.

The changes in the amended Regulation will deliver on the NSW EPA's policy objectives of strengthening environmental outcomes and helping operators of underground petrol storage tanks to improve their monitoring and environmental performance.

Changes in the amended Regulation include:

- enabling the use of certain secondary leak detection systems;
- enabling environment protection plans to be kept electronically and as either a consolidated document or a collection of documents;
- providing greater flexibility in the devising of loss monitoring procedures for a storage site;
- including new and clarified definitions; and
- clarifying reporting requirements.

Sustainable remediation technology choices reflect the scale of the remediation, the technical challenges, local stakeholder and community concerns, as well as the economics land value considerations – Rhodes Peninsula remediation, Sydney, early 2000s. *Thiess Services*

Applying sustainable remediation principles in Australasia

JW Hunt, CIMIC, & GJ Smith, Geosyntec Consultants

This article describes a simple semi-quantitative method for remediation sustainability evaluation based on Australian and overseas practice and experience.

Sustainable remediation (SR) concepts appear in many international remediation frameworks, are consistent with Australian Ecologically Sustainable Development (ESD) policies, and are being considered in Australian National Remediation Framework (NRF) development. The application of SR principles brings value to remediation approvals, design, implementation and stakeholder engagement.

What is sustainable remediation?

The definition adopted by the Sustainable Remediation Forum of Australia and New Zealand (SuRF ANZ) is "a remediation solution selected through the use of a balanced decision making process that demonstrates, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than any adverse effects."

Key points are:

- mitigating risk
- meeting minimum regulatory, social and financial requirements
- achieving a balance of these
- achieving a net overall benefit in these.

The SuRF UK method

The method described here introduces a simple way of comparing remediation strategies, based on evaluation by persons experienced in a range of remediation methods. It is inspired by the SuRF-UK SR evaluation methodology, which uses a tiered approach where:

- Tier 1 is a qualitative approach for simple cases
- Tier 2 is a semi-quantitative approach

- Tier 3 is a complex approach such as monetised cost-benefit analysis (CBA).

The simplest approach, which supports a justifiable decision, is recommended.

Soil remediation working example – hypothetical Australian site

The following example is based on remediation of a hypothetical small (0.25 hectares) contaminated industrial site located on the outskirts of a city, in an area of mixed industrial and residential development. The site is to be remediated for ongoing industrial use. It has been investigated, risk based remediation criteria derived and remedial options developed. The sustainability analysis is being used to create a short list of remedial options.

It is informative to quantitatively define the problem and the Conceptual Site Model before trying to solve it. In particular:

- This site is flat and only pavements remain.
- The stratigraphy is 0.3 m of pavement, overlying 0.6 m of sandy fill, overlying 6 m of interbedded alluvial sand, silt and clay, overlying 5 m of tight clay.
- The soil is contaminated by petroleum hydrocarbons in the C6-10 range. The average total hydrocarbon concentration is 2500 mg/kg, and average benzene concentration is 1500 mg/kg.
- The contamination footprint extends over 40 x 40 m to a depth of 7m.
- The contaminated soil volume is 2800 m^3 and the soil mass is 5040 tonnes.
- The mass of contaminants is about 15,000 kg.
- There is potential for migration of hydrocarbon vapour to the surface.
- Groundwater is at 7 m bgl, and is not currently contaminated.

Remediation objectives determined by the State EPA, Planning Department and local stakeholders are to:

- return the site to industrial use without management requirements
- protect groundwater quality by removing or destroying benzene
- protect human health by removing or destroying benzene
- minimise impacts to residents and industry during remediation
- minimise disruption to operations on adjacent industrial sites.

The site soil clean-up standards are 1 mg/kg for benzene and 255 mg/kg for light petroleum hydrocarbons.

Sustainability analysis method

A simple qualitative Tier 1 sustainability analysis is not sufficient to discriminate between viable alternative remedial options, so a semi-quantitative Tier 2 approach was used.

SuRF UK separately considered the following factors in their Upper Heyford case study :

- practicability and effectiveness to meet the remediation objectives
- sustainability indicators for environment, social and economic factors.

While practicability and effectiveness are strictly not sustainability indicators, they are useful in screening out options. They are defined as follows:

- *practicability* – the ease with which an approach can be implemented
- *effectiveness* – the extent to which minimum requirements are met.

Initial screening of remediation methods

Some methods that did not meet critical requirements (mainly effectiveness in terms of mass removed or destroyed) and could have been eliminated in a Tier 1 assessment were, however, carried forward for the exercise. The remediation methods considered were therefore:

- *Ex situ* Dig and Dump (ESDD) – well understood, high cost, disruptive to local community, short duration.
- *In situ* Cap and Contain (ISCC) – cut off wall and vapour cap required, short duration. Future benzene impact to groundwater is an issue
- *Ex situ* Encapsulation (ESEC) – lined encapsulation on a small site and requires an Odour Control Enclosure (OCE) and Emission Control System (ECS) for excavation. Limited design life. Short duration.
- *Ex situ* Solidification / Stabilisation (ESSS) with reuse – OCE/ECS, short duration.
- *In situ* Solidification / Stabilisation (ISSS) with reuse – OCE/ECS, medium duration.
- *Ex situ* engineered biopile (ESBR) – OCE/ECS, medium duration.
- *In situ* Bioventing (ISBV) (aerobic bioremediation), no OCE/ECS, long duration.

- *In situ* Soil Vapour Extraction (SVE) – catalytic oxidiser / carbon beds required, no OCE/ECS, long duration.
- *Ex situ* Chemical Oxidation (ESCO) – OCE/ECS, long duration.
- *In situ* Chemical Oxidation (ISCO) – no OCE/ECS, moderate duration.
- *In situ* thermal conductive heating (ISCT) – gas and thermal oxidiser (TO) required, no OCE/ECS, medium duration.
- *In situ* thermal resistive heating (ISRT) ETDSPTM. Electricity and TO required, no OCE/ECS, medium duration.
- *Ex situ* Batch Thermal (ESBT) – gas and TO requried, OCE/ECS, long duration.
- *Ex situ* Continuous Thermal (ESCT) (directly-heated plant) – gas and TO required, OCE/ECS, medium duration.
- *Ex situ* Continuous Thermal (ESCT) (indirectly-heated plant) – gas and condenser required, OCE/ECS, long duration.

Stage 1 – Tier 2 options appraisal and semi-quantitative sustainability analysis

Effectiveness

- ISCC, ESEC, ISSS, and ESSS do not destroy contaminants (a fundamental requirement), may not effectively prevent benzene migration and ISCC and ESEC have relatively short design lives. Environmental outcomes, cost and duration are uncertain.
- The effectiveness of the remaining *in situ* non-thermal options (ISBR, ISCO, SVE) is questionable given the complex stratigraphy. Environmental outcomes, cost and duration are uncertain.
- The ESDD, ESBR and ESCO options readily are effective in reducing contaminant mass. However treatment may be required to meet landfill disposal criteria for ESDD.
- The remaining *in situ* and *ex situ* thermal methods readily address remediation objectives but are high cost, use a lot of energy and have emissions to air from combustion.

Practicability

Considering practicability:

- The *ex situ* options and ISSS are less practicable than the remaining *in situ* options, requiring construction and operation of an OCE/ECS
- The *ex situ* options less are practicable than *in situ* options, require shoring along the adjacent industrial site and have a higher potential for other impacts on neighbours
- The *ex situ* options excluding ESDD are less practicable, requiring multiple handling of large amounts of materials on the small site
- ESCO is less practicable requiring treatment of batches of soil in a lined pond over a longer timeframe
- Shorter options are more practicable and the longer options less practicable
- ISSS less practicable needing to export soil to landfill for volume expansion.

Environmental indicators

The environmental indicators assessed were:

- ENV 1a: Air – emissions of particulates and chemicals, including earthworks and treatment.
- ENV 1b: Air – GHG emissions from treatment, transport and OCE/ECS.
- ENV 2: Soil – contaminant mass removed and / destroyed.
- ENV 3: Groundwater – contaminant mass removed and / or destroyed (not applicable here so not scored).
- ENV 4: Ecology – not applicable here so not scored.
- ENV 5: Natural Resource use – additives and energy, assuming natural gas in pipe and electricity from black coal.

ENV1 was separated into two parts and averaged, because the impacts are unrelated.

Social Indicators

The social indicators assessed were:

- SOC 1: Health and Safety impacts onsite and offsite by soil, vapour, odour and dust.
- SOC 2: Ethics and Equality including duration and intergenerational equity.
- SOC 3: Neighbourhood and locality including hours of work and traffic movements.

