



Australian Government



EVALUATING PERFORMANCE: MONITORING AND AUDITING

*Leading Practice Sustainable Development
Program for the Mining Industry*

September 2016



EVALUATING PERFORMANCE: MONITORING AND AUDITING

*Leading Practice Sustainable Development
Program for the Mining Industry*

September 2016

Disclaimer

Leading Practice Sustainable Development Program for the Mining Industry.

This publication has been developed by a working group of experts, industry, and government and non-government representatives. The effort of the members of the Working Group is gratefully acknowledged.

The views and opinions expressed in this publication do not necessarily reflect those of the Australian Government or the Minister for Foreign Affairs, the Minister for Trade and Investment and the Minister for Resources and Northern Australia.

While reasonable efforts have been made to ensure that the contents of this publication are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

Users of this handbook should bear in mind that it is intended as a general reference and is not intended to replace the need for professional advice relevant to the particular circumstances of individual users. Reference to companies or products in this handbook should not be taken as Australian Government endorsement of those companies or their products.

Support for the LPSDP was provided by the Australian aid program administered by the Department of Foreign Affairs and Trade due to the reports' value in providing practical guidance and case studies for use and application in developing countries.

Cover image: Deleeze Mackey, Environmental Advisor at the Hail Creek Coal Mine, monitoring vegetation at the mine site. Source: Rio Tinto Coal Australia.

© Commonwealth of Australia 2016

This work is copyright. Apart from any use as permitted under the *Copyright Act 1968*, no part may be reproduced by any process without prior written permission from the Commonwealth. Requests and inquiries concerning reproduction and rights should be addressed to the Commonwealth Copyright Administration, Attorney-General's Department, Robert Garran Offices, National Circuit, Canberra ACT 2600 or posted at www.ag.gov.au/cca

September 2016.

Contents

ACKNOWLEDGEMENTS	vi
FOREWORD	ix
1.0 INTRODUCTION	1
1.1 Scope and background	1
1.2 The role of monitoring and auditing in leading practice	2
1.3 Corporate social responsibility	5
1.4 Deficiencies in current monitoring and auditing practices	8
1.5 Links to the impact assessment process	8
1.6 Monitoring and evaluating cumulative impacts	10
2.0 SUSTAINABLE DEVELOPMENT	19
2.1 Guiding principles	19
2.2 National and international standards	19
2.3 Risk planning, management and mitigation	25
3.0 MONITORING: DESIGN	26
3.1 Planning to manage risk	26
3.2 Life-of-mine planning and management	28
3.3 Adjustments for changes in the mine plan	31
3.4 Community involvement in monitoring design	33
3.5 Elements of the monitoring program	36
3.6 Links to research and investigations	37
4.0 MONITORING: IMPLEMENTATION	42
4.1 Overview of leading practice monitoring procedures	42
4.2 Open pits	43
4.3 Waste rock dumps	44
4.4 Tailings storage facilities and heap leach piles	49
4.5 Contaminated land	52
4.6 Groundwater	54
4.7 Heritage values	56
4.8 Radioactive minerals	56
4.9 Community involvement in monitoring implementation	63
4.10 Data management	72
4.11 Data analysis and interpretation	74
4.12 Completion criteria	78
4.13 Safety of monitoring	81
4.14 Monitoring technologies	82
4.15 Long-term relevance	93
4.16 Public reporting and assurance	94
4.17 Voluntary reporting	98
4.18 Governance	99

4.19 Assurance	101
4.20 Review of monitoring programs	102
5.0 AUDITING	108
5.1 Evaluating performance using audits	108
5.2 Reasons for conducting an audit	109
5.3 Voluntary, mandatory and statutory audits	109
5.4 Environmental audits	111
5.5 Maturity models	113
5.6 Social audits	118
5.7 Specific-subject audits	118
5.8 Greenhouse and energy audits	119
5.9 Audit personnel	120
5.10 Audit plan	120
5.11 Audit protocol	121
5.12 Audit evidence	122
5.13 Audit report	122
5.14 Assurance	123
6.0 CONCLUSIONS	124
APPENDIX 1: TEN PRINCIPLES OF SAMPLING	126
APPENDIX 2: TYPICAL ELEMENTS OF A MONITORING AND PERFORMANCE EVALUATION PROGRAM	127
APPENDIX 3: GRIEVANCE MANAGEMENT MECHANISMS	144
REFERENCES	145
FURTHER READING	153

CASE STUDIES:

