

Issue 15 2013

Remediation Australasia



REVIEW

Contaminants of
emerging concern



SIZE MATTERS

Asbestos case study



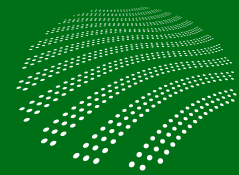
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Welcome to Issue 15 of *Remediation Australasia*.

It's hard to believe that 2013 is almost over (in fact it might be finished already by the time you read this). It has been a huge year for us here at CRC CARE. As we move into the third year of our second term of funding, our research projects are gathering momentum and beginning to yield some excellent results. It was also the year in which the updated National Environment Protection (Assessment of Site Contamination) Measure came into being, and – perhaps most significant of all for me personally – we hosted the 5th International Contaminated Site Remediation Conference (CleanUp 2013).

Many readers would have attended CleanUp 2013, and I hope you agree that it was a resounding success. It was by far the biggest CleanUp yet, with nearly 700 delegates descending on Melbourne to network, share knowledge, and learn about the latest happenings in remediation research and practice. This issue of the magazine includes a roundup of the event along with some photographic highlights. A brief video highlighting the conference is available at www.crccare.com/cleanup-conference/2013/2013.

CleanUp 2013's major sponsor, EPA Victoria, has generously agreed to support the event again in 2015, when the conference will return to Melbourne. I invite readers to let us know which topics they would like to see highlighted in 2015 – please send us your feedback via CRC CARE's website: www.crccare.com/enquiry-form.

The 2013 CARE Award was presented at CleanUp 2013, and I'd like to reiterate my congratulations to the winner, Thiess Services, for its innovative sealed relocatable building, which provided a controlled environment for the remediation of volatile contaminants under a Sydney car park. You can read more about the project in this issue.

Issue 15 also takes a look at risk-based remediation decision making in developing countries, and includes case studies on a small-scale asbestos clean-up project and the use of biosolids for mine drainage remediation. The magazine includes an illuminating literature review of gaps in analytical methodology related to contaminants of emerging concern, and asks how to improve risk assessments by considering source concentrations.

I hope that the year has been an excellent one for you, and that 2014 promises even better things to come. As Australia settles into its first year under a new government, it will be fascinating to see how the landscape unfolds for the remediation industry nationally.

From everyone on the CRC CARE team, I offer you a happy and safe festive season and look forward to an even better Remediation Australia next year.

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

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Acid tar sludge in Africa
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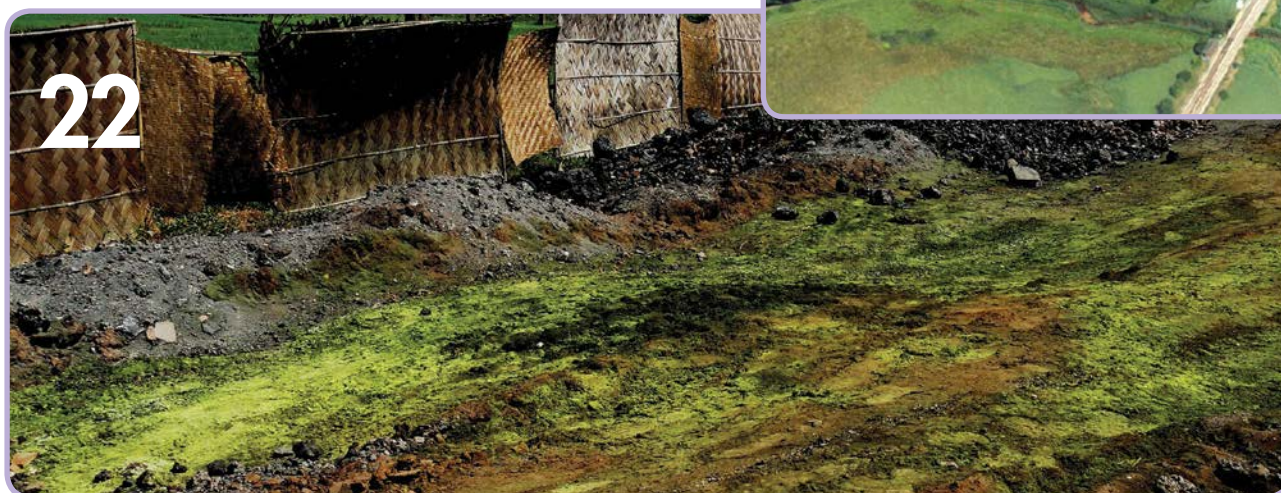
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Your guide to environmental contamination and remediation issues in the media

Indooroopilly's lead legacy

A retired lead and silver mine in Indooroopilly has recorded lead levels in surrounding sites at up to 10 times the industry safety level, reports the *Brisbane Times* (bit.ly/1bT6xoq). The mine is now owned by the University of Queensland, which previously used the site for training and research. The site is now under consideration with the Department of Environment and Heritage Protection in Queensland, whose recommendations could include evacuating the site and covering it with bitumen. ■



Singing a song of PCB contamination

A recent study published in the journal *PLoS ONE* has shown that polychlorinated biphenyl (PCB) contamination can change the song of two bird species living in PCB-contaminated sites, with implications for communication among birds and therefore the survival of the species. Black-capped chickadees and song sparrows were captured in the areas surrounding the PCB-contaminated Hudson River in New York State, USA. The birds then had their blood PCB levels measured and their distinctive songs recorded. The results sung a song of the dangers of non-lethal doses of PCB contamination, with the well-recognised birdsongs changing in a variety of ways. Read the full report at bit.ly/16HuhYl. ■



Acidic stop to BHP mine sale

Sale of the Mount Goldsworthy iron ore mine in Western Australia may be halted due to potential acid contamination reports *Australian Mining* (bit.ly/1M2xcC). The mine, currently owned by BHP Billiton, was earmarked for sale to Nimbus Mines. The potential acid forming substances found at the mine would need to be remediated to below the water table level – at an estimated cost of up to \$100 million. ■



Illegal e-waste headed for China

Despite a ban on importation, an estimated 70% of the world's electronic waste (e-waste) is still headed for China reports *BEN Waste* (bit.ly/1kgFXVf; subscription only). The waste, much of which originates in Canada, Japan, Europe and the US, is smuggled in under the guise of second-hand goods. The value of e-waste stems from the desire for the valuable materials it contains, including copper and gold. It can also contain potentially harmful substances, such as lead and mercury. ■



Air pollution woes for asthma sufferers

A study from the University of Melbourne has shown that asthma sufferers should steer clear of air pollution. The study, which was published in *Respirology* journal, looked at exposure to wood-fire smoke and traffic pollution, reports *Science Alert* (bit.ly/1bkkllA). Researchers found a link between pollution exposure frequency and asthma symptoms and episodes. Traffic pollution was

found to increase the symptoms in 80% of participants, with likely mechanisms for this being increased airway inflammation in response to heavy exhaust particles. The authors of the study have recommended that, because of this link, asthmatics should try to avoid living near busy roads. The findings have particular relevance for people living in developing countries where wood-fires remain a major source of energy for cooking and heating. ■



Bushfire clean up an asbestos risk

As Australia moves into bushfire season, Australians are being told to stay away from their fire-damaged homes to prevent asbestos exposure, reports ABC News. Former Rural Fire Service Commissioner Phil Koperberg, who now advises the NSW Government on emergency response strategies, said that the government will be advising the public that they may now be in a potentially contaminated site (ab.co/1cEhR4K). With 90% of homes containing asbestos, the Department of Health, Environment Protection Authority (EPA), and Department of Public Works will be making recommendations for short-term remedial action. ■





Delegates explore the trade exhibition the Crown Convention Centre in Melbourne.