Table 1. Semi-quantitative sustainability assessment results

Method	Eff.	Prac.	Subtotal E x P	ENV	SOC	ECON	Subtotal E+S+E	Total	Rank
ESDD – OCE & ECS	5	2.5	12.5	4.3	2	3.8	10.1	22.6	3.0
ISCC	1	3	3.0	3.0	2.5	1.2	6.7	9.7	13.0
ESEC – OCE & ECS	1	2	2.0	2.5	2.25	2.2	7.0	9.0	15.0
ESSS – OCE & ECS	1	2	2.0	2.3	2.75	2.9	8.0	10.0	12.0
ISSS – OCE & ECS	1	1	1.0	2.3	2.75	2.9	8.0	9.0	14.0
ESBR – OCE & ECS	3	2	6	4.2	3.75	4.1	12.0	18.0	7.0
ISBV	3	2.5	7.5	4.0	3.5	2.8	10.3	17.8	8.0
SVE	2	2.5	5.0	3.2	3.25	2.8	9.2	14.2	11.0
ESCO – OCE & ECS	4	1.5	6	3.8	3.25	3.5	10.6	16.6	9.0
ISCO	2	2.5	5.0	3.7	3	2.8	9.5	14.5	10.0
ISCT	5	3	15.0	3.2	4.625	4.3	12.1	27.1	1.0
ISRT	5	3	15.0	2.7	4.625	4.3	11.6	26.6	2.0
ESBT ETC – OCE & ECS	5	1.5	7.5	3.0	4.375	4	11.4	18.9	6.0
ESCT DTD – OCE & ECS	5	2	10.0	3.2	4.875	4.5	12.5	22.5	5.0
ESCT ITD - OCE & ECS	5	1.5	7.5	3.5	4.375	4.6	12.5	20.0	4.0

- SOC 4: Community Involvement including engagement, transparency and inclusiveness (not assessed and assumed the same for all).
- SOC 5: Uncertainty and Evidence including robustness and quality of work.

Economic Indicators

The economic indicators assessed were:

- ECON 1a: Direct Costs including costs and sensitivity to changes.
- ECON 1b: Direct Benefits including benefits of works and site value uplift.
- ECON 2: Indirect Economic Costs / Benefits including financing, property, reputation.
- ECON 3: Employment and Employment Capital including job creation, and training.
- ECON 4: Induced Economic Costs and Returns including opportunities for inward investment and effects on other projects in the area.
- ECON 5: Project Lifespan and Flexibility including duration, changing regulations, and requirements for institutional controls.

ECON 1 was split into two parts and averaged because of the difficulty in balancing the scoring when both are considered together.

Outcome of stage-1 assessment

The outcome of the semi-quantitative assessment is summarised in Table 1, where total is the sum of (E x P) + (E+S+E). The results have been broken into four groups by total score and colour coded from best to worst.

The lowest-ranked options overall have low rankings for both E x P and sustainability indicators, confirming the validity of excluding them based on a Tier 1 process.

ESDD is highly ranked because it is effective and relatively low cost. We assumed that there is no landfill levy to provide a social unacceptability signal. As discussed on page 20, however, it does not provide a balanced solution.

Balance for the SR indicators is illustrated in Fig. 1. The chart shows results for environmental, social and economic aspects as percentage of total.

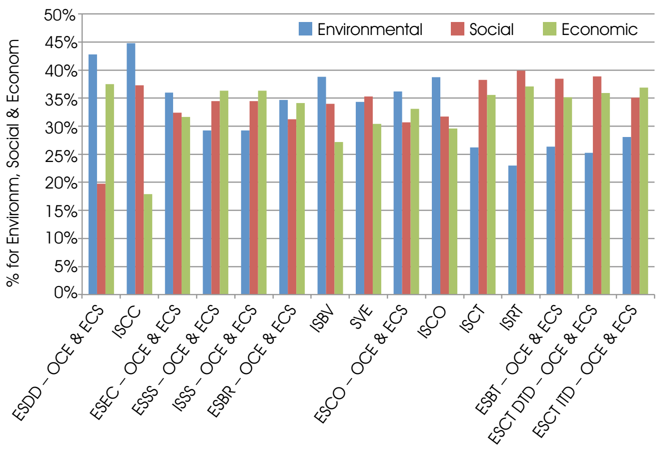
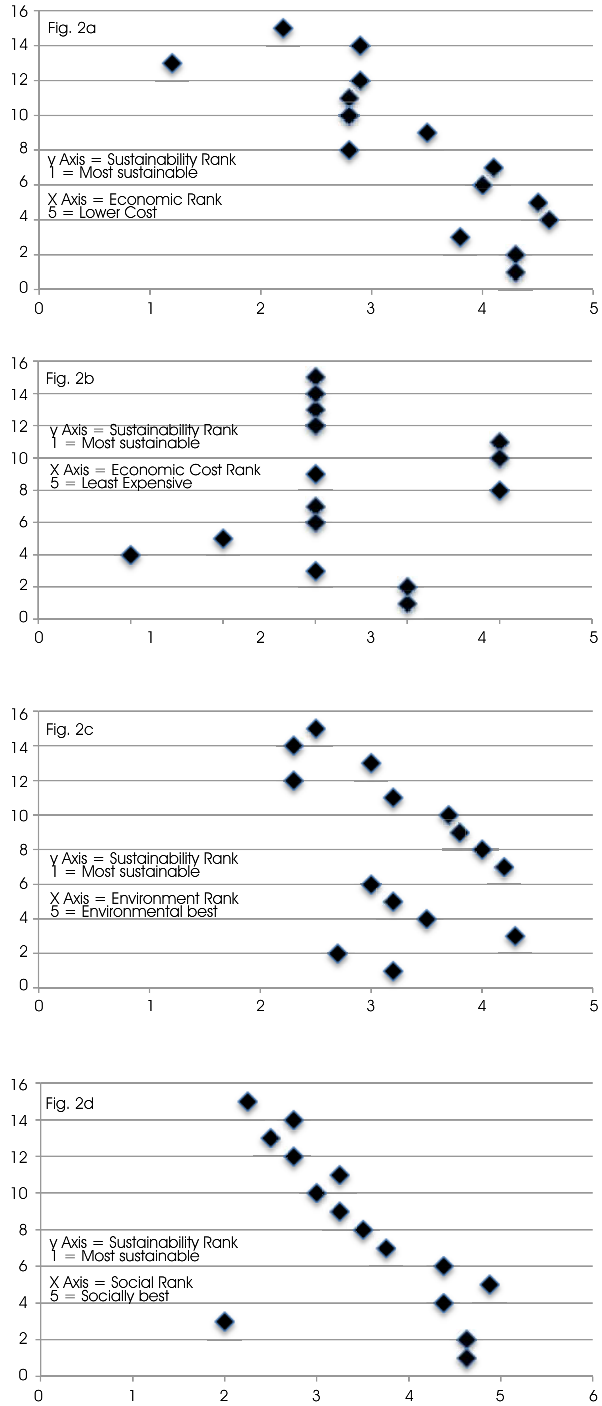


Figure 1. Balance for environmental, social and economic factors

Many of the other higher scoring options do not show good balance, including most of the thermal options, with electric heating worse than gas heating. The most balanced solution is ESBR ranked 7, mainly reflecting (im)practicability considerations on the small site.

Figure 2: Relative sustainability rankings of each option (Y axis), relative to economic ranking (Fig. 2a), technology direct project cost (Fig. 2b), environmental ranking (Fig. 2c) and social ranking (Fig. 2d).



The costs and benefits of sustainable remediation practice

An analysis of the data shown in Table 1 provides insight into the project costs and benefits of sustainable versus routine remediation technologies proposed for the hypothetical site. Figures 2a-2d show the relative sustainability ratings of each option, relative to economic ranking (Fig. 2a), technology direct project cost (Fig. 2b), environmental ranking (Fig. 2c) and social ranking (Fig. 2d). The prediction is that for the 15 options considered, the more sustainable options are uniformly more economically, environmentally and socially effective (Figs. 2a,c,d). Furthermore, many of the more sustainable technologies on balance exhibit lower direct project costs (Fig. 2b).

Discussion

The semi-quantitative sustainability evaluation method provides a straightforward way to compare the relative performance of remediation options if they cannot be distinguished using a Tier 1 qualitative process. For large or contentious projects, options with similar sustainability characteristics may require a Tier 3 quantitative analysis to identify the most acceptable and balanced option.

Options with the low scores for practicability and effectiveness tend to exhibit low scores for many sustainability indicators. The top 5 ranked options in Table 1 all achieve high contaminant removal or destruction efficiencies, which is a fundamental stakeholder requirement. The shortlisted options are mainly discriminated by their practicability scores. However, the indicator scores for ESDD and ISRT are not well balanced.

Several *ex situ* treatment and reuse options are not listed due to limited space on site, which would mean an extended duration and higher unit costs. If duration and cost were not important to key stakeholders, the overall ranking would change significantly.

It is evident that a team approach, with input from and interaction with various stakeholder groups, would maximise the effectiveness of the semi-quantitative approach.

A more detailed protocol for this assessment method and working example is available as a discussion draft on the SuRF ANZ website (see www.surfanz.com.au).

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Streamlining phase 1 assessments

Geo-Environmental Engineering (GEE) is a boutique consultancy that has seen a steady increase in the volume of environmental phase 1 assessments they have been instructed to undertake over the past 12-24 months.

Stephen McCormack, principal at GEE has managed this growth successfully through a couple of different initiatives. One key approach has been to outsource the manual searches and gathering of background information, mapping and aerial imagery.

"By utilising Lotsearch's services we have helped to not only reduce the time taken to complete phase 1 assessments," says Mr McCormack, "but we have also benefited from an improvement in the overall presentation of the background raw data, mapping and aerial imagery that is required to satisfy audit."

As Stephen confirms, the benefit of this is not only in productivity, but also in staff morale. Junior consultants that typically would have undertaken these laborious tasks can now spend more time on-site and writing preliminary site assessments, while Stephen can focus on building new and maintaining existing client relationships.

"The fact that Lotsearch provides relatively inexpensive reports of the site in 2-3 business days is very positive," says Mr McCormack. "We are able to take on more work, yet keep our staff and operating costs at similar levels."