Case Study: Strategic management of cumulative impacts of coalmine wastewater releases in the Fitzroy River Basin—a regulatory perspective	13
Case Study: Integrated water management by Anglo American’s Metallurgical Coal Business Unit	15
Case Study: PanAust in Laos—working with communities for sustainable livelihoods	23
Case Study: Co-management of impacts of below-watertable mining on culturally significant and ecologically sensitive Weeli Wolli Springs and Creek system by traditional owners and Rio Tinto	33
Case study: Monitoring to improve the quality of rehabilitation	39
Case Study: Erosion monitoring for stable landforms	46
Case Study: Integrated monitoring program for a former uranium mining region in Germany	59
Case Study: Rum Jungle Environmental Values Project	63
Case Study: Indigenous community involvement in monitoring for improved land management	70
Case Study: Sample size estimated for monitoring impacts of undermining on a plant growing on damp rock faces	76
Case Study: Pushing technology to meet expected future requirement—Tampakan Project baseline water quality monitoring	86
Case Study: Fauna monitoring to assess offsets and mine rehabilitation	90
Case Study: Democratic Republic of the Congo: shedding light on tax collecting agencies’ practices—greater scrutiny uncovers US\$26 million that was unaccounted for	101
Case Study: Upgrading monitoring systems to inform water management	103
Case Study: Environmental evaluation of QAL’s red mud dam and receiving waters	105

ACKNOWLEDGEMENTS

The Leading Practice Sustainable Development Program is managed by a steering committee chaired by the Australian Government Department of Industry, Innovation and Science. The 17 themes in the program were developed by working groups of government, industry, research, academic and community representatives. The leading practice handbooks could not have been completed without the cooperation and active participation of all working group members.

Misha Coleman, Monitoring and Evaluating International, and Dr Owen Nichols, Environmental Management and Research Consultants, as co-lead authors gratefully acknowledge and thank the following contributors who participated in the drafting of the 2016 Evaluating performance: monitoring and auditing handbook:

CONTRIBUTOR	MEMBER	CONTACT
	Dr Owen Nichols Lead co-author Principal Environmental Management and Research Consultants	emrc@bigpond.com.au
	Ms Misha Coleman Lead Co-author Director Monitoring and Evaluation International	misha_coleman@hotmail.com
	Dr David R Jones Key author Principal DR Jones Environmental Excellence	drdrjjones@gmail.com
	Ms Corinne Unger Key author Environmental Consultant and p/t Industry Fellow The Centre for Mined Land Rehabilitation, Sustainable Minerals Institute, University of Queensland	kasung@bigpond.com and c.unger1@uq.edu.au
	Mr David Donato Key author Principal Donato Environmental Services	ddonato@rbe.net.au
	Dr Catherine Pattenden Key author Principal AliCat (WA) Pty. Ltd. Social Performance Consulting	cathip@bigpond.com

CONTRIBUTOR	MEMBER	CONTACT
 Hydrobiology	Dr Ross Smith Key author Director, Hydrobiology	www.hydrobiology.biz
	Mr Peter Waggitt Key author Consultant in Mining Environmental Management peterwaggitt@hotmail.com	
 THE UNIVERSITY OF QUEENSLAND <small>AUSTRALIA</small>	Professor David Williams Key author Golder Professor of Geomechanics University of Queensland	www.uq.edu.au
	Peter Erskine Contributing author	
 Graham A Brown & ASSOCIATES <small>Environmental & Resource Consultants</small>	Dr Graham Brown Contributing author Principal Graham A Brown & Associates	www.grahamabrown.com.au
 EARTH SYSTEMS <small>Environment Water Sustainability</small>	Sophie Pape Contributing author Earth Systems	www.earthsystems.com.au
 SENTINEL	Rod Sandison Contributing author Director Sentinel	www.sentinelepl.com.au
	Kate Bennett Independent Sustainable Development Practitioner	Ktlbennett@gmail.com
 Banarra	Paul Davies & Claire Tucker Contributing authors Banarra	www.banarra.com
 World Vision	Victoria Thom Contributing author Manager, Innovative Business Development World Vision Australia	www.worldvision.org.au

The working group would like to acknowledge the following contributors to case studies:

Title of case study	Author(s)	Other assistance
Indigenous community involvement in monitoring for improved land management	Eloise Hoffman, Ingrid Meek (Rio Tinto Alcan Weipa)	
PanAust in Laos-working with communities for sustainable livelihoods	Jeff Millgate, Jethro Stern (PanAust Asia)	Cath Pattenden (AliCat Consulting)
Monitoring to improve the quality of rehabilitation	John Koch, Matthew Daws (Alcoa)	
Erosion monitoring for stable landforms	Rob Loch (Landloch)	
Rum Jungle Environmental Values Project	Ross Smith (Hydrobiology), Tania Laurentcont (Northern Territory Dept. Mines and Energy), Andy Markham (Hydrobiology)	
Pushing technology to meet expected future requirement-Tampakan Project baseline water quality monitoring	Phil Whittle (Hydrobiology), Mike Chapman (Xstrata Copper), Ross Smith (Hydrobiology), Andrew Bradbury (Advanced Analytical Australia)	
Upgrading monitoring systems to inform water management	Ally Sinclair, Turner Kate, Michelle Iles, David Jones	
Fauna monitoring to assess offsets and mine rehabilitation	Owen Nichols (EMRC), Michael Murray (Forest Fauna Surveys), Glenn Cook (Glencore Mount Owen Complex)	David Donato (Donato Environmental Services), Corinne Unger
Strategic management of cumulative impacts of coal mine wastewater releases in the Fitzroy River Basin- a regulatory perspective	Reinier Mann, Ian Ramsay (Queensland Department of Science, Information Technology, Innovation and the Arts)	Ross Smith
Integrated water management by Anglo American's Metallurgical Coal Business Unit	Claire Cote, Carl Grant (Anglo American)	David Jones, Corinne Unger
Environmental evaluation of QAL's red mud dam and receiving waters	Diana Bozzetto and Anja Urban, Queensland Alumina Limited, Gladstone, Queensland; Claire Streten-Joyce and David Williams, Australian Institute of Marine Science, Darwin, Northern Territory; and David Parry, Rio Tinto, Brisbane, Australia	David Jones, Corinne Unger
Integrated monitoring program for a former uranium mining region in Germany	Elke Kreyszig, Corinne Unger	
Co-management' of impacts of below water table mining on culturally significant and ecologically significant Weeli Wolli Springs and Creek system by traditional owners and Rio Tinto	Brian Tucker (Niyiarparli People), Sunil Samaraweera (Rio Tinto Iron Ore, Western Australia), and Linda Parker (Banyjima People)	Sugar Gonchigjantsan (Rio Tinto - Mongolia), Cath Pattenden (AliCat Consulting)
Sample size estimate for monitoring impacts of undermining on a plant growing on damp rock faces	Nick McCaffrey (Centre for Mined Land Rehabilitation, University of Queensland)	
Democratic Republic of Congo: shedding light on tax collecting agencies' practices [insert em dash] greater scrutiny uncovers US\$26 million that was unaccounted for		

FOREWORD

The *Leading Practice Sustainable Development Program for the Mining Industry* series of handbooks has been produced to share Australia's world-leading experience and expertise in mine management and planning. The handbooks provide practical guidance on environmental, economic and social aspects through all phases of mineral extraction, from exploration to mine construction, operation and closure.

Australia is a world leader in mining, and our national expertise has been used to ensure that these handbooks provide contemporary and useful guidance on leading practice.

Australia's Department of Industry, Innovation and Science has provided technical management and coordination for the handbooks in cooperation with private industry and state government partners. Australia's overseas aid program, managed by the Department of Foreign Affairs and Trade, has co-funded the updating of the handbooks in recognition of the central role of the mining sector in driving economic growth and reducing poverty.

Mining is a global industry, and Australian companies are active investors and explorers in nearly all mining provinces around the world. The Australian Government recognises that a better mining industry means more growth, jobs, investment and trade, and that these benefits should flow through to higher living standards for all.

A strong commitment to leading practice in sustainable development is critical for mining excellence. Applying leading practice enables companies to deliver enduring value, maintain their reputation for quality in a competitive investment climate, and ensure the strong support of host communities and governments. Understanding leading practice is also essential to manage risks and ensure that the mining industry delivers its full potential.

These handbooks are designed to provide mine operators, communities and regulators with essential information. They contain case studies to assist all sectors of the mining industry, within and beyond the requirements set by legislation.

We recommend these *leading practice* handbooks to you and hope that you will find them of practical use.