Dr Vivian Balakrishnan, Singapore Minister for the Environment and Water Resources, presents the commemorative Brian Robinson lecture.

CleanUp 2013

With a move to the Crown Conference Centre in Melbourne, the 5th International Contaminated Site Remediation Conference (CleanUp 2013) was the biggest and best yet, hosting over 650 delegates, 230 oral presentations, 100 posters and 9 workshops.



EPA Victoria Chair Cheryl Batagol officially opens CleanUp 2013.



An enthralled audience at one of CleanUp's many technical sessions.



A poster Q&A session

Officially opened in front of a full house on Sunday 15 September, the first order of business included speeches from CRC CARE Managing Director Ravi Naidu and Cheryl Batagol, Chair of EPA Victoria, the event's major sponsor. Both spoke of the immediate dangers of the 80 million tonnes of chemicals being produced every year.

This was followed by the Brian Robinson Commemorative Lecture, presented by Vivian Balakrishnan, Singapore Minister for the Environment and Water Resources. Dr Balakrishnan presented the inspiring results of two remediation projects in Singapore, focusing on the challenges inherent in a country with limited natural resources.

All three days saw programs packed with presentations and posters from leaders in the field. On Tuesday night, the gala dinner included the presentation of the 2013 CARE Award and a speech from Matthew Sutton, AECOM Chief Executive of Environmental Business, with entertainment provided by magician Tim Ellis.

The main body of the conference program culminated on Wednesday, with the launch of the Global Contamination Initiative. This constituted the first step in a much-needed collaborative approach to regulating, preventing and remediating chemical contamination throughout the world.

CleanUp 2013 also attracted plenty of media attention with well over 150 stories being run as a result of work being presented at the conference. This included articles in Australian and international newspapers, and stories on radio and television – including an appearance on ABC's national TV news by Prof. Naidu.

EPA Victoria has generously committed their support to the next CleanUp, which will be held at the same venue on 13–17 September 2015. Delegates past and future are welcome to provide feedback and suggestions via the CRC CARE website at www.crccare.com/enquiry-form.



Realistic risk assessment: the issue of transient source concentration

Renato Baciocchi, Laboratory of Environmental Engineering, University of Rome Tor Vergata, Italy.



Standard assumptions used in contamination risk assessments often result in conservative estimates of both risk and clean-up goals – how do we relax some of these assumptions to improve the accuracy of risk assessments?

The management of contaminated sites in most countries is based on the results of human health risk assessments – often performed following risk-based corrective action standard of the American Society for Testing and Materials (ASTM-RBCA).¹ This standard relies upon a description of the fate and transport of contaminants, which is established using a set of simplifying assumptions. These assumptions include: equilibrium partitioning of the contaminants between soil, liquid and gas phase; steady state conditions; no biodegradation; and constant source concentration. However, basing risk assessments on these assumptions may lead to an overestimation of the concentration at the point of exposure and consequently to a conservative estimate of both risk and clean-up goals.

The potential for overestimation of risk could be diminished greatly by developing fate-and-transport models based on assumptions that are less conservative – while still simple enough to be implemented using the ASTM-RBCA procedure.

Steps towards a solution

The recent 5th International Contaminated Site Remediation Conference (CleanUp 2013) provided the perfect platform for industry and research to come together and discuss the options for improving these guidelines. Here I present two solutions proposed at Cleanup 2013 with the aim of relaxing the assumption of constant source concentration to improve the accuracy of risk assessments.

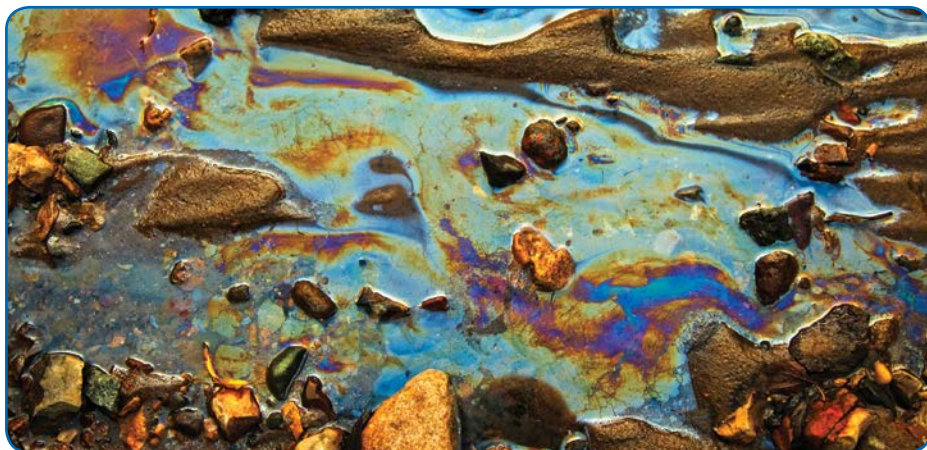
One suggestion is the introduction of source attenuation – specifically

a simplified approach for dissolved groundwater contamination – to the ASTM-RBCA method.^{2,3} This method allows for estimation of the effective exposure duration of contaminants, based on the time needed for complete source depletion, assuming a mass balance model. In this proposal we demonstrated that under proper site-specific conditions – depending upon the hydraulic gradient, the hydraulic conductivity and the soil-water partition coefficient of the contaminant – the effective exposure duration could be considerably lower than the standard value assumed by the ASTM-RBCA standard (e.g. 25 years for industrial receptors).

This result, however, is limited to situations in which the contaminant is completely dissolved in the groundwater in the absence of any separate phase. Although

this is typically the theoretical starting condition assumed for risk assessment application, it is seldom the case at actual contaminated sites, which are often characterised by the presence of non-aqueous phase liquids (NAPLs).

Dealing with source attenuation in the presence of light NAPLs (LNAPLs) was recently addressed by two groups of researchers, who compared results obtained assuming constant source concentration with those attained considering either exponential decay or decay based on a mass-balance approach.^{4,5} Comparison with field groundwater source data collected at a site characterised by the presence of BTEX and MTBE LNAPL validated both methods, with their data able to correctly predict the risk for a 1000-metre downgradient



receptor. The results indicated a two-orders-of magnitude reduction of the risk related to groundwater ingestion, assuming constant source concentration and source attenuation through the mass-balance model.

These results suggest that including the effect of source attenuation in

the risk assessment procedure would help in setting more meaningful and cost-effective clean-up goals. To gain acceptance by regulatory agencies, this approach should be tested under different site conditions before being implemented in risk assessment standards and software.



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Improving risk-based remediation decisions in developing countries

Sophie Wood, Environmental Resources Management (ERM), Sydney, Australia; Chih Huang, ERM, Taipei, Taiwan (R.O.C.); Stephen McKeown, ERM, Cape Town, South Africa; Karin Guiguer, ERM, São Paulo, Brazil; and Suyash Misra, ERM, Mumbai, India.



Improved decision-making processes will reduce the risks of contaminated soil in developing countries.
Photo: Sophie Wood

The challenges surrounding risk-based remediation decisions in Australia and New Zealand – particularly the interaction of regulatory regimes and the decision-making process – are familiar to most remediation specialists. Lack of clarity in (or absence of) guidance documents regarding procedures for remediation decisions and differences in expectations between stakeholders, trips us up on a regular basis. Some other developed countries – such as the UK, the Netherlands and the US – are somewhat better in terms of clarity of process, although protracted negotiations to reach agreement, and regional inconsistencies are still significant issues.