Howard Waldron, Director of Lotsearch says he's pleased to have been able to support Stephen and the team at Geo-Environmental Engineering. "We have worked hard over the past nine months to collate a large number of datasets and tailor our reports to meet the requirements of environmental consultants and practitioners," he says.

"Delivering comprehensive site-specific reports at relatively low cost and within two business days is changing the way in which this industry operates. Stephen has realised that collating the information manually and piecemeal is not practical. By using Lotsearch he can instead add significant value to other aspects of his operations."

Lotsearch reports are available in New South Wales and Victoria. For further information please visit www.geoenvironmental.com.au and www.lotsearch.com.au.

Lotsearch

Soil contamination, crop quality and human health risk assessment in Korea

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Although Korea has naturally occurring sources of cadmium and other metal(loid)s that are known to contaminate food crops and water, it also has nearly 2000 metalliferous mines, most of which are abandoned. Although the levels of cadmium, arsenic and other contaminants vary widely, wastewater from many of these sites represents a risk to human health that require more detailed investigation.

Heavy metal(loid)s reach soils through natural geogenic processes and anthropogenic activities. Often the concentrations of metal(loid)s released into the soil system by geogenic processes are low and largely related to the origin and nature of the parent material. Anthropogenic activities primarily associated with agricultural and mining activities, industrial processes, manufacturing, and the disposal of domestic and industrial waste materials are the major sources of metal(loid) enrichment in soils. Unlike geogenic input, metal(loid)s added through anthropogenic activities often have high bioavailability.

Soil contamination by toxic elements such as arsenic (As) and cadmium (Cd) mainly originate from anthropogenic activities and cause a decrease in the quantity and quality of agricultural products. Particularly, mine tailings and waste rocks contaminate agricultural fields with toxic elements during weathering and heavy rainfall.

Korea has a long history of metalliferous mining, with the most extensive activities occurring during the early twentieth century. Large areas of agricultural land, including paddy fields, have been contaminated (see photo 1). Cultivated land in Korea comprises around 21% of total land area, and 61% of the cultivated land is paddy fields. High levels of toxic elements in soil lead to detrimental effects on crop growth and yields (see photo 2), and may pose a severe toxic risk to animals as well as human beings through the food chain.

Rice (Oryza sativa L.) is one of the most widely consumed staple cereal foods in the world, constituting up to 90% of the diet of people in Asian countries. In

Photo 1. Arsenic- and cadmium-contaminated paddy fields near a mining area.

Photo 2. Rice fields affected by arsenic and cadmium contamination.

many East and South Asian countries, including Japan, Bangladesh, Indonesia, and Korea, the accumulation of metal(loid)s – particularly As and Cd – in rice ecosystems, and its subsequent transfer to the human food chain, is a major environmental issue.

Arsenic is considered one of the most important toxic elements in the environment because of its potential risk to human health and to ecosystems. Apart from drinking water, rice consumption may be the most important pathway for human As uptake. This is in part due to rice being more efficient than other grain crops like barley and wheat at taking up As from soils. Chronic exposure to As can lead to cancer and other health problems.

Arsenic exists in both organic and inorganic forms. The inorganic As content in rice can vary from 10-90% of the total As amount. Information on the health risk of As in rice has largely been based on the inorganic As content because this form has generally been considered to be more toxic than the organic form.

Rice is also a major source of Cd intake by humans. Excessive intake of Cd into the human body is detrimental to human health, causing serious illnesses such as itai-itai disease. Current regulations have designated paddy fields which have produced rice grains containing more than 0.4 mg/kg of Cd, as 'contaminated paddy fields'. Furthermore, the Codex Alimentarius Commission of the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO) recently proposed a new international standard for Cd concentrations in polished rice of 0.4 mg/kg, as well as a draft maximum level for inorganic As in polished rice of 0.2 mg/kg.

Geogenic sources of contamination

The Okchon black shale, which is underlain by the black slates in the central part of the southern Korean Peninsula, provides a typical example of natural geological materials enriched with potentially toxic elements. The Okchon Zone of the central part of Korea has an area of about 5100 km^2 and covers about 5.5% of the total territory of the entire country.

Soils derived from these parent materials tend to reflect their extreme geochemical composition and may influence human health by affecting the elemental composition of crop plants. In particular, barium (Ba), Cd, molybdenum (Mo), vanadium (V), and uranium (U) in Okchon black shale are highly enriched, and their mean concentrations are significantly higher than those in black slates (Table 1).[1] Cadmium occurs predominantly in an exchangeable phase in these soils, thereby influencing the high Cd uptake of crop plants.

Table 1: Ranges and mean concentrations of cadmium in black shales and slates from different areas in the Okchon Zone, Korea (modified from Lee et al., 1998).

Area	CD concentration mg/kg	
	Range	Arithmetic mean
Chung-Joo (N=7)	0.5-6.5	1.4
Duk-Pyung (N=9)	1.0-36.0	10.9
Geum-Kwan (N=4)	0.4-0.6	0.5
I-Won (N=5)	0.5-1.0	0.6
Bo-Eun (N=5)	2.3-3.8	3.0
Chu-Bu (N=10)	0.5-3.9	1.1
Average shale		0.3
Average black shale		1.0

Black shales act as a source of these elements in the rock–soil–plant–human system. Cadmium concentrations in surface soils are higher in most of the examined areas (Chung-Joo, Duk-Pyung, Geum-Kwan, I-Won, Bo-Eun and Chu-Bu) than the world average of 0.4 mg/kg Cd (Table 2).[1] In the black shale areas, high Cd concentrations are found in residual soils developed from bedrock with high Cd content. Elevated levels are also found in alluvial soils in the black slate, black shale, or grey chlorite schist areas.

Cadmium concentrations in rice grains are higher in the black shale areas than in the black slate or grey chlorite schist areas. Mean Cd concentrations of rice cultivated in these areas were significantly higher than those in normal rice grown on uncontaminated soils. Among the six examined areas, the highest mean concentrations of 0.61 and 1.74 mg/kg Cd were found in rice grains and stalks from the Duk-Pyung area, respectively (Table 2).[1]

Anthropogenic sources of contamination

In Korea, there are nearly 2000 metalliferous mines, and most of them are abandoned due to lack of ore minerals and the economic recession. This means that a large amount of mine waste materials including tailings have been left without proper remediation work. Arsenic and heavy metal(loid)s in the materials can thus be dispersed down slope by surface erosion, wind action, and effluent draining from the mine wastes, contaminating the low-lying arable lands. Around 21% of arable soil near mining and industrial areas has been found to be contaminated by toxic metal(loid)s.

The fate and transport of metal(loid)s in the materials can be influenced by their physical and chemical characteristics and the environmental conditions of mining areas. The elements leached from mine wastes, such as tailings and spoil heaps, have caused serious environmental problems related to ecosystems and subsequently to human health.

The Daduk gold (Au), silver (Ag), lead (Pb) and zinc (Zn) mine, located in central Korea, is a major source of heavy metal(loid) contamination of arable soils. This mine was one of the largest Au–Ag–Pb–Zn mines in Korea. The mine ceased production in 1984 and large amounts of mine wastes have been left without proper environmental treatment. The mine tailings contain high concentrations of metal(loid)s, and have been dispersed down slope by erosion and effluent draining into low lying land mainly used for paddy cultivation. Elevated levels of Cd were found in soils sampled in paddy fields and the forest area. According to the Korean Soil Environmental Conservation Act, soils containing more than 1.5 mg/kg Cd extracted by 0.1 N HCl solution, and 4.0 mg/kg Cd total, need to be continuously monitored and not used for agricultural purposes, respectively.

The metal(loid) smelting process is regarded as the most important metal(loid) contamination source for paddy soils. A Zn smelting factory located in the eastern part of the Korean peninsula is a typical example of Cd contamination resulting from the smelting process. This is the third largest Zn smelting facility in the world. This factory, founded in the 1970s, produces 280,000 tonnes of Zn, 450,000 tonnes of sulfuric acid, 1700 tonnes of Cu, and 900 tonnes of Cd/year. However, there have been reports of ill-health effects on exposed workers, nearby communities and the environment. Specifically, about 20 hectares of arable land near the factory cultivated with different crops were reported to be contaminated by Cd and Zn.

Table 2. Cadmium concentrations (mg/kg) of rock, soil and rice (dried weight base) samples in the Duk-Pyung area in the Okchon Zone, Korea (modified from Lee et al., 1998).