Senator the Hon Matt Canavan

Minister for Resources and Northern
Australia



The Hon Julie Bishop MP

Minister for Foreign Affairs

1.0 INTRODUCTION

1.1 Scope and background

This handbook addresses the theme of evaluating performance through monitoring and auditing, which are key elements in the Leading Practice Sustainable Development Program for the Mining Industry. The aims of the program are to identify the key issues affecting sustainable development in the mining industry and provide information and case studies that illustrate how to establish a more sustainable basis for the industry.

In updating the 2009 edition of this handbook, the authors were instructed to focus on those dimensions of practice where significant change and innovation had occurred. Therefore, the more detailed sections reflect the additional and updated information that was added to this 2016 edition. The authors were also asked to focus on ensuring that the handbook was more operational and practical. To that end, links to manuals and operational guidelines have been included wherever possible.

The handbook addresses the ongoing assessment of impacts at all stages of a resource project, from pre-feasibility through planning, environmental and social impact assessment, development, operation, rehabilitation, decommissioning and closure.

While abandoned mines demonstrate the antithesis of leading practice in many ways, it is intended that managers of abandoned mines will use the information in this and the other program handbooks as one of several resources to plan and implement monitoring and auditing as part of an overall rehabilitation program to transform a site from 'negative legacy' to 'positive inheritance' (IUCN-ICMM 2008). This handbook will also support implementation of the Strategic Framework for Managing Abandoned Mines in the Minerals Industry (MCMPR-MCA 2010).

Leading practice companies seek to manage financial and sovereign risk by identifying and engaging all stakeholders so that outcomes are expressed not just as the financial bottom line but rather as a triple bottom line that includes positive financial, social and environmental outcomes for all stakeholders. While much of this handbook focuses on environmental management, social and economic aspects are also addressed because they too are integral components of performance within a sustainable development framework.

Leading practice organisations are now incorporating social considerations into all aspects of their performance evaluation. This takes two forms, both of which are addressed in this handbook: monitoring and reporting local and regional socioeconomic adjustment that may occur as a consequence of mining activity; and engaging the community in environmental monitoring. Leading practice examples of both approaches are inclusive of communities at each stage of the monitoring process from participation in program design through to data collection and reporting.

Mining companies that are recognised for implementing leading practice sustainable development understand that their social licence to operate is largely influenced by their performance in these areas, and they understand the business case for good performance and continuous improvement. They also recognise that assessing and achieving good outcomes is not limited to the immediate and surrounding environment and communities affected by operations, but must cover a larger temporal and spatial scale by taking into account all relevant site, local, regional, national and even international aspects.

The primary audience for this handbook is management at the operational level, which is the level responsible for implementing leading practice at mining operations and ensuring that monitoring and auditing are conducted to evaluate and improve performance. The handbook is also relevant to environmental officers; mining consultants; governments and regulators; non-government organisations; (NGOs) neighbouring and mine communities; and students. It also provides a valuable reference on benchmarking practices and training for the emerging mining industry in developing countries.

By applying the principles outlined in this and other related handbooks, all users are encouraged to work together in partnership and take up the challenge to continually improve the mining industry's standards of monitoring and auditing, as part of its approach to sustainable development.

What is 'leading practice'?

In the context used in this series of handbooks, leading practice is defined as 'the best available current practice promoting sustainable development'; that is, proven practices or procedures currently being implemented by mining companies which go beyond the minimum legislative requirements, and which are endorsed by stakeholders. Leading practice improves over time to apply new knowledge and standards to existing and new situations while also meeting changing community expectations.

Monitoring and auditing together enable companies, governments and stakeholders to evaluate the performance of the industry and regulatory frameworks and guide the improvements that demonstrate leading practices.

1.2 The role of monitoring and auditing in leading practice

In the simplest terms, monitoring and auditing help a mining company achieve good sustainable development performance by ensuring that processes and procedures are in place to track specific social and environmental values and to verify that those processes and procedures are functioning effectively. In broad terms, this can involve tracking progress over time, determining whether agreed objectives or standards have been met, and benchmarking procedures and performance against those of other mining operations.

What is 'monitoring and auditing'?