The development of regulatory systems has resulted in extended periods of uncertainty in a number of countries. The UK, for example, lacked clear guidance for about 10 years while the state wrestled with the significant difficulties associated with determining acceptable levels of risk, and generating risk-based generic guideline values. The underlying issue appears to be the conflict between desire for a rigorous scientific basis (uncertainties tending to push the system into increased conservatism) and desire to achieve better sustainability, practicality and improved rates of site clean-up (which argue for lower levels of conservatism). Resourcing and funding the workload was also a big contributor to the delay. The final outcome is clear on process, but somewhat unclear on what constitutes acceptable risk. In contrast, Australia provided good clarity on acceptable risk and produced guideline values in a timely manner; however Australia's system is rather less flexible,





India is establishing a framework for the remediation of legacy polluted sites.
Photo: Sophie Wood

and is unclear on process around remediation decision-making (as opposed to assessment). The result for Australia is a more conservative, less sustainable and probably more expensive system for industry to implement than the UK's.

Although there are difficulties in developing a complex regulatory system, risk-based decision making has become a fundamental part of the contaminated land management process in the majority of nations with well-developed contaminated land legislation. Benefits such as improved sustainability and ability to cost-effectively return brownfield land to productive use strengthen the argument for preventing resource expenditure on unnecessary remediation and focusing on significant risks.

We might expect that countries in the process of developing regulatory systems for contaminated land would be adopting risk-based approaches; learning from the experience of others would better enable us to avoid some of the pitfalls encountered by the early pioneers. This case study illustrates the

approaches and challenges that are developing in Brazil, India, Taiwan and South Africa.

Taiwan

Legislation in Taiwan has permitted the use of risk assessment to determine remedial goals since 2005. Its high-level procedure is very clear: the *Soil and Groundwater Pollution Remediation Act 2000*, (amended 2010) establishes control levels for concentrations of contaminants in soil and groundwater. Previously any site where the control levels were exceeded by a factor of greater than 20 was classified as a statutory remediation site. However, in favour of the risk-based approach, the simple 20-fold factor has recently been replaced by a risk-based screening protocol which calculates a 'threshold score' level based on the site conditions (for example plume size, toxicity factors of the contaminants, exposure pathways, and vicinity land uses). This classification is applied to the land until concentrations are remediated to below the threshold score.

In 2005, a risk assessment guideline was published, permitting the use of quantitative risk assessment to derive risk-based goals for remediation (which are used in place of the threshold score) under restricted conditions: either the proponent needs to demonstrate that remediation is technically impracticable, or the site must be destined for redevelopment. There is a sting in the tail of this approach, with the site remaining on the public register of statutory remediation sites if the risk-based targets are higher than the threshold score. This is a serious obstacle for development sites, since the land is then stigmatised, potentially devalued and therefore harder to sell. So in practice, most developers will choose to remediate to the threshold score levels if it is economically viable.

Taiwan's risk assessment guideline adopts an approach similar to the ASTM risk-based corrective action system, and specifies an increased lifetime cancer risk of 1 in 1 million as an acceptable risk level from exposure to genotoxic carcinogens at a site. Discussions have suggested a possibility of permitting acceptable

risk level up to 1 in 10 thousand if the assessor can provide evidence to justify the outcomes, with the final protocol due to be released by the end of 2014.

For threshold contaminants (essentially everything except genotoxic carcinogens), a hazard index of 1 is specified. Currently, these are US standard, and potentially highly conservative risk levels; the outcome remediation goal is often heavily dependent on the selection of toxicity reference value, for which the Taiwanese guidance recommends six databases to be used.

The guidance also provides acceptable model (default) input values for other variables. The Taiwanese regulator's technical ability to effectively review the risk assessment and negotiate the details is limited by the availability of qualified staff. This leaves significant power in the hands of industry, with most of the negotiating effort expended on whether risk assessment is permitted, rather than on the remedial outcome once that decision is made.

Taiwan's system is effective in a regulatory control sense, and is the clearest system we looked at. However, it sacrifices the much of the potential economic and sustainability benefit of a fully risk-based system by restricting the use of quantitative risk assessment to sites meeting specific criteria. The recent modifications have reduced the level of conservatism, and it appears likely that development in this direction will continue.

South Africa

South Africa's National Environmental Management Waste Act (NEMWA, 2008), which established a risk-based system and national risk-based soil screening values together with supporting guidance, was published in 2013.

The draft framework for site-specific risk assessment has been available since 2010, but could not be applied in practice until it was finalised and officially adopted. Experience with how it will be regulated is therefore limited. During the last 4–5 years, it has been possible to apply a risk-based approach on a case-by-case basis without specifically drawing upon the draft framework, as the approach documented in the framework follows international best practice for risk assessment.

Currently, risk-based remediation is supported by application of international screening values and risk assessment guidance including those from the Netherlands, US, UK and Australia. Goals are normally negotiated, and the outcome position can vary radically between local jurisdictions and over time as high staff turnover results in loss of information and expertise. Excellent benefits for both landowner and environmental protection can be achieved; however there is no guarantee in any given case that this will be possible.

The effectiveness and consistency of South African risk-based remediation is compromised by the inexperience and low technical expertise of the regulators, together with similar problems in many of the smaller local environmental consultancies. Good regulators are regularly poached by large consultancies and industry, which offer higher salaries, driven by the general scarcity of good technical skills, and the affirmative action targets for employment of African staff. Clients can also be prey to unscrupulous consultants recommending unnecessary remediation to increase the consultant's fees. All of these barriers are likely to compromise the new system as it is implemented, although they should begin to reduce in magnitude as the overall level of experience grows. Despite these potential issues, the new system

should improve both clarity and consistency of risk-based remediation decision making.

South Africa's emerging approach has the advantage of a reasonable degree of clarity on the basis of the generic screening values, and the framework for carrying out development of risk-based remedial goals based on modelling. Expectations on the process for risk-based decision making when simple model-derived goals are not achievable remain unclear (for example, existence of free-phase liquids, or technically unfeasible risk-based goals).

Brazil

Brazil is the most developed of our four examples, having had a nationally applicable contaminated site management framework since 2009. This establishes for all Brazilian states soil and groundwater protection policy and generic values (not risk-based) for soil protection. Within the framework, a human health risk assessment constitutes the basis for the development of site specific target levels for soil and groundwater. The site-specific target levels are used as remedial levels, or in the development of risk management measures to be implemented at the site.

However, only São Paulo has developed its own risk assessment procedures, which include a mandatory spreadsheet model, an acceptable risk criterion of 1 in 100,000 for increased lifetime cancer risk, and a threshold hazard index of 1. The spreadsheet model is based on Risk-Based Corrective Action for Petroleum Hydrocarbon Contaminated Sites. The model was developed for four land uses including urban residential, country residential, industrial/commercial and construction. Site specific modification is permitted only to the use of site characteristics (percentage





Acid tar sludge in Africa.
Photo: Sophie Wood



A brick wall showing evidence of chromium VI contamination.
Photo: Sophie Wood

organic carbon in soil and depth to groundwater, for example). Exposure scenarios cannot be modified which limits its utility for site specific assessment.

Outside São Paulo, other approaches can be negotiated, and the outcome is variable dependent on the attitude, experience and technical capability of the regulators. São Paulo, Rio de Janeiro, Minas Gerais and Rio Grande do Sul are generally perceived to be proactive, stringent and enforcement motivated.