Sample type	Black shale area			Grey chlorite schist, or black slate area		
	Geometric	Arithmetic mean	Geometric mean	Range	Arithmetic mean	Geometric mean
Rock	0.4-46	6.3	2.4	0.4-1.7	0.8	0.8
Residual soil	0.3-3.9	1.3	1.0	0.5-1.2	0.8	0.7
Alluvial soil	0.3-8.3	1.2	0.9	0.3-11	1.1	0.8
Rice shoot	0.1-2.7	0.6	0.3	0.1-0.2	0.2	0.2
Rice stalk	1.0-6.6	1.7	1.0	0.1-1.7	0.5	0.3
Rice grain	0.1-3.5	0.6	0.4	0.2-0.3	0.2	0.2

Table 3. Arsenic and cadmium concentrations in contaminated paddy soils, waters and polished rice (Park et al., 2011)

Metal(loid) concentrations	As	Cd	As	Cd	As	Cd
	mg/kg		mg/L		mg/kg	
	Paddy soils (n=89)		Irrigation waters (n=57)		Polished rice (n=34)	
Ave.	22.99	3.48	0.0151	0.0003	0.18	0.04
Min.	2.51	2.07	0.0001	0.0001	0.08	0.001
Max.	84.90	4.95	0.353	0.0073	0.44	0.27
Concern level (threshold value)	25	4	0.05	0.01	0.2 (inorganic As)	0.2
Countermeasure level	75	12	-	-	-	-

As accumulation has been reported in rice from the floodplain around the Guryong stream.[2] The floodplain is underlain by a ~2-m-thick layer of tailing materials. The alluvial aquifer contained As and other toxic metal(loid)s, and subsequently posed a threat to groundwater contamination. Analyses from the tailing materials and stream sediments of the study area showed Cd ranging from 16 to 109 mg/kg, copper (Cu) from 93 to 186 mg/kg, Pb from 663 to 2719 mg/kg, Zn from 459 to 2284 mg/kg, and As from 380 to 438 mg/kg.[3]

Gubong mine, one of the largest Au–Ag mines in Korea, operated from 1908 to 1990 with a maximum production of gold of 13,150 kg/year. During this period, ~900,000 m^3 of mine dumps and gangues were stored. The major metal(loid)-containing minerals – such as arsenopyrite, pyrite, cerussite, sphalerite and iron oxides – have been identified in tailings and stream sediments in the Gubong area.[3] The fine sands and silts in the wastes were dispersed into the surrounding environments by surface runoff and by wind-suspended particles. Farmers living downstream of the Gubong mine noticed a decline in their crops when these waste materials arrived.

Table 3 shows the As and Cd concentrations in contaminated paddy soils, irrigation waters and rice grains collected near the mine sites.[4] The maximum concentrations of As and Cd were above the threshold levels; in particular, the As value in irrigation water exceeded the guideline level by seven times.

Human health risk assessment

Long-term exposure to toxic elements by regular consumption of rice and vegetables may pose potential health problems to residents in the vicinity of mines. The health risk to humans from exposure to As and Cd is associated with both cancer and non-cancer toxic effects. Based on the average daily dose (ADD) values, the probabilistic health risks at mean and 95th percentile values were assessed by both cancer risk probability (CR) and hazard quotient (HQ). The R value represents the possibility of cancer due to lifetime exposure through rice intake, and under current Korean regulations a concentration of 10−6 to 10−4 is acceptable.

The total As concentrations from 300 polished rice samples cultivated near mining areas in Korea were


Cadmium tailings

analysed to estimate a probabilistic assessment of human health risk from As-contaminated rice.[5] The mean of total As concentrations in rice was 0.09 mg/kg. Human health risk for As in rice was estimated using gender-specific rice consumption data and ADD.

The mean CR posed by total As was 2.16 (for male) and 1.83 (for female) per 10,000. The HQ for the general population from rice cultivated near mining areas in Korea was below 1 at the 50th percentile of the general population. However, less than 10% of the general population consuming rice cultivated near mining areas would exceed 1.0.

The health risks through groundwater and rice intake were therefore considered greater than those through inadvertent ingestion of soil and dermal contact.[6]

Containing the health risk

Managing As and Cd together in the soil–plant–human system is challenging. Currently, studies and projects are underway to minimise the contamination and remediate heavily contaminated areas. These include:

- evaluating the state and trend of metal(loid) contamination in paddy soils and rice and to assess the potential level of metal(loid) movement from paddy soil to rice with different physico-chemical characteristics
- developing techniques to conserve and remediate contaminated paddy fields and to improve the food safety of rice
- water management studies in arsenic- and cadmium-contaminated paddy fields
- examining the effect of soil amendments (e.g. phosphate, silicate) on the uptake of As and Cd by rice grains
- examining the effect of washing rice and cooking methods on the reduction of total arsenic and its species.

Minimising the intake of Cd and As from rice and other agricultural food products in the diet is an important health issue. It is thus crucial to assess the potential environmental risks posed by untreated abandoned mines and to establish proper pollution management plans that lead to remediation. More studies, in the vein of those listed above, are badly needed.

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South Korea's big clean

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A legacy of environmental contamination stemming from historical practices has prompted the South Korean government to regulate for emerging contaminants such as discarded ammunition from firing ranges.

Since the 1995 Soil Environment Conservation Act, the South Korean Ministry of Environment has regulated various environmental contaminants to protect the ecosystem and human health. It categorised contamination into 'worrisome' and 'hazardous' levels. The former indicates the level of soil contamination likely to affect human health and property, as well as animals and plants; the latter requires landowners to take immediate action to clean up (see www.law.go.kr).

The contaminants include toxic metals, hydrocarbons and organo-phosphorus compounds, but heavy metals and hydrocarbons are the most common. Initial guidelines limited toxic metals to below the HCl extractable concentrations, introduced to draw attention to the reactive metal pools in the soils. But in 2010, the ministry set a new guideline for heavy metals, reflecting the concept of risk assessment based on 'pseudo-total concentrations'.

This is a big issue because stabilisation techniques are no longer applicable to the rehabilitation of soil; there is urging from both researchers and policymakers to develop new guidelines for agriculture.

Due to the outbreak of foot-and-mouth disease in 2010–11, about 4 million animals were buried in nearly 5,000 pits, some of them on agricultural land such as rice paddies. A recent report indicated that leachate from these pits – veterinary antibiotics and some trace elements – could have contaminated land and crops, so the government is engaging in long-term monitoring.

Chemical accidents have become increasingly frequent. For example, a spill occurred in 2012 in Gumi city, an industrial hub, releasing hazardous hydrogen fluoride gas and destroying crops over some 200 hectares. The Ministry of Environment said there had been no contamination, but continuous and intensive monitoring was instituted anyway.

As a result of numerous abandoned mines nationwide, a wide range of waste material – such as acid drainage and mine tailings – have contaminated nearby agricultural land, with elevated metal concentrations (especially for lead and cadmium) in soil and crops. The government has legislated for maximum concentrations of these metals at 0.2 mg/kg dry weight in rice; it also screens out and discards any crops that exceed the limits.

Military firing ranges assumed to be contaminated have been closed down, but the true extent of this source of contamination is not clear. In general, military ranges have been reported to be a significant source of hydrocarbons and heavy metals in nearby soils and waterways.

Due to the Four Major Rivers Restoration Project, huge amounts of sediment were dredged onto agricultural land without proper evaluation. Reports of abnormalities in rice and other crops followed. Research is now underway into how the arable land affected by the dredged sediment can be better managed.

Since 2005, the Ministry of Environment has investigated contamination at major industrial sites – caused by hydrocarbons, heavy metals and other toxic compounds – that could threaten human health. But now at least 65% of the contaminated soil and groundwater has been successfully rehabilitated.

Restoring cadmium-contaminated soil

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A better, more cost-effective way to restore cadmium-polluted paddy fields can help ensure rice consumption is safe for all.

Mention of cadmium (Cd) may remind some people of itai-itai ('ouch-ouch') disease in Japan, where Cd poisoning caused renal disorders and soft bones. The main source of the Cd was wastewater released from mines into the rivers that were used to irrigate paddy fields. People ingested the Cd in the rice and in contaminated drinking water. Such environmental pollution contributed to the formulation of the Agricultural Land Soil Pollution Prevention Law in 1971, which designated paddy fields producing rice with a Cd content of 1 or more mg/kg as requiring anti-soil-pollution measures.In 2005 and 2006, the Codex Alimentarius Commission, founded by the World Health Organization and the United Nations Food and Agriculture Organization, adopted standard Cd contents in various food products. Following the Codex threshold set for rice, the Japanese threshold was reduced to 0.4 mg/kg in 2011.

At present, the main method for restoring contaminated fields is dressing with uncontaminated soil. However, not only is this method expensive, but clean soil is difficult to source. At the same time, the trend towards the conversion of paddy fields to upland fields presents an opportunity to contribute to Cd reduction in upland crops.

Thus, we need better ways to restore Cd-polluted paddy fields.

Soil washing method

'Soil washing' usually means off-site remediation, and 'soil flushing' usually means on-site remediation. We use 'soil washing' to cover both in vitro and *in situ* techniques.

On-site soil washing can be appropriate for paddy fields, which usually have an impervious clay layer that keeps the wash solution in the surface soil. To develop a suitable technique, we focused on chemicals that have low environmental impact but high efficiency, the development of an on-site washing and wastewater-treatment system, and maintaining soil fertility and plant growth.

Mechanism of cadmium extraction from soil by ferric chloride

By considering the Cd extraction efficiencies, environmental impacts, costs and application methods of various washing agents, we selected ferric chloride ($FeCl_3$) as the optimum agent for washing Cd-contaminated paddy soil. This section describes how ferric chloride extracts Cd from soil in comparison with calcium chloride, a salt with neutral salt.

We sampled three kind of gray lowland soils from three locations and added either ferric chloride or calcium chloride. As the concentration of both reagents increased, the pH of the extraction liquid (broken lines in Fig. 1) decreased, but the decrease was much greater with ferric chloride (Fig. 1). In the case of calcium chloride, the Ca^{2+} ions displace the H^+ and Al^{3+} ions adsorbed to the soil in an ion-exchange reaction, lowering the pH. In the case of ferric chloride, however, the extraction of exchangeable Al^{3+} cannot explain the sharp lowering of pH, which falls below 3 at 50 mM. Instead, when ferric chloride is applied to the soil, it dissociates first into Cl^- and Fe^{3+} ions (reaction 1). The Fe^{3+} ions then react with water to generate iron hydroxide ($Fe(OH)_3$) and H^+ ions (reaction 2). The solubility product of $Fe(OH)_3$ is very small, so the two reactions occur quickly, providing optimal pH for soil-Cd extraction, around 2-3.

$$FeCl_3 \rightarrow Fe^{3+} + 3Cl^- \quad (1)$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \quad (2)$$

This reaction sequence suggests that this pH lowering effect displaces the strongly adsorbed acid-soluble Cd from the soil.