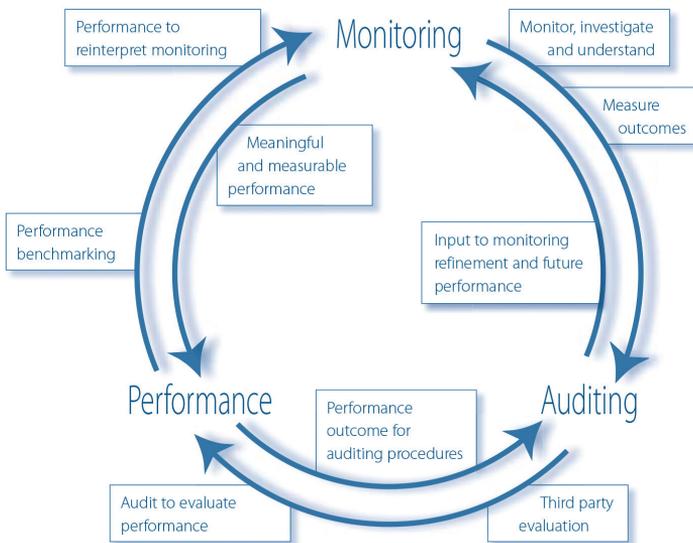
Monitoring is the gathering, analysis and interpretation of information for the assessment of performance. Examples commonly used in the resources industry include monitoring of water quality; impacts on flora and fauna (as well as recovery following the implementation of control or rehabilitation measures); social aspects and community development; air quality; noise; vibration; greenhouse gas emissions; and the extent to which rehabilitation and final land-use objectives are being met.

Auditing is systematically reviewing monitoring procedures and results, and checking that all commitments have been fulfilled or completed by comparing the audit findings against agreed audit criteria. Auditing can be undertaken internally, by experts in specific disciplines who provide a check on methods or success against internal company standards, or externally, by an independent consultant or expert who can demonstrate transparency and add value to the audit process.

In any leading practice environmental management program, the elements of monitoring and auditing for evaluating performance are inextricably linked. This is illustrated in Figure 1. Planning is a critical initial component in establishing lead practice performance. The typical plan/do-check-act approach is also an integral part of the performance schematic.

Figure 1: Leading practice performance evaluation

Evaluating performance: monitoring and auditing leading practice schematic



Source: David Donato, Donato Environmental Services.

Significant components or potential impacts that need to be monitored and managed at key stages of the mine's life are identified at the development stage of a greenfield mining project. This is usually done using a risk-based approach that incorporates the following elements.

- Regulatory requirements are identified to define the minimum standard of achievement for environmental protection and associated monitoring.
- Baseline studies are used to identify pre-mining environmental, social and economic values and impacts and to establish monitoring and management programs. This enables companies to commence long-term planning for sustainable development and mine closure before any project-related impacts occur and to develop robust and defensible closure performance criteria.

- An environmental and social impact assessment is conducted to enable regulators and other stakeholders to review predicted impacts and proposed mitigation measures. This must be a transparent process based on both good science and extensive consultation, and conducted using an agreed risk management and sustainable development approach.
- Company risk management frameworks are defined to identify potentially 'significant' residual risks so that control measures can be developed and applied and the success of their implementation can be evaluated.
- A budget and estimation of time should be allocated to ensure that the requisite monitoring has been incorporated into the overall business and operational plans for the operation.
- Internal company standards and procedures are applied to ensure that the corporate objectives are clear and provide a minimum standard of environmental protection for individual sites to attain.
- Leading practice guidelines from Australia and overseas, such as the International Council on Mining and Metals principles (ICMM 2003), provide guidance, case studies and frameworks for planning.
- Ongoing monitoring programs are established to assess performance through time against specified objectives. Together with research programs, ongoing monitoring enables continuous improvement by providing information to guide future adjustments that may need to be made to monitoring and environmental management. Rigorous and timely review of the data collected by a monitoring program is critical to ensure both that advance warning is provided of developing issues and that the content of the monitoring program remains relevant.
- Because every mining project and community is different, ongoing research is conducted to address gaps in knowledge and to develop innovative solutions to emerging challenges. The use of research findings to improve the effectiveness of monitoring is a key element of the continuous improvement loop that comprises leading practice.
- Audits are used to evaluate compliance with regulatory requirements, company standards and/or other adopted systems and benchmarks. This helps industry to demonstrate its performance to stakeholders and encourages continuous improvement. Transparent communication of these findings is an important element of a leading practice monitoring and performance evaluation system. When audits of monitoring programs identify gaps in knowledge or inadequacies in control measures, they enable monitoring programs to be improved.

Often, these elements are part of an environmental management system (EMS) that complies with AS/NZS ISO 14001:2004 *Environmental management systems—requirements with guidance for use*. An EMS helps the company to achieve leading practice by providing a framework for the development and regular review of procedures used to assess, mitigate and manage environmental impacts. The elements also apply to monitoring and auditing the performance of brownfield sites. Some adaptations may be needed depending on the site and its context, including the physical and social aspects, the age of the mine, key risks or issues and the historical evolution of the site and its ownership.