Brazil's system has an advantage over many developing countries (and some developed ones), in that the process for deciding on the extent to remediate is reasonably clear. However, it is still challenged with issues of establishing technical and economic feasibility, by the scarcity of technically qualified and experienced risk assessment practitioners, and the large variability in the training and experience of regulators.

India

In terms of contaminated land management regulatory systems, India is the least developed of the four examples. However, India's plans are (somewhat typically) both ambitious and unusual. In line with its strategic plan (2012–17), the Government of India is in the process of implementing a program for managing industrial pollution. The program will establish a framework for the remediation of legacy polluted sites, however it will not necessarily incorporate a national system for risk-based decision making on contaminated land remediation. India doesn't currently have national risk-based guidelines for assessment or remediation, and the practicality and relevance of the international practice of quantitative risk assessment as a decision tool is questioned by many Indian regulators.

As a means of capacity building, India is undertaking a series of demonstration projects funded by the World Bank. ERM is managing one of these, led by West Bengal

state; this project includes a 'best practice' risk assessment which supports a remedial action plan for hexavalent chromium, mercury and polycyclic aromatic hydrocarbons in a variety of site circumstances. Development of Indian-specific exposure scenarios, including human characteristics (such as body weight and eating habits) is included. One potential outcome of this work would be a template for development of national risk-based generic guidelines for India. Whether India wants risk-based guidelines remains to be seen.

On a case-by-case basis, risk-based remediation is often acceptable to Indian regulators provided their confidence in the approach and expertise of the consultant and client team can be established. Regional differences in regulator approach are significant, and most regulators lack the expertise required to review risk assessments effectively. Differences in opinions of individuals within a single regulator are also commonplace. Uncertainty for a landholder on beginning



Chromium contamination is particularly problematic in India.

Photo: Sophie Wood

a negotiation with an Indian regulator is therefore significant. Public awareness of pollution issues is very high, as a consequence of the population density and the daily reality of many people really subsisting from contaminated land and groundwater. High-profile environmental disasters such as Bhopal are also very important in both public and regulator thinking. The potential for a contaminated site to provoke outrage is therefore a very significant factor.

Conclusions

Although their approaches differ significantly, all four countries reviewed here have implemented, or are in the process of implementing, contaminated land management regimes based on similar principles to those of developed nations.

India and Taiwan appear likely to choose clarity and regulatory control over pragmatism and complexity, an approach common among European nations until the realisation by

many that this approach was not economically viable in the long term. As its experience develops, Taiwan may become more pragmatic and consequently feel more comfortable to pursue improved cost effectiveness and sustainability. However, India may avoid the problem entirely by foreseeing the likely path of a complicated, conservative, Western-style risk-based approach (which is likely the only kind that is publically justifiable), and instead adopt a pragmatic hazard reduction approach with the objective of remediating enough of their very serious contamination to realise meaningful public health benefits without getting tied up with arguments about acceptable risk levels. Whether this will prove possible is uncertain.

On the other hand, Brazil and South Africa are following paths to risk-based systems that are substantially similar to the approaches of more developed regimes. Brazil (São Paulo) in particular is well ahead of many more economically developed countries, and experiencing

challenges that are very familiar to the Australian and New Zealand industry. The size of the country and the potential for poor communication between Brazil's regulators, together with very wide economic differences between regions, exacerbates Brazil's issues in comparison with the developed world. South Africa's system closely resembles those of Australia and the UK, but the current ability of the country to implement and regulate it effectively outside the major centres and sites owned by global multinationals is questionable.



Innovative toxic sealoff wins award



Ian Brookman (left) and John Hunt, Thiess Services Ltd., at their exhibition stand at CleanUp 2013.



Ian Brookman receives the CARE Award from Senator Sean Edwards.



The unique sculpted glass trophy presented with the CARE Award.

The 2013 CARE Award recognises a pioneering method of safely sealing off a huge volume of contaminated soil under a Sydney car park while it was cleaned up.

The award went to Thiess Services for its highly innovative design of a sealed relocatable building that provided a controlled environment for the remediation of volatile contaminants left over from the manufacture of dry cleaning fluids and coolants, ensuring the health of workers and the surrounding community.

The project involved excavating and treating 45,000 cubic metres of contaminated soil that was encapsulated in a synthetic liner underneath a car park at the Botany, NSW, site. The soil was contaminated with hexachlorobutadiene as well as low levels of hexachlorobenzene and hexachloroethane – byproducts from historical manufacturing of chlorinated solvents by Orica. The encapsulated waste was treated using thermal desorption technology.

“Thiess first had to develop a solution for enclosing the car park waste encapsulation so that onsite workers and people from the surrounding community would not be exposed to emissions from the contaminated soil during its excavation. The solution was the Excavation Soil Building,” the company’s nomination explained.

This innovative building featured internal walls and pillars that could be progressively moved as excavation and clean-up progressed. The air-

tight seal on the building had to trap any vapours or emissions so that workers on the site and nearby residents would not be exposed.

Thiess was responsible for the building’s concept, functionality, layout, staged excavation concept, ventilation design and airlock design. GWH Build Pty Ltd was subcontracted by Thiess as the structural engineer and installer of the building.

The main innovation was the installation and relocation of the building’s internal walls and columns as the excavation progressed, so as to maintain air volumes compatible with the capacity of the building’s emission control system.

“The design and construction of the Excavation Soil Building has set a new benchmark for the remediation industry,” said CRC CARE Managing Director Professor Ravi Naidu, in presenting the award at the Gala Dinner of CleanUp 2013. “This is a fine example of Australian clean-up technology.”

The CARE Award recognises technologies and innovations in the area of contamination assessment and remediation of the environment, and celebrates the achievements of the winner among the industry sector and peers. The winner received a unique, hand-crafted glass sculpture and a \$10,000 cash prize.

Using biosolids to treat acidic metalliferous mine drainage

Jamie Robinson, Sinclair Knight Merz

It has been more than 30 years since the discovery that naturally occurring bogs, or wetlands, affect the chemistry of mine drainage.



Fig 1. Mine drainage
Photo: SKM

When used to treat mine drainage, such systems are indeed often termed wetlands, as they encourage the biogeochemical reactions observed in natural wetland systems. In reality, however, they are engineered systems designed to optimise the treatment of mine drainage by removing the inefficiencies of natural systems and, in most cases, by adding alkalinity.

Types of system

There are a number of systems that can be used for treating mine drainage, the selection of which is critical. Understanding the load and concentration of the acidity in the mine drainage is key. A 2007 Department of Industry, Tourism and Resources study indicated that drainage that has more than 800 mg/L CaCO_3 acidity and a loading of greater than 150 kg

CaCO_3 per day is unlikely to be suitable for passive treatment systems.¹ However loads greater than this could be treated, if there is sufficient area to accommodate the load. The drainage can undergo passive treatment either aerobically (in the presence of oxygen – e.g. hydroxide precipitation) or anaerobically (in the absence of oxygen – e.g. sulfide precipitation).