Soil washing in the paddy field

Soil washing is commonly used for the decontamination of soil at former factory sites, but examples of its application to farmland are few. Fortuitously, the common presence of an impervious clay layer beneath paddy fields makes it possible to

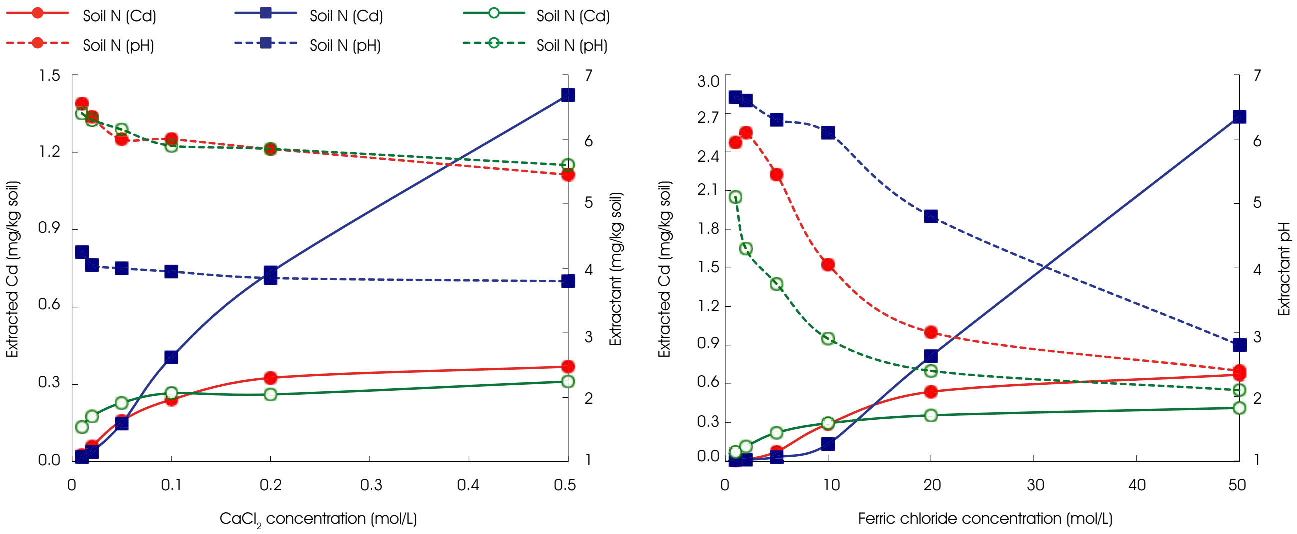

Figure 1. Relations between the concentrations of washing chemicals added to the soil and (left axes) the quantity of Cd extracted and (right axes) the pH of the extraction liquid. (0.1 M HCl-Cd; soil N, 0.63 mg/kg; soil H, 2.50 mg/kg; soil T, 0.55 mg/kg)

wash soil in the field. We devised the following process for on-site washing (Figures 2 and 3):

1. Application of the washing agent to the paddy field: Ferric chloride solution is an inexpensive and safe material that is easily applied to soil, which will send to paddy fields by pumping with additional irrigation water.
2. Mixing the washing agent with the soil: Irrigation water is applied, and the soil is puddled by a tractor with a rotary harrow. This process washes the soil-Cd out into the paddy water.
3. Sedimentation and drainage: The water is allowed to stand until it becomes clear. Then supernatant is pumped into the wastewater treatment equipment set up on site.
4. Treatment of the wastewater: The wastewater treatment equipment has an alkali chamber to form metal hydroxides, chelating chamber to eliminate heavy metals, and aggregation chamber to separate sludge and purified water.
5. Discharge of treated wastewater: In our testing, the Cd concentration in the treated wastewater was below the Japanese environmental quality standard (0.003 mg Cd/L), proving that this technology is effective for the on-site treatment of soil, which could be directly discharged to agricultural canal.
6. Water washing: After the sedimentation and drainage, agricultural water was sent to the paddy field and mixed with soil to washes the soil-Cd and residual Cl out into the paddy water which was sent to the treatment system.

Figure 2. On-site process of soil flushing

1. Application of washing chemicals
2. Mixing (Extraction of Cd)
3. Sedimentation and drainage
4. Treatment of wastewater
5. Discharge of treated wastewater
6. Water washing

Figure 3. Niigata – On-site soil washing

Cropping trials showed that soil washing adversely affected some measures of soil fertility; for example, it greatly reduced the content of exchangeable calcium and exchangeable magnesium, increased the electric conductivity and reduced the pH, but these soil properties are all correctable. Washing only slightly decreased the contents of carbon and nitrogen. The dry weight of the above-ground parts and the grain yield of rice grown in the washed fields tended to be nearly the same as or even greater than those of rice grown in unwashed fields. Thus, the soil washing method did not compromise soil fertility or rice yields.

Extraction of washed soil with 0.1 M HCl revealed that the Cd content was 60% to 80% of that in unwashed soil. In addition, the Cd concentration of the brown rice was reduced by 70% to 90%. These data confirm the efficacy of ferric chloride as a soil washing agent.

Future prospects

Washing paddy soil with ferric chloride removed a large amount of Cd from the soil and lowered the Cd content of rice grown in the washed soil. The developed washing method has a large cost advantage over conventional remediation method, soil dressing. At NIAES, we have identified rice cultivars that take up little Cd, and other cultivars that take up high amounts and that may be suitable for use in phytoremediation. The alleviation of risks due to Cd in agro-ecosystems must rely on the development of a variety of methods.

Soil contamination in Bangladesh

S.M. Imamul Huq, Bangladesh–Australia Centre for Environmental Research, SWED, Dhaka University

A range of contamination issues present serious problems for Bangladesh's rice-dependent population.

Except for forest, there are no regulations on the use of land in Bangladesh – the world's eighth most populous country. Pressure on land has risen in recent decades, with a population of now over 160 million and agriculture and cities growing fast.

About 1% of the arable land in Bangladesh is lost every year to urbanisation and commercial activity in both the public and private sector. Using good agricultural land for brickfields is a vivid example.

Brick kilns are an important agent in the degradation of topsoil. Brick ovens destroy organic matter and 90% of microbial biomass carbon, and affect the balance of nitrogen, phosphorus, potassium and sulphur in the soil.

Industrial pollution is a growing environmental concern. The country still has a relatively small industrial sector, including manufacturing, construction, mining and utilities, contributing about 20% of GDP. More effort is also being made to stimulate local industries, now growing constantly, but appropriate waste management remains largely a dream.

Bangladesh has more than 30,000 distinct industrial units, large and small. They discharge mostly untreated waste and pollute the environment with heavy metals and organic toxins. Hazardous wastes and effluents are spewed into low-lying areas near their source. The toxic heavy metals discharged from industries in Bangladesh include cadmium, lead, chromium, zinc, arsenic (As), copper and manganese. Mercury has also been detected in some areas.

Industries such as tanning, paper and pulp, textiles, carbides, pharmaceuticals, pesticides and distilleries discharge heavy metals, which can find their way into crops from contaminated soils. Peri-urban areas and land alongside highways are contaminated with heavy metals from vehicle emissions, pesticides, herbicides, fertilisers, sewage and faulty irrigation. Improper disposal of city and municipal waste has also degraded agricultural lands.

Geogenic As from groundwater is considered the single most important contaminant of Bangladesh soils. Accumulation of As on the surface also occurs through the capillary rise of water during drought. Although the average concentration is less than 10 mg/kg, figures as high as 80 mg/kg have been obtained from regions where groundwater irrigation is practiced. The annual build-up through irrigation in soil is put at 5.5 kg/ha.

A vast area of the Ganges-Meghna-Brahmaputra catchment has emerged as the single largest As-contaminated region in the world, with 85% of the groundwater extracted used for irrigation.

About 40% of the country's cultivable area is under irrigation, and 60% of the total irrigation need is met by groundwater. The major recipient of the irrigation water is boro rice (irrigated crops grown in the drier winter months), wheat and some vegetables. There are indications of a slow build-up of As in many areas, with soil further degraded by human intervention. This is exacerbated when As-laden filter sludge (the product of filtering contaminated groundwater) is disposed of on agricultural land. As, iron and aluminium then show up in crops that grow on this land, and ultimately make their way into the food chain where they can cause serious problems such as arsenicosis, diarrhoea and other complications of malnutrition.

Metal uptake and health risks of rice in Taiwan

Horng-Yu Guo, Taiwan Agricultural Research Institute, and Zueng-Sang Chen, National Taiwan University

Trials in Taiwan show how rice varieties differ widely in their ability to take up heavy metals such as cadmium and deliver them into the food chain – but what are the risks to consumers?

An understanding of the differences among rice varieties is clearly important for rice producers and safe food. However, in soils with heavy loads of other metals, such as zinc (Zn), copper (Cu), chromium (Cr) and nickel (Ni), rice varieties also tend to observe a plateau effect in which a maximum uptake of these metals is reached regardless of their levels. While there are no regulations for Cu, Zn, Cr and Ni levels in Taiwan, this study concludes that brown rice grown in soils with even quite elevated levels of these four metals poses almost no health risk.