Leading practice often also includes a social management system (SMS), which guides the implementation and regular review of procedures to assess, mitigate and manage social impacts. While there is no certifiable standard in accordance with which such a system can be developed, it follows much the same structure as an EMS, but is based on key social rather than environmental themes, such as human rights; community investment and development; land access and acquisition; resettlement; cultural awareness and heritage; local employment; local procurement; social impact management; and stakeholder engagement. Generally, an SMS will include a policy and set of standards, along with guidelines for the implementation, monitoring and assessment of those standards and a regular audit and review process.

This handbook describes how mining companies integrate all of these elements over the life of the mining operation to achieve leading practice sustainable development. The handbook outlines the key principles and procedures now recognised as leading practice for monitoring and auditing to evaluate performance: assessing and managing environmental, social or economic values, and identifying, minimising and managing any primary, secondary or cumulative impacts on those values. Leading practice requires the principles to be addressed over the whole potential project sphere of influence, always in consultation with government and other key stakeholders, and often in partnership with non-government organisations.

A number of case studies are used to illustrate and reinforce the approaches outlined in the handbook.

Most of the environmental, economic and social aspects discussed in the handbook are relevant to both open-cut and underground mines. However, it should be noted that some issues specific to underground mines, such as subsidence, underground coal gasification and geothermal aspects, are beyond the scope of the handbook. For sites where there may be risks associated with such issues, readers are urged to consult other relevant publications and information sources. Occupational health and safety matters are also not covered, except where they are directly relevant to the implementation of monitoring and auditing procedures.

1.3 Corporate social responsibility

Expectations on mining companies regarding their social and environmental impacts and contributions are rapidly changing. Single-sector solutions to poverty and sustainability challenges are not progressing fast enough, and increasingly companies are being called on to collaborate with government and civil society. Most recently, several extractive companies have been contributing to multi-stakeholder discussions to shape the sustainable development agenda, in drafting Rio+20 'The Future We Want' and United Nations Sustainable Development Goals. The goals are the next generation of collective global action that succeed the United Nations Millennium Development Goals, which expired in 2015. With an increased corporate focus on integrated reporting, combined with the emerging discourse on creating shared value and the growing demand for improved social impact metrics, mining companies are under increasing pressure to incorporate more robust evidence of social value creation into their core business through corporate social responsibility agendas.

Increased focus on responsible business practices has emerged over recent years, with the endorsement of the United Nations Guiding Principles on Business and Human Rights in 2011 being a key milestone. Social performance reporting has become relatively commonplace among big multinational mining companies over the past decade. The advent of voluntary initiatives and frameworks such as the Global Reporting Initiative, the United Nations Global Compact and the Dow Jones Sustainability Index mean that there are many reporting frameworks available; a challenge for companies is to select how best to embrace and respond to them according to reporting needs and objectives.

An additional challenge is that existing reporting practices no longer fully address stakeholder expectations; there is increasing demand for greater disclosure of environmental, social and governance performance (Paul and Nieland 2013). Until recently, stakeholders (investors, customers, employees, NGOs, communities) have been content with disclosures that demonstrate a company's commitment to responsible practices and to managing the social and environmental risks and impacts of its operations. Increasingly, however, stakeholders are pushing to see evidence of the positive social contribution companies are making to society, while companies are recognising that social value is often critical to their social licence to operate, and to managing risk and creating long-term business value. Companies across all industries are thus being called upon to measure and report the social impacts of their business activities

and corporate social responsibility initiatives. Often the need for a business case for particular components of the operation further compounds the challenge and calls for an approach to corporate reporting that not only measures social outcomes, but also promotes the delivery of social outcomes in a way that is strategically aligned with broader business objectives.

A recent evaluation of several leading reporting methods commonly used by Australian mining companies was undertaken to assess their ability to contribute to demonstrating sustainable social development (Bennett and Thom 2013). The following frameworks were selected for analysis, as they are those most commonly used by companies to report social performance at the corporate and site level.