Many metals become relatively easy to separate in alkaline conditions. When mine drainage is net alkaline, the treatment options for removal of the metals are relatively simple and some very large systems have been constructed. Such systems (see Figure 2) are capable of treating relatively high flow rates of net alkaline water. In South Wales, UK, the systems in Morlais (170–289 litres per second and up to 53 mg/L Fe) and Taff Merthyr (30 to 122 litres per





Fig 2. Aerobic treatment systems in South Wales. Morlais (5 hectares) and Taff Merthyr (4 hectares) are some of the largest constructed.²

Photo: SKM

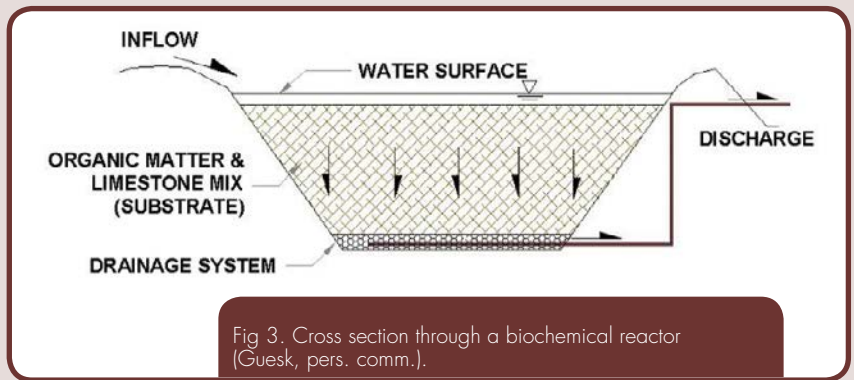
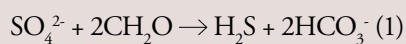


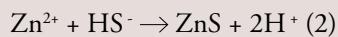
Fig 3. Cross section through a biochemical reactor (Guesk, pers. comm.).

second and 20 mg/L Fe) achieve a 95% treatment rate for elevated iron and flow rates.²

Net acidic drainage treatment requires anaerobic treatability trials and consideration of suitable candidate substrates. The net acidic mine water requires bicarbonate to buffer and prevent the pH of the treated drainage decreasing to the point where the precipitation rate of iron as a hydroxide is too slow. The use of limestone, through anoxic limestone drains, is an economical way to add alkalinity (although, in the case of iron and aluminium, clogging is relatively common). Bacteriological sulfate reduction during anaerobic processes within a wetland can also add alkalinity:



In addition, sulfate reduction and the production of sulfide cause the precipitation of insoluble metal sulfides within the treatment system.



where the additional protons formed by the reaction are neutralised by the alkalinity generated in Equation 2.

Such systems, known as biochemical reactors, comprise vertical or upward flow through an organic substrate that often comprises a combination of cellulose-based material (e.g. sawdust, hay, alfalfa, mulch or wood chips) and organic material (e.g. manure, compost, sewage sludge or peat). In addition, carbonate in the form of limestone can boost alkalinity generation while also minimising clogging. Subsequent low dissolved oxygen, iron, manganese and elevated biochemical oxygen demand can be polished using a downstream aerobic system. A cross section through a biochemical reactor is presented in Figure 3. This shows a downward flow system, although the more successful designs allow flow to be reversed between upward and downward modes.

Tiered design of a passive treatment system

Construction of a system for treating net acidic minewater needs to be staged. Candidate substrates for anaerobic treatment systems

Table 1. Tiered approach for assessing treatment potential using a biochemical reactor

| Test type | Description |
|-----------------|--|
| Static jar test | Often termed proof-of-concept testing, these mix small volumes of candidate substrate with the mine water, which are left to stand for 6–8 weeks. These tests are static and designed to select the candidate material (or blend of materials) that treat the drainage most effectively. Samples are filtered and the treated water analysed. |
| Bench scale | This dynamic test takes the selected substrate or substrates and uses them in a bench-scale permeameter. |
| Pilot scale | The final stage of the assessment includes the construction of a pilot-scale system that allows the flow, loading and outflow results from the bench-scale tests to be verified. The preceding testing enables successful, locally derived candidates to be used as part of the final wetland design and the dynamic tests allow confidence in the sizing of the final system. |

are collected from local sources and tested through a logical and progressive tiered approach. This is described in Table 1 below.

Current study

The SKM Technical and Innovation Panel is currently funding the preliminary stages of identifying and testing organic and inorganic materials that could be used to treat acidic mine drainage. The study is considering use of biosolids as a potentially sustainable treatment system for the mine drainage in the Northern Territory. The research is also investigating the water quality implications of using old shredded tyres as an inert drainage layer in a wetland system.

The project selected acidic drainage from a site and used a variety of organic and inorganic material as static jar tests. The study also considered the availability of the substrates in the region – for example, sawdust and wood chippings were not readily available and therefore mulch was used as a cellulose source.

Proof-of-concept testing

The proof-of-concept test involved the use of substrate or mix of substrates (old and new biosolids, cow manure and crocodile manure, mulch, oyster shells, and local dolomite) that were placed in sealed 250-mL amber jars. Temperature, pH, electrical conductivity, dissolved oxygen and redox potential of mine water in the jars were tested weekly for six weeks. The test was established in a dedicated area of the mine office laboratory (see Figure 4).

After six weeks, the contents of each jar was filtered in the laboratory and the water analysed for a range of standard water-quality parameters, heavy metals, metalloids and sulfur compounds.

Results

The pH results of the proof-of-concept tests are shown in Figure 5.

The results show that the successful candidate substrates (old biosolids and crocodile manure) reduced the metal content by 90–100% in many cases. Iron and manganese require aerobic systems and would not be expected to be reduced significantly in anaerobic substrates such as those tested here. The shift in pH makes aluminium (Al) insoluble as a metal hydroxide and thus facilitates Al³⁺ reduction.

The oyster shell caused a pH change, meaning redox-insensitive metals (such as Al) were precipitated, but also sulfate-reducing bacteria are more prevalent in an environment with a relatively neutral pH. The reduction in sulfate is therefore attributed to the inorganic reaction with calcium (from the oyster shell).

The results indicated that bench- and pilot-scale tests of the most successful candidate substrates are warranted.

This article is an edited version of a paper published in the Proceedings of the 5th International Contaminated Site Remediation Conference in September 2013.



Fig 4. Layout of proof-of-concept testing.
Photo: SKM

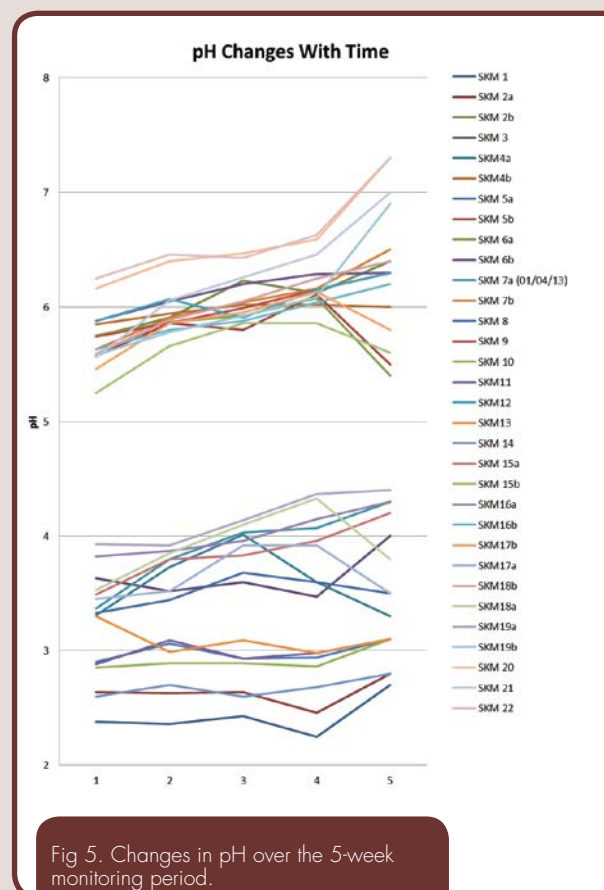


Fig 5. Changes in pH over the 5-week monitoring period.