Even though consumption of wheat products has increased in recent years, rice still dominates the daily intake of cereals in Asian countries. Half of arable land is used for rice-growing in Taiwan. Two rice varieties including Indica and Japonica species are cultivated, but the latter is the major one (90%) because of taste preferences. Cropping lands were contaminated by heavy metals in water discharged from industrial parks.. According to the Soil and Groundwater Pollution Remediation Act (SAGPRA), announced in 2000 by the Taiwan Environmental Protection Administration (Taiwan EPA), cropping land with total soil cadmium (Cd) concentration exceeding 5 mg/kg will be declared a Pollution Control Site and no farming activities will be allowed. However, field surveys in previous years have showed that Cd-contaminated rice can still be produced from fields with total soil Cd levels lower than 5 mg/kg.

Cd pollution in rice is the major source of dietary intake of toxic Cd in Taiwan. The Standard for the Tolerance of Cd in rice was revised to 0.4 mg/kg in 2007, and numerous studies have been subsidised by government to assess the food safety of rice cultivated in Cd-contaminated soil. In 2007, approximate 400 ha of rural soils in Taiwan were contaminated with single or combined heavy metals (copper, zinc, chrome and nickel) and they are fallow according to SAGPRA of Taiwan. These contaminated sites were restored with turnover/dilution and acid washing methods to reduce the concentration of heavy metal to conform to new regulation level.

Field studies of 12 rice varieties grown in different contaminated soils

During 2005 to 2010, field studies were conducted in Taiwan to investigate the uptake characteristics of 12 rice varieties growing in 19 different paddy fields contaminated with cadmium (Cd) or combined heavy metals (copper, zinc, chrome and nickel) (photo 1). Twelve rice cultivars of Indica or Japonica varieties were planted in each field with 5-9 replicates for each cultivar, depending on field size. Samples of topsoil (0-25 cm) and rice plants at full maturity were collected together at the same location in May (harvest 1) and November (harvest 2) each year. The total number of soil and rice plant samples in this study were approximately 2300 and 3200 respectively. The total soil cadmium concentration ranged from 0.06 mg/kg to as high as 27.8 mg/kg, almost six-fold higher than the Soil Pollution Control Standards (5 mg/kg) enacted in Taiwan.

Cadmium concentration of brown rice in different varieties

Soil pH, CEC, and soil organic matter varied widely in the 19 paddy fields. Cd concentrations in rice grains were quite different among cultivars even though they were planted in soils with comparable soil properties and total soil Cd levels. Overall, median Cd concentrations in rice grains of Indica variety were

Photo 1. Field studies were conducted in Taiwan to investigate the uptake characteristics of 12 rice varieties grown in 19 different paddy fields contaminated with cadmium (Cd) or combined heavy metals (copper, zinc, chrome and nickel).

almost 2-3 times higher than that of Japonica variety no matter whether the rice was planted in low or high Cd-contaminated fields or in different climates (Fig. 1).

- Higher variation was found in the concentration of Cd in Indica brown rice compared with that in Japonica brown rice. The majority of brown rice harvested from seriously Cd-contaminated fields was not safe for consumers.
- Results indicated that Cd accumulation in brown rice of three Indica varieties was 2-3 times higher than that of nine Japonica varieties. Clearly the uptake potential of different rice varieties is important for selecting rice cultivars with low Cd-accumulating ability in brown rice grown in slightly Cd-contaminated soil.
- Total Cd concentration in soil is not a reliable index to determine whether rice grain is safe for consumers. Rice varieties and different soil characteristics are important factors affecting Cd concentration in rice grain.
- To determine whether a rice-growing field can produce safe brown rice with acceptable Cd levels, Taiwan EPA has developed a simple and reliable soil-testing model to predict the Cd concentration of brown rice grown in Cd-contaminated soils.

Arsenic (As) uptake characteristics of brown rice

In 2007, 13 topsoil (0-15 cm) and rice (*Oryza sativa L.*) samples were collected together from 13 paddy fields with various levels of soil total As, ranging from 12 to 535 mg/kg. Two Japonica rice cultivars were planted in these As-contaminated sites. Although total soil As concentrations varied widely from 100 to 535 mg/kg (photo 2), As concentrations in brown rice were all in the range 0.1 to 0.35 mg/kg (dry weight basis). It was felt that there wasno risk to rice growth or to human health because the soils have high amounts of amorphous materials that capture As from the soil and reduce its uptake (Fig. 2).

Current standards for heavy metals in brown rice in Taiwan still do not include As. According to the statutory limits on As concentration in cereals or food crops in different countries, the rice harvested from the As-contaminated soils in Guandu Plain was still safe for consumers.

Other key issues are:

- The global normal range of As concentration in brown rice is 0.08-0.20 mg/kg, according to a data set (n = 411) derived from various countries.

Figure 1. The relationship between $CaCl_2$ extractable Cd concentration in soil and Cd concentration in brown rice (• Japonica species, ◦ Indica species) harvested in Taiwan.

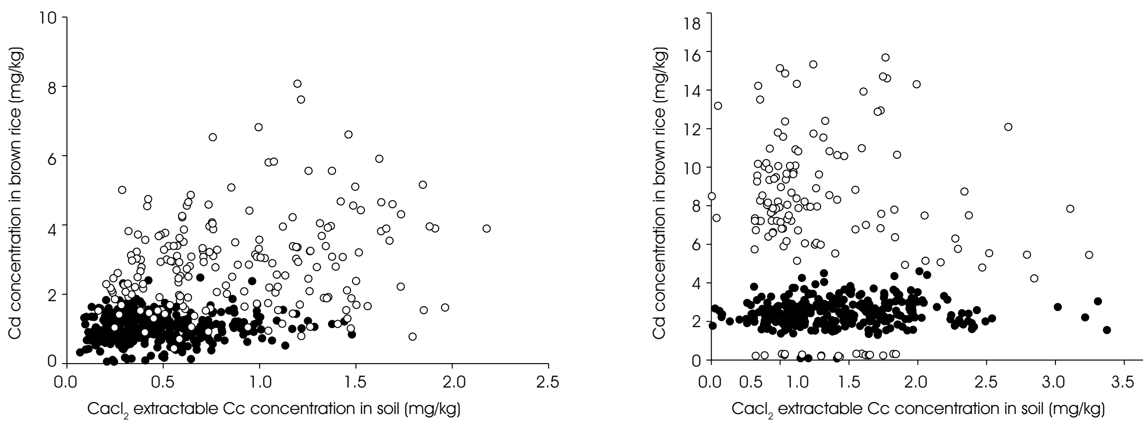

Photo 2.

The As levels of rice produced in Asia were significantly lower than that from US or EU. The As concentration in the majority of rice samples from Asia were lower than 0.2 mg/kg.

- The As levels of brown rice grown in Guandu Plain located at Taipei, Taiwan, were higher than the suggested global normal range even though they did not exceed the statutory limits (0.5 or 1.0 mg/kg). However, a pot experiment conducted in Taiwan also showed that As concentrations of brown rice ranged from 0.1 to 0.4 mg/kg, even when the rice was cultivated in soils not seriously contaminated by As (soil total As is < 25 mg/kg).
- Recognising that rice samples collected from many countries may not be representative of major rice consumption in those countries, it was decided to conduct a comprehensive survey for As concentrations in different rice cultivars produced in Taiwan to estimate the normal levels of As in rice (0.1-0.2 mg/kg).

Copper and zinc concentration in brown rice

- Copper (Cu) concentration in brown rice ranged from 2 to 14 mg/kg, although the soil total concentrations of Cu-contaminated soils ranged from 10 to 500 mg/kg.
- The relationship between Cu content of brown rice and different soil extraction Cu concentration (n= 2256) observes the 'plateau theory', which means the Cu content of brown rice is always at 2-10 mg/kg under any soil total Cu concentration (Fig. 3). This result indicated that there is almost the same Cu concentration (only 4 mg/kg difference) in brown rice grown at very high Cu-contaminated soils ranging from 300 to 500 mg/kg (total Cu content).
- Zinc (Zn) concentration in brown rice ranged mostly from 10 to 50 mg/kg although extractable concentrations of Zn-contaminated soils ranged from 100 to 500 mg/kg.
- The relationship between Zn content in brown rice and different soil extraction Zn concentration (n= 2259) also observe the 'plateau theory' – thus the Zn concentration of brown rice ranged mostly from 10 to 40 mg/kg although the different total soil Zn concentration ranged from 100 to 600 mg/kg (Fig. 4). This result indicated that there is almost the same Zn concentration (only 5 mg/kg difference) in brown rice grown at very high Zn-contaminated soils ranging from 600 to 1000 mg/kg (total Zn content).