- Global Reporting Initiative: Sustainability Report (GRI)
- United Nations Global Compact: Communication on Progress (UNGC)
- Dow Jones Sustainability Index: RobecoSAM Corporate Sustainability Assessment (DJSI)
- International Integrated Reporting Framework: Integrated Report (IR)
- London Benchmarking Group: Community Investment Report (LBG)

The following site-specific framework and methodology were also included in the analysis:

- Mining Association of Canada: 'Towards Sustainable Mining' Framework (TSM)
- socioeconomic monitoring and assessment.

The performance of each of the frameworks was assessed against seven key criteria (Table 1, Table 2).

Table 1: Criteria for assessing frameworks

CRITERIA	DESCRIPTION
1. Ability to promote performance	The extent to which the framework promotes social performance through both internal and external engagement and capacity building.
2. Sustainable outlook	The extent to which the framework promotes a sustainable long-term outlook and approach to monitoring and promoting performance.
3. Social coverage	The extent to which the framework focuses on the social issues considered material to both the company and its stakeholders.
4. Outcomes focus	The extent to which the framework focuses on social outcomes (as opposed to inputs, processes and outputs).
5. Ease of application	The extent to which the framework is easily accessible, adoptable and adaptable.
6. Reliability	The reporting framework is mandatory for all Mining Association of Canada members, and content is externally verified, which ensures disclosure is a true representation of performance.
7. Business case	The extent to which the framework makes the connection between social performance and the broader business strategy.

The results of the analysis show those frameworks that performed best against each of the abovementioned criteria.

Table 2: Reporting frameworks that performed best against each criterion

CRITERIA	FRAME WORK	JUSTIFICATION
1. Ability to promote performance	TSM	The reporting process is conducted at site level, rather than corporate, which promotes broader internal engagement and operational accountability for social performance and enhances internal capacity building. It also promotes performance by aligning mining activity with the priorities and values of its communities of interest.
2. Sustainable outlook	TSM	The focus on management systems, the promotion of community participation and the progressive performance rating system based on incremental improvements to management approach promote a sustainable, long-term outlook.
3. Social coverage	GRI	Encompasses the widest range of social aspects and encourages companies to consider those social issues of significance both to stakeholders and to the company.
4. Outcomes focus	LBG	One of the only reporting frameworks to focus specifically on the measurement of social outcomes. Rigorous data requirements also enable companies to effectively evaluate social and business outcomes and identify opportunities for shared value creation.
5. Ease of application	TSM	Clear, succinct principles and frameworks coupled with a simple and progressive self-assessment protocol that can easily be implemented at site level. This simplicity renders it the most accessible, adaptable and adoptable of all the frameworks assessed.
6. Reliability	TSM	The reporting framework is mandatory for all Mining Association of Canada members, and content is externally verified, which ensures that disclosure is a true representation of performance.
7. Business case	IR	The reporting process calls for integrated thinking, collaboration and connectivity across the entire business. It also places social capital on the same plane as financial and environmental capital and provides a means for social development to be valued and integrated into the overall value of the company.

Despite the strengths outlined in several reporting frameworks and site-based methodologies above, no one framework alone is sufficient to drive sustainable development outcomes to the extent that would optimise returns on social investment and satisfy stakeholder expectations. Instead, a blended approach, that includes the following, is encouraged:

- Site-based reporting that promotes community participation in planning and decision-making for social investments is critical for purposeful and material social outcomes, in combination with socioeconomic surveys that generate valuable data and ensure that local action is contributing to regional and international development indicators.
- A mix of corporate reporting frameworks that link social investments to business strategy ensures a depth of focus on a range of social issues and illustrates the value and impact of those investments.
- A multi-sectoral approach that promotes cross-sector collaboration strengthens local systems, capabilities and processes and tracks progress towards long-term sustainable development objectives.

Along with a blended approach to social investment and reporting, regular independent assurance, technical and behavioural training, and ongoing efforts to ensure company and leadership buy-in are critical to embedding strong social performance within mining companies. This should be reinforced by a values-driven culture that locates social and environmental risks and contributions within core business, as everybody's business, not only the business of those that are closest to the issues.