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All photos: sampling soil at a small-scale asbestos-contaminated site in Western Australia. Photos: DingleBird Environmental



Asbestos-contaminated land: no size too small

Joel Swadling, Geraldine Treloar and Ronie Magcamit,
Dinglebird Environmental

When it comes to cleaning up asbestos, a small site doesn't necessarily mean a small problem.

Asbestos was a key construction material in Western Australia well into the 1980s and, consequently, the majority of pre-1980 homes contain asbestos. The heavy reliance on asbestos in construction, in combination with urban redevelopment and application of the Western Australia's *Contaminated*

Sites Act 2003, has resulted in asbestos-contaminated sites becoming a significant human health risk and management issue. The ever-increasing social stigma surrounding asbestos – due largely to its potential to cause a number of lethal conditions – can often add another layer of difficulty to clean-up operations.



Asbestos clean-up at large-scale sites has been well documented, but little has been done on the importance of remediating small-scale sites.

In 2012–13, Dinglebird Environmental was contracted to manage asbestos-containing material (ACM) and possible ACM (PACM) at a site in Cottesloe, Western Australia. The approximately 8000 m² site – relatively small for asbestos remediation – was deemed sensitive due to the presence of a primary school, an early learning centre and a cancer support facility on the property.

Dinglebird conducted pre-removal sampling of PACM and air monitoring during ACM removal, and performed a clearance inspection. During the inspection, PACM was discovered buried in soil under buildings, necessitating further detailed contamination investigations.

During removal works and the preliminary site investigation, sheets of asbestos were discovered directly beneath buildings. The majority of the asbestos observed on the site was likely to be ACM that was dumped during historical building works.

During the detailed site investigation, attempts were made to delineate asbestos in soil contamination via soil sampling. However, continuous excavation and construction works resulted in the discovery of ACM buried in numerous locations throughout the site. Consequently, an ongoing site management plan was developed to ensure that future contractors, employees, residents and children entering the site were not exposed to asbestos fibres.

The site in its entirety underwent excavations including the removal of ACM-contaminated soils and loose asbestos fines. Soil under the building was sieved and handpicked prior to sampling to aid validation of this section of the site. Unfortunately not all of this area was accessible for remediation and will be managed by the ongoing site management plan along with the rest of the site. A geofabric layer was also installed to demarcate the clean imported fill from the locations where contaminated soils were removed.

Where practical, all ACM was separated from the soil prior to off-site disposal. Any soils potentially

contaminated with ACM or asbestos fibres were removed and disposed of to an appropriately licenced waste disposal facility. The removal of the known ACM and contaminated soils will reduce the impact on site workers, visitors and residents in the surrounding areas now and in the future. At least 350 tonnes of ACM-contaminated soil was removed from the site.

After the clean up, the site was deemed suitable for its current and future proposed uses. The difficulties encountered during this asbestos remediation exercise highlight that size doesn't matter – even small-scale sites can house complex risks. The site described here demonstrates powerfully that all risks posed by asbestos must be addressed, investigated and managed seriously, no matter what the size of the asbestos-contaminated site.





Contaminants of emerging concern – a literature review of gaps in analytical methodology

Lesley Johnston, Meg Croft, John Murby and Cheryl Lim, National Measurement Institute, Australia

The term 'contaminants of emerging concern', or CECs, refers to chemicals that have attracted recent concern about the risk they potentially pose to human health or the environment. These chemicals may be newly developed, only recently recognised as a potential environmental risk, or be now used in new ways.

Contaminants of emerging concern PART 1

To better understand the relevance of CECs to Australia, the National Measurement Institute (NMI) has recently completed a comprehensive literature review for CRC CARE on analytical methodology gaps relating to CECs, focussing on Australian analytical capabilities and contaminants considered potentially relevant to Australian environmental regulators. The findings of the review, summarised in this article, have been published as a CRC CARE Technical Report¹, which is available for download at www.crccare.com/publications.

The CEC review – which encompassed input from international experts and the peer-reviewed international literature – was prepared in consultation with Australian regulators, senior environmental auditors and measurement service providers. It identified a shortlist of 19 classes of contaminants for which a more detailed assessment was then performed on the basis of two key criteria: the relevance of each contaminant to the Australian environment, and the degree to which appropriate analytical capability is available in Australia. Quality assurance tools essential for ensuring comparability of results between laboratories were also considered.

The availability of analytical methodology with sufficient detection sensitivity and selectivity is essential for the effective management of environmental contaminants. In addition to analytical methodology and capability, appropriate quality assurance is necessary to ensure accuracy and comparability of results between laboratories. Suitable analytical standards, certified reference materials and proficiency testing schemes are all aspects of quality assurance that need to be available for better measurement.

Selection of CECs for review and stakeholder consultation

Three categories of CECs were selected by NMI for review. The ‘first-tier priority’ contaminants were selected by participants in a 2012 CRC CARE workshop on CECs, nominated on the basis of requiring further research in at least one of the areas of policy, measurement or risk assessment.² The ‘priority two’ contaminants were those recognised as significant contaminants worldwide and expected to be present in the Australian environment. Finally, the ‘priority three’ contaminants were named in international literature or flagged by key stakeholders and required further investigation regarding

their relevance in the Australian remediation context, based on their likely use and environmental prevalence. The three categories of contaminants considered are shown in the table below (see Part 2 on pages 27–28 for more information on the various categories):

The contaminants named in the table range from industrial chemicals to components of everyday products, and include chemicals with wide-ranging or quite specialised applications. Some of the reasons these contaminants were of interest to this review are presented in Part 2. More information on each class can be found in the Technical Report.

To measure the extent to which analytical capability was available for the CECs identified, a short survey was developed with anonymous feedback requested from all Australian laboratories listed on the National Association of Testing Authorities (NATA) website as holding accreditation for Chemical Testing and providing a public testing service, or being conditionally available for public testing. The laboratories were also invited to provide their suggestions as to what other CECs should be considered. Twenty-nine responses were received. The survey questions and summaries of the responses are published in the Technical Report.

Table 1. The three categories of contaminants of concern considered in the NMI/CRC CARE literature review.

| First-tier priority | Priority two | Priority three | |
|------------------------|------------------------|-----------------|--------------------|
| MTBE | other PFASs | 1,4-dioxane | microbicides |
| PFOS, PFOA | novel flame retardants | benzotriazoles | organoboron |
| weathered hydrocarbons | SCCPs | ionic liquids | organoplatinum |
| benzo(a)pyrene | methylsiloxanes | benzidine dyes | arsenic speciation |
| PBDEs | | musk fragrances | nanoparticles |





Contaminants of emerging concern threaten the health of the environment.
Photo: Cheryl Lim

Summary of review findings

At this time, there appear to be no significant Australian analytical methodology gaps for the first-tier priority compounds identified by the CRC CARE workshop. However, tools to assess laboratory performance for these compounds, such as Australian proficiency-testing schemes, were found to be lacking. This has important implications for the development of policy and enforcement of regulation, which assume that measurements of contaminant levels by all laboratories are accurate (at least to a minimum level) and comparable.

All the second-priority compounds are significant contaminants worldwide, and are expected to be present in the Australian environment. While evidence was found for some Australian analytical capability for short-chain chlorinated paraffins (SCCPs), local capabilities are extremely limited or non-existent for:

- perfluoroalkyl substances (PFASs), with the exception of first-tier priority contaminants perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA)
- flame retardants
- methylsiloxanes.