Chromium and nickel concentration in brown rice

The background concentrations of Cr and Ni generally range from 20 to 50 mg/kg and from 15 to 70 mg/kg respectively in the surface soils of rural lands in Taiwan. Twelve rice varieties were grown in Cr- and Ni-contaminated soils of 8 regions in Taiwan in 2005-10. However, high background levels of Cr and Ni in the rural soils derived from serpentine parent materials

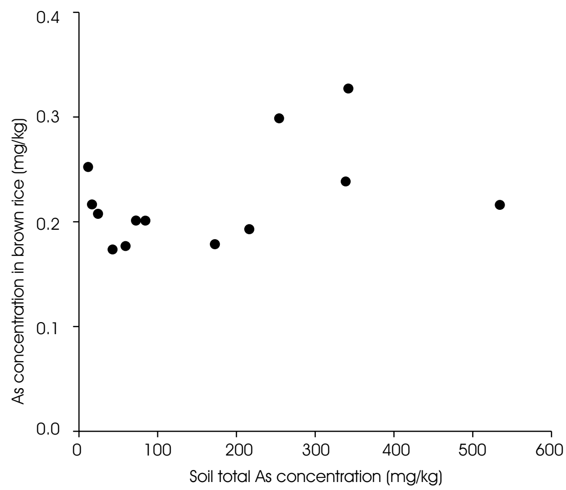

Figure 2. The relationship between As concentration in soil and in brown rice collected together from 13 paddy fields in Guandu Plain, north Taiwan.

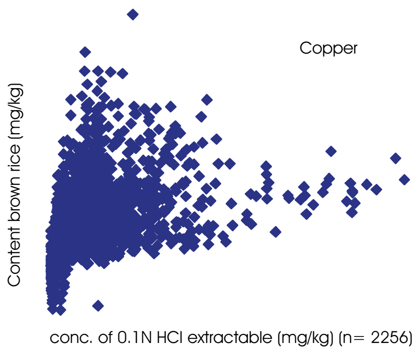

Figure 3. The relationship between copper concentration in different soils and brown rice collected from 12 rice varieties grown in copper-contaminated soils in Taiwan.

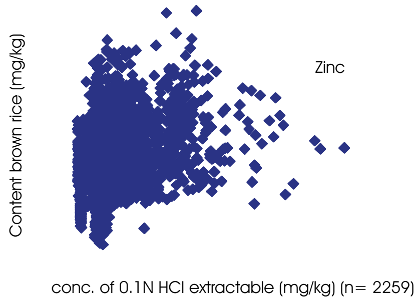

Figure 4. The relationship between zinc concentration in different soils and brown rice collected from 12 rice varieties grown in zinc-contaminated soils in Taiwan.

corresponding to paddy rice were also investigated in 2010-13 in Eastern Taiwan. In non-serpentine derived soils with normal background concentrations of Cr and Ni, total Cr and Ni contents are lower than 50 mg/kg, and the Cr and Ni concentrations in brown rice commonly ranged up 0.5 mg Cr/kg and 6.0 mg Ni/kg respectively. In this study, the results indicated that no difference was found between Cr and Ni (Cr ND-0.8 mg/kg and Ni ND-8 mg/kg) in brown rice grown at very high Cr- or Ni-contaminated soils ranging from 200 to 500 mg/kg (brown rice sample numbers, n= 2300).

The Cr concentration in brown rice samples was lower than 1.5 mg/kg, collected from serpentine soil with total Cr concentration ranging from 200 to 1000 mg/kg. The Ni concentration in brown rice samples was lower than 4.5 mg/kg, collected from serpentine soil with total Ni concentration ranging from 100 to 2000 mg/kg (n=67). Regardless of the Cr and Ni source in the soils, the field studies indicated that there are no differences in Cr and Ni levels in brown rice collected from anthropogenic- or geogenic-derived soils. The relationship between Cr and Ni levels in brown rice and soil total concentration of Cr or Ni also observe the 'plateau theory' (n=2300).

Health risk assessment

In Taiwan, the average total intake of brown rice is 150-180 grams per person per day. The regulation of food standards of metals are Cd 0.4 mg/kg, Hg 0.05 mg/kg and Pb 0.2 mg/kg in brown rice. There are no regulations for Cu, Zn, Cr and Ni in Taiwan. The Cr and Ni concentrations in brown rice in this study were in the range of edible crops and food stuffs found aroundthe world. The upper intake level calculated for Cr and Ni in brown rice are at an acceptable value. We concluded that the total intake of Cu, Zn, Cr or Ni in brown rice, even grown at highsoil concentrations of Cu, Cr, Ni (< 600 mg/kg), and Zn (<900 mg/kg), can be considered safe and carry almost no health risk (less than 10^{-6}).

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Cadmium contamination in Thailand – and a court victory

Tanapon Phenrat, Naresuan University, and Ashijya Otwong, ENLAWTHAI Foundation

Cadmium contaminates the soil, accumulates in crops, leaks into the human food chain, and can cause a range of debilitating or fatal diseases. It was a threat to Thai rice cultivation for a decade or more.

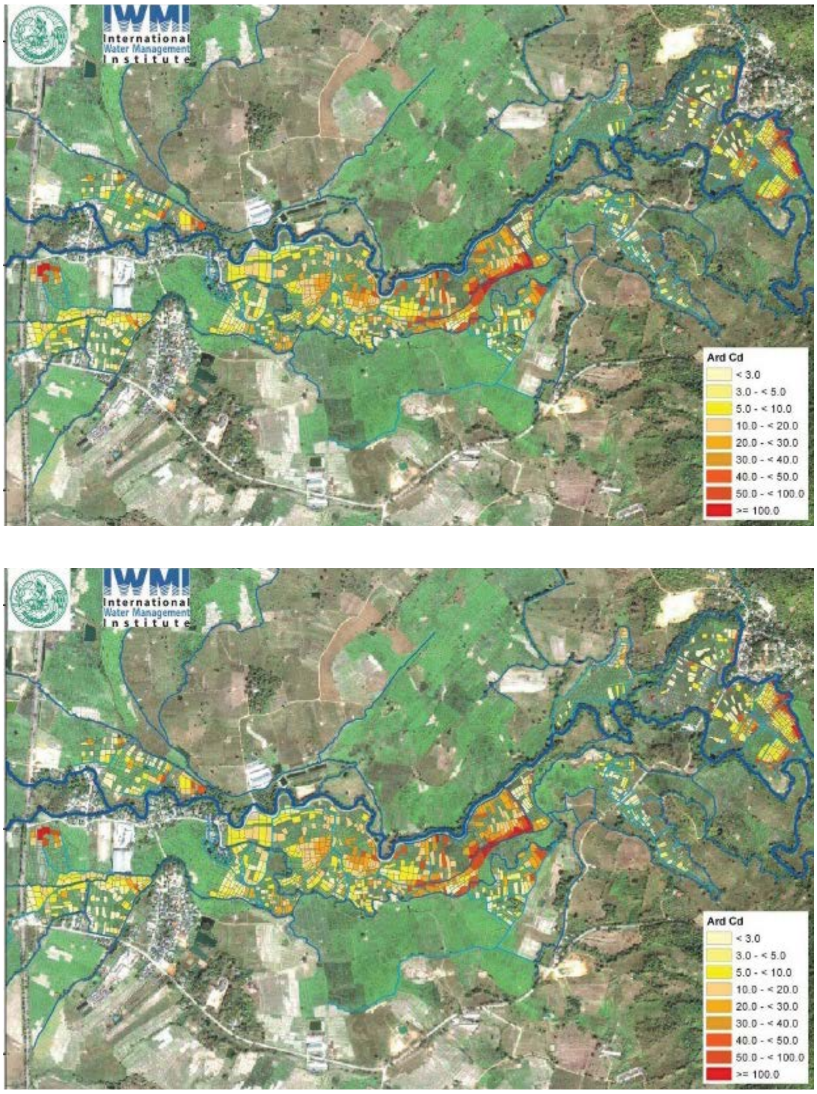

Figure 1a and 1b: Cadmium concentration in (a) paddy fields and (b) rice grain along Tao River in Mae Sot.

The impact of mining

The Pha Daeng ('red cliff') area of Mae Sot district in Tak province, near the border with Myanmar, contains the largest zinc deposit in Thailand, and of the highest quality anywhere in Asia. Zinc mining dates back to 1969, and the Thai Zinc Company extracted a total of around 230,000 tons between then and 1982. Then the Pha Daeng company started zinc mining and had produced a total of more than 7 million tons of ore up to 2012. Another zinc mining operator was the Tak Mining company, which started around 1985 and ended operations in 2003. Neither environmental nor health impact assessment was mandatory before 1992.

In addition to being a rich deposit of zinc ore, Mae Sot district is also home to Karen hill people (mostly of the Papakayo tribe) who live by rice cultivation. One area, Mae Tao, used to produce up to 14,000 tons of rice per year. Mae Sot jasmine rice came second in the national rice competition in 2002, but the following year the International Water Management Institute (IWMI) reported cadmium contamination of fields and crops in three sub-districts.

The paddies with the highest levels of cadmium concentration were irrigated by the Tao river that flowed through the zinc mining areas (Fig. 1), and along with other anthropogenic causes such as phosphate fertilizer, zinc mining is considered to be the major cause of contamination in the area.

Cadmium exists harmlessly in nature with zinc sulfide, zinc silicate or zinc carbonate. But once extracted by mining the zinc 'mineral lattice' – its molecular structure – becomes unstable and can leak cadmium, especially, according to one study, when the ratio of zinc to cadmium in zinc sulfide falls below 20.

Because of the absence of monitoring in the past, no one can be sure which mine was responsible for the Thai contamination. Studies have shown the total area of Mae Sot where cadmium contamination exceeds the maximum permitted by European Union regulations at more than 76,000 rai (1 rai equals 6.5 hectares). And estimated cadmium contamination rises with time because, presumably, of migration.

Contamination and villagers' rice culture

The level of cadmium concentration in paddy fields was as high as 338 mg/kg according to one study – more than a hundred times greater than allowed by the EU. About half the cadmium is 'exchangeable', making it easy for rice to absorb.