With increasing regulatory control over the use of earlier-generation PFASs and flame retardants (such as PFOS, PFOA, polybrominated diphenyl ethers, tetrabromobisphenol A and hexabromocyclododecane), a plethora of replacements have arisen. Specific analytical methodology has not been reported in the literature for many of these novel compounds. Some contaminants can be detected by methods optimised for related analytes, but others have not been studied. Additionally, there is a lack of reference materials and proficiency testing schemes, making it hard for laboratories to establish analytical capability.

Not surprisingly, the wide-ranging selection of contaminants in the priority three list means that the analytical capabilities are also widely variable. In particular:

- Benzotriazoles, synthetic musks and microbicides appear in commercial and personal-care products as extensively in Australia as overseas, and hence are expected to be widespread in the environment. Some methodology is reported in the literature for these compounds but this analytical capability is not generally available in Australia.
- Nanoparticles are particularly challenging analytes and very little methodology is available that is capable of detection at realistic levels in the environment.
- Commercial testing for arsenic species is available in Australia, but analysis is not easy, and there are no official standard methods or certified reference materials

available to help laboratories ensure accuracy of their results.

Analytical methodology for environmental analysis of organoplatinum species and benzidine dyes is not well established; however it seems unlikely that these contaminants are a widespread or nationally significant problem in Australia. Similarly, 1,4-dioxane, ionic liquids and organoboron contaminants are expected to be of little environmental significance to Australia as they are not currently used widely on a commercial scale.

Implications of the review findings for Australian regulators and industry

Significant gaps in appropriate analytical methodology and quality assurance tools have been identified for a number of CECs expected to be of relevance to Australia. These gaps should be addressed to assist Australian regulation and industry to:

- comply with Australia's obligations under international treaties such as the Stockholm Convention
- rapidly obtain analysis results for Australian environmental samples potentially containing one or more CECs
- ensure that laboratory results are comparable across Australia and with results from laboratories in other parts of the world
- determine whether laboratory analyses can be compared with the data on which regulation/guideline values have been based.

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Potential sources of selected CECs and the anticipated risk for Australia

Methyl-tert-butyl ether (MTBE) is a significant contaminant in some parts of the world where it has been added to fuel in large quantities as an oxygenate. It is extremely water soluble and has very strong taste and odour. Australian refineries do not use MTBE, so any contamination is expected to come from imported fuel.

Perfluoroalkyl substances (PFASs), including **perfluorooctane sulfonate (PFOS)** and **perfluorooctanoic acid (PFOA)**, can be extremely persistent in the environment, and can be transported great distances in the atmosphere. They are found in humans and animals worldwide, including the Arctic environment. Because of this, PFOS is listed by the Stockholm Convention on persistent organic pollutants (POPs). PFASs have many commercial and industrial uses, including as stain repellents for fabrics and carpets, for grease-proofing food packaging, and in the manufacture of paints, adhesives, waxes, polishes, metals, electronics, fire-fighting foams and caulks.

Weathered hydrocarbons must be analysed for the risk assessment, management, treatment and monitoring of contaminated sites. It is also used to identify the source of the contamination and determine liability and responsibility for clean up. Petroleum products are complex mixtures of hydrocarbons whose composition varies according to the source material and the nature and degree of processing. When released to the environment, these mixtures undergo a range of weathering processes which further change their composition, and hence availability, toxicity and partitioning.

Benzo(a)pyrene, formed as a by-product of combustion, is a polycyclic aromatic hydrocarbon that can have natural as well as anthropogenic sources.

Polybrominated diphenyl ethers (PBDEs) are a series of 209 compounds differing in their bromine substitution patterns. They have been used extensively as flame retardants in many different products, often in high concentrations. They have been found to be toxic and persistent in the environment and so their use is being phased out, with some formulations already restricted in most parts of the world.

Halogens or phosphorous are components in many of the novel flame retardants being developed to replace PBDEs. These types of compounds can capture the high energy H and OH radicals that are part of the flame propagation process. Unfortunately, they are also very likely to be persistent in the environment.

Short-chain chlorinated paraffins (SCCPs) are chlorinated linear alkanes, containing between 10 and 13 carbon atoms, that are used widely in manufacturing and as flame retardants. In the environment they have been found to be toxic, persistent and bioaccumulative, and to undergo long-range atmospheric transport. They are under consideration for listing on the Stockholm Convention as POPs.

Cyclic and linear methylsiloxanes are used as precursors in the production of silicone polymers, as dry-cleaning solvent, and in consumer products such as cosmetics, deodorants, soaps, hair conditioners, hair dyes, car waxes, baby pacifiers, cookware, cleaners, furniture polishes and water-repellent windshield coatings. They do not appear to be highly toxic, but are certainly widespread in the environment due to their extensive use and persistence.



Some fire-fighting foams contain potentially harmful PFASs that can leave a legacy of contamination.



Appropriate regulation of contaminants of emerging concern is crucial for ensuring the health of future generations.

1,4-dioxane is a high-production chemical in the USA, used as a solvent stabiliser in a range of manufacturing processes, and is a probable human carcinogen.

Benzotriazoles are complexing agents used as anticorrosives in engine coolants, antifreeze and aircraft de-icing fluids, and as silver protection in dishwasher detergents. Many ultraviolet stabilisers in personal care and industrial products contain 2-hydroxyphenol benzotriazole derivatives. The continuous release of these products to the environment from wastewater means that they are pseudo-persistent.

Ionic liquids are a 'green chemistry' research area of great interest, being considered as alternatives to traditional organic solvents because of their low volatility and flammability. They are not yet used widely in industry, but when they are, their toxicity, resistance to biodegradation and high water solubility may result in them being less green when it comes to environmental contamination.

Benzidines are components in a very large family of azo dyes and pigments. The International Agency for Research on Cancer has found benzidines to be carcinogenic to humans. Benzidine-based dyes are regulated or under assessment in Europe, the US and Canada.

Nitromusks, polycyclic musks and OTNE, used as fragrances, and the **microbicides triclosan and triclocarban** are ubiquitous in personal care products. In the environment, their chemical structures make them potentially persistent, toxic to some organisms and bioaccumulative, and evidence of these tendencies has been reported for many of these compounds.

Organoboranes have been described as potential replacements for organotin anti-fouling agents, but very little is reported about their analysis, fate and effects in the environment.

Organoplatinum is a component in some anti-cancer drugs. After treatment with such drugs, many species of organoplatinum are excreted – including in some cases the unchanged parent chemical. These compounds can be very toxic, and little is known about their fate in hospital and urban waste water.

Arsenic often occurs as a natural contaminant, but its toxicity depends on the form present, with inorganic species considerably more toxic than organic forms. Analysis of the total amount of arsenic present is not particularly useful for assessment of environmental contamination, but analysis of different species without perturbing the distribution can be very difficult.

'**Nanoparticles**' is a term that covers an enormous range of potential contaminants – often sharing nothing more than their size. Many types of chemicals are now being synthesised or formulated as nanomaterials for a variety of applications. While many are potentially toxic, very little is known about the behaviour of materials on this scale. Nanoparticles are generally very difficult to isolate from complex matrices without changing their structure and composition.



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Research RoundUp

Research roundup keeps you up to date with current research on environmental contamination assessment and remediation in Australia.