The corresponding concentration of cadmium in rice was 7.75 mg/kg, according to this study, nearly 40 times greater than the amount allowed by the Thai authorities of 0.2 mg/kg. Since Thailand is an international leader in the production and export of rice, this had serious implications.

The Thai government decided to burn all the rice produced from contaminated paddy fields in Mae Sot, compensating farmers appropriately – a policy followed from 2004 to 2006 and costing US$14 million. It also prohibited cultivation on contaminated lands and promoted the cultivation of sugarcane for ethanol, reducing the risk of cadmium getting into the food chain.

But in time villagers returned to cultivating rice for local consumption after finding that sugarcane did not suit their land or their way of life. They also consumed various vegetables grown in contaminated ground. Fig. 2a illustrates cadmium contamination of various types of vegetable, using the Codex Alimentarius threshold of acceptability.

Fig. 2b shows a 'hazard quotient' of non-carcinogenic risk from cadmium due to food consumption as high as 14.32 for male, while consumption of contaminated rice accounts for more than 90% of the total risk. As of 2009, an estimated 12.5% of villagers showed cadmium concentration in their urine greater than normal, while 33.2% were judged to be at risk of kidney disease.

The villagers, however, believed they had no choice but to eat this rice and vegetables despite the risks, since their lifestyle and culture are closely associated with rice. Thus soil restoration is vital for their future well-being.

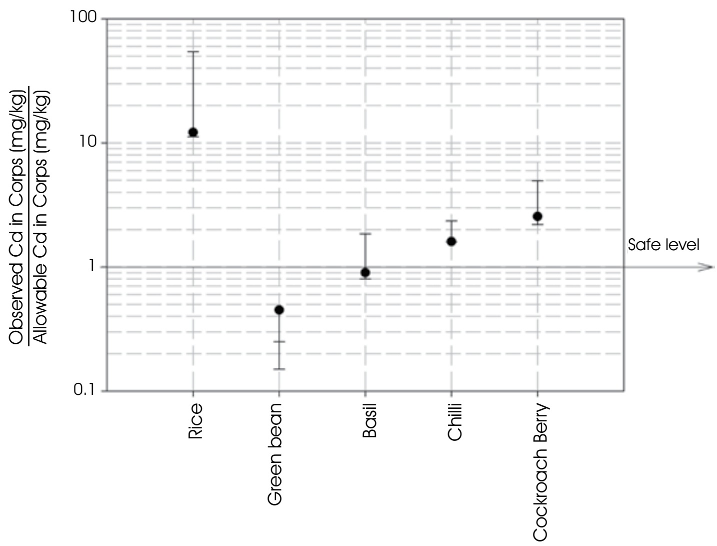

Figure 2a. Cadmium contamination of various types of vegetable, using the Codex Alimentarius threshold of acceptability.

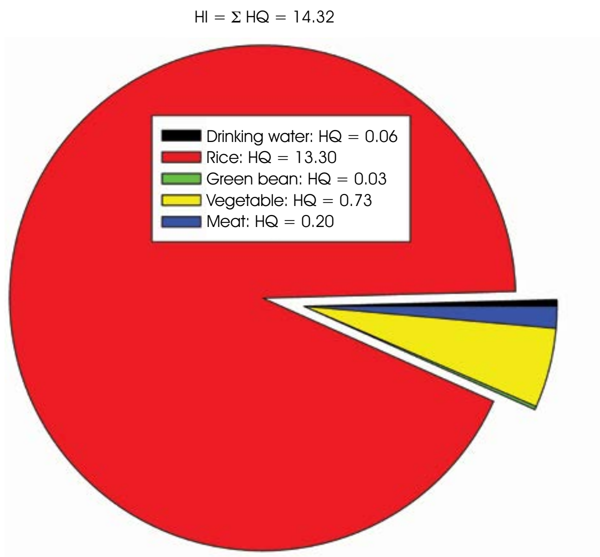

Figure 2b. 'Hazard quotient' (HQ) of non-carcinogenic risk from cadmium due to food consumption.

A court order and future restoration

Even though Thai environmental regulations clearly designate government agencies responsible for restoration of contaminated sites – unlike other countries including the US, for example – they specify neither a clear operational protocol nor funding for remedial work.

Because of this lack of clarity, cadmium has jeopardized the quality of life of Mae Sot villagers for more than 10 years. After many fruitless protests, the villagers decided to sue to the National Environmental Broad for negligence, asking it to declare the area protected under the 1992 Environment Quality Promotion and Protection Act, which stipulates that contaminated areas are automatically rehabilitated.

After a four-year legal battle, the court ordered the relevant government agencies to do this, and also instructed the government to apply restoration and mitigation measures under Article 44 of the 1992 Act – a verdict that gave the villagers new hope.

Now the government is cooperating with the villagers, as well as researchers, lawyers, and NGOs, to delineate the protected area. Stakeholders believe this is the first essential step to trigger remediation. Villagers hope once again to be able to live in harmony amid traditional rice culture, their constitutional rights successfully protected.

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30
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October

18–21
8th International Workshop on Contaminant Bioavailability in the Terrestrial Environment

http://hjxy.nju.edu.cn/bte/
Nanjing University/Nanjing, China

19–23
Advanced Master Class in Groundwater

www.srit.com.au/course_details.php?id=51
Sustainable Resources Industry Training Pty Ltd/Brisbane

December

1–4
Soil and Groundwater Pollution and Remediation Workshop

Sustainable Resources Industry Training Pty Ltd / Melbourne
www.srit.com.au/course_details.php?id=106

2–4
Introduction to Coal Seam Gas, Mining and Groundwater

Sustainable Resources Industry Training Pty Ltd/Melbourne
www.srit.com.au/course_details.php?id=120

Various from May to November

Contaminated Site Assessment, Remediation and Management (CSARM) short courses series

University of Technology, Sydney/Sydney

www.uts.edu.au/future-students/science/go-further/short-courses/csarm

Site Contamination Practitioners Australia certification deadlines

- Round 4: closes 30 September 2015 for certification from January 2016 to June 2016.
- Round 5: closes 31December 2015 for certification from July 2016 to June 2017

http://scpaustralia.com.au

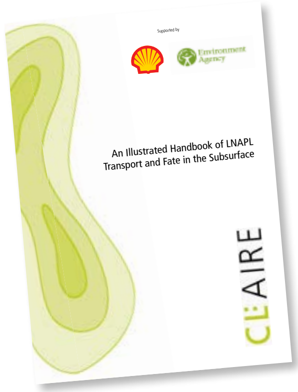
PUBLICATIONS UPDATE

This section contains publications that have been published since the last edition of *Remediation Australasia*. The publications may originate from research institutions, regulators or industry groups. Let us know if you have any appropriate publications (no promotional material) for inclusion by emailing **dee.halil@crccare.com**

CRC CARE 2014, Flux-based criteria for management of groundwater, CRC CARE Technical Report no. 31

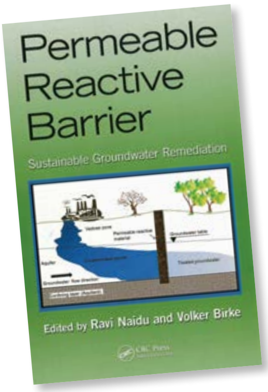
CRC CARE 2014, Development of guidance for contaminants of emerging concern, CRC CARE Technical Report no. 32

CRC CARE 2015, A practitioner's guide for the analysis, management and remediation of LNAPL, CRC CARE Technical Report no. 34



CL:AIRE, 2014, An illustrated handbook of LNAPL transport and fate in the subsurface. Download at www.claire.co.uk/LNAPL

CRC CARE 2014, Environmental impact of priority contaminants: A literature review, CRC CARE Technical Report no. 29



Naidu, N & Birke, V (Eds) 2014, Permeable Reactive Barrier: Sustainable Groundwater Remediation, CRC Press

CRC CARE Technical Reports are available for free download at www.crccare.com/publications/technical-reports

Thanks to the mysterious Mike O'Rhiza for this contribution to the burgeoning field of remediation poetry. Reader contributions welcome!

Remediate!

Tiny little bug life munching through the dirt
Calmly turning filth to soil as product of their work
Soil and filth are not the same despite what some may think
For soil is life supporting; is precious and should not stink.
Yet stinking soil is often found, sadly though I say
The problem is the nasty things that people use each day

On landfill sites there's seepage. On mining sites there's lead.
There's water and air pollution. And it all ends up widespread
Add to this the pesticides, the herbicides as well.
Biocides and slimicides... All things that people sell
There's metal and there's rubber; and plastics all displaced
All breaking down around us to make a lot of waste
Mountains of muck and nastiness left in the beat-up soil
We really are so lucky that these tiny bugs do toil

A very simple life form. A single cell in fact.
These tiny wee bacteria have a very big impact
Remediate! Remediate! That is our war cry
They may not really know it, but heroes they will die
For into the troubled soil they release their newborn cells
Splitting. Yes, with gusto. And removing the nasty smells
They'll take a complex molecule and chew bits off, they will
Leaving it less toxic. At least we hope they will

So may I please remind you that soil is not just dirt
Be careful how you treat it, and be mindful of its worth
For the bugs can surely help us with their appetites so strange
But we should not be complacent lest we those wee bugs estrange
And even happy bugs can't help us, with all our muck and goo
For they cannot eat the metals. No wonder though, would you?

Mike O'Rhiza