Guidance for emergent and priority contaminants



Although a number of contaminants have been identified as 'emerging' or 'priority', the development of their regulatory guidance is limited by the scarcity of information regarding their disposition, fate and toxicity. Now that an in-depth literature review of such contaminants has been completed, further work will develop a staged approach for generating guidance for their management and remediation.

Guidance development may include adoption of existing guidance from other jurisdictions, benchmarking for clean-up levels, defining standards for emerging contaminants, and developing a common standard for what constitutes 'clean'.

As this project will involve the management of information from other jurisdictions, the system managed by the Minnesota Department of Health for contaminants of emerging concern will be investigated, with a view to determining whether a similar system can or should be replicated in Australia through CRC CARE, and/or whether CRC CARE should act as an 'agent' or clearing house for the Minnesota Department of Health (or other similar agencies in the United States or elsewhere).

Additionally, as concentration-based criteria are commonly used in Australia and internationally to regulate the management of contaminated groundwater environments, regulation and practice regarding the flux-based assessment of groundwater contamination and how this complies with Australian regulatory guidance will be considered. ■

Development of analytical tools and biosensors

Methods for assessing contamination in the environment have traditionally involved the collection of environmental samples (soils/sediments and fresh-, ground- and marine-water) from potentially contaminated sites followed by laboratory analysis. Unfortunately this approach not only requires a well maintained laboratory with expertly trained staff and expensive equipment, but the sampling in itself imposes additional costs and an inability to provide data in real time – placing considerable constraints on the scale of investigations into environmental contamination. Chemicals such as arsenic, cadmium, copper, chromium and BTEX all pose serious environmental and human health risks, which exacerbates the need for accurate on-site measurement tools.

This project focuses on the development of much-needed novel, simple and cost-effective microsensor tools (both chemically and biologically based) for real-time monitoring of chemical contamination in soil and water at highly contaminated sites.

The project has already developed a chemically modified electrode with a novel sandwich film for more sensitive and selective detection of cadmium, copper and lead; and a preliminary general toxicity biosensor, based on expression in *E. Coli*. The next stage in the project will enhance these laboratory-based developments by creating field-ready test kits for rapid and inexpensive monitoring of on-site chemical contamination. ■

Cost-benefit and sustainability analysis of remedial alternatives

The remediation of contaminated sites in Australia is currently regulated separately within state or territory jurisdictions – there is no nationally consistent approach to site clean-ups. This presents difficulties for all parties involved in the remediation of sites in multiple jurisdictions, including consultants and regulators. The development of a national framework for the remediation of contaminated sites is therefore a priority.

The development of methodology and user guidelines for cost-benefit and sustainability analyses of remedial alternatives to be incorporated into the National Remediation Framework (NRF) is the focus of this project.

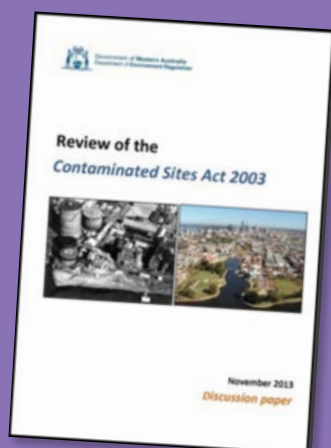
The work includes:

- identification and review of relevant existing guidelines, drawing on reports previously published as part of the initial stages of the formulation of the NRF
- development of a methodology, and draft guidelines, for cost-benefit and sustainability analysis of remedial options
- engagement with project stakeholders, including the National Remediation Framework Steering Group
- production of a methodology report. ■

Have your say on the review of the WA Contaminated Sites Act 2003

The Western Australian Department of Environment Regulation (DER) has launched a second round of public consultation on the statutory review of the Contaminated Sites Act 2003.

DER is inviting further public comment on a discussion paper which is now available on DER's website at www.der.wa.gov.au/contaminatedsites/csactreview.



The discussion paper is aimed at specialists in land contamination and anyone else with an interest in this field, including members of the public. It identifies several areas of the Act and Regulations that may need some modification. DER is seeking feedback on these possible changes and how they might affect you.

All submissions will be made available on DER's website and considered when preparing the review report, which the Minister for Environment will table in Parliament.

The comment period closes on Monday 24 February 2014.

Please use the response template provided on DER's website and then send your comments via email to consitesreview@der.wa.gov.au or by post to:
Contaminated Sites Branch
Department of Environment Regulation
Locked Bag 33 Cloisters Square
Perth WA 6850

Phone queries can be made via the Contaminated Sites Information Line on 1300 762 982. ■



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Training and events calendar 2014

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18–20

Introduction to Australian Groundwater

SRIT/Adelaide

www.srit.com.au/course_details.php?id=74

October

29–31

EcoForum 2014

ALGA/Brisbane

www.ecoforum.net.au/

April

28 April – 2 May

8th Australian Workshop on Acid and Metalliferous Drainage

JKTech/Adelaide

<http://jktech.com.au/8th-amd>

November

10–14

7th International Congress on Environmental Geotechnics (7ICEG)

WALDRON SMITH Management/Melbourne

www.7iceg2014.com

May

6–8

Waste 2014

Coffs Harbour City Council/Coffs Harbour NSW

www.waste2014.impactenviro.com.au/

December

7–12

Royal Australian Chemical Institute national Congress

RACI/Adelaide

www.racicongress.com



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 victoria.leitch@crccare.com.

Bolan, NS, Mahimairaja, S, Kunhikrishnan, A & Choppala, G 2013, 'Phosphorus-arsenic interactions in variable-charge soils in relation to arsenic mobility and bioavailability', *Science of the Total Environment*, vol. 463–464, pp. 1154–1162.



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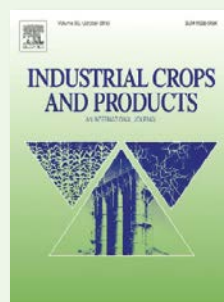
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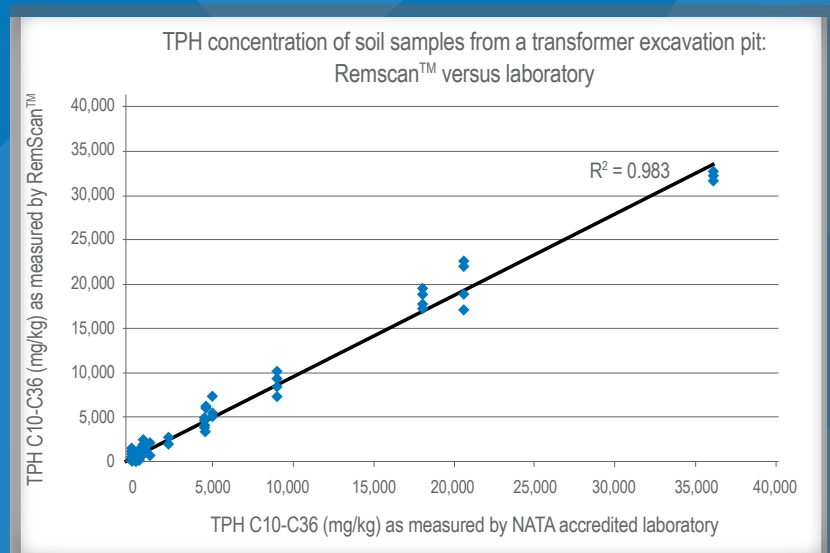
Weng, X, Huang, L, Chen, Z, Megharaj, M & Naidu, R 2013 'Synthesis of iron-based nanoparticles by green tea extract and their degradation of malachite', *Industrial Crops and Products*, vol. 51, pp. 342–347.

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