1.4 Deficiencies in current monitoring and auditing practices

While focusing on leading practice, it is useful to understand the key deficiencies of past monitoring and auditing practices in order to avoid repeating them. Commonly encountered deficiencies include:

- lack of a clearly defined purpose for the monitoring program and/or audit process, leading to unsatisfactory outcomes, wasted resources and potential conflict with stakeholders because expectations are not met
- dysfunctional feedback loops, meaning that data is not analysed or the analyses are not used to enable continuous improvement
- performance measures that are too narrow and fail to include adequate socioeconomic and environmental perspectives
- an inappropriate level of public reporting, meaning that the purpose, context and findings from monitoring and auditing programs are not clearly understood
- monitoring plans that are not able to evolve through the life of the mining operation because key elements remain largely focused on start-up issues
- adequate baseline data not being obtained to enable the effective identification or management of long-term issues
- not adequately dealing with problems relating to the alteration and destruction of monitoring infrastructure (for example, inadequate planning to avoid or otherwise address this, not documenting infrastructure changes to enable the explanation of vagaries in the dataset)
- inadequate attention to data quality control
- inadequate maintenance of records following planned or unplanned changes in monitoring methods or monitoring infrastructure or equipment
- time frames for review that reflect regulatory requirements but are not consistent with changes to site operations or suitable for proactively addressing developing site issues
- annual monitoring reports that are treated as a regulatory compliance requirement only, with an inadequate level of technical interpretation to proactively identify and manage developing site issues and/or are not integrated with the continuous improvement process on site
- inappropriate or inadequate use of risk assessment methods to provide an additional mechanism to identify changing monitoring needs.

1.5 Links to the impact assessment process

Environmental impact assessments (EIAs) have been required by the Australian Government and state governments in Australia for more than three decades. The primary basis for impact assessment is to examine the potential impacts of any project before it proceeds so that a fair and balanced decision can be arrived at as transparently as possible. Impact assessment can also be required before a significant expansion or change in the originally approved project scope, such as changing from an underground to an open-cut operation.

The scope and statutory basis for EIA is continually evolving as community knowledge and expectations mature, technology improves, projects become larger in scale and the status of regions changes. EIA has evolved over the past decade from being largely focused on environmental issues to more explicitly accounting for social or economic impact assessment and planning, with increasing emphasis on combined environmental and social impact assessments. A particular shift in recent times has been the consideration of cumulative impacts. At its highest level, cumulative impact assessment addresses the sum of impacts of a proposed project across the social, environmental and economic dimensions. In the specific context of environmental impact, there is an increasing expectation by regulators that the cumulative effects of existing or proposed multiple operations in a region (such as impacts on water resources in a river catchment) will be addressed as part of the approvals process. Changes in the EIA process are expected to continue, and the emphasis on sustainability is likely to become more important for future mining projects.

Both monitoring and auditing are integral parts of the impact assessment and management process that is ongoing throughout the life of a mining operation. For example, monitoring systems play a key role in the initial assessment of values and likely impacts, while the establishment of environmental management programs to minimise ongoing impacts and facilitate recovery or rehabilitation requires ongoing monitoring, research, auditing and overall performance evaluation.

Leading practice sustainable development increasingly requires the application of impact assessment and management tools in a multidisciplinary manner above and beyond the requirements of legislation alone.¹

What are the different types of impact assessment?

Environmental impact assessment (EIA) is an assessment of the possible impacts—positive or negative—that a proposed project may have on the environment and the affected community, including impacts on heritage values and economic impacts. At the federal level in Australia, EIA provisions are contained in the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). At the state level, EIA provisions are typically contained in land-use planning law, apart from in Western Australia, where they are in the state's *Environmental Protection Act 1986*.

Environmental and social impact assessment incorporates both a social impact assessment and an EIA, which may have been undertaken separately in the past, and explicitly accounts for social or economic impact assessment and planning. Guidelines for EIA in Queensland and some other states now specifically require social and heritage values to be included.

Socioeconomic impact assessment (SIA) is an analysis of the economic impacts of a proposed project on communities, as required by leading practice in both life-of-mine-planning and impact assessment. A new methodological handbook for conducting SIAs was produced in 2012 by the International Mining for Development Centre (Franks 2012).

Primary versus secondary impacts: Primary impacts are often called direct impacts, while secondary impacts are referred to as indirect or induced impacts.

¹ For example, see http://www.angloamerican.com.au/development/social/community-engagement/-/media/Files/A/Anglo-American-Plc/siteware/docs/seat_toolbox2.pdf.

Cumulative impacts and effects are also an important consideration in resource development. Cumulative impacts and effects on the environment, people and communities can occur incrementally and involve a number of different inputs, some of which may be related to the development, while others might not. As the International Finance Corporation (IFC) states, 'In some cases, the most ecologically devastating environmental effects and subsequent social consequences may result not from the direct effects of a particular action, project, or activity, but from the combination of existing stresses and the individually minor effects of multiple actions over time' (IFC 2013).

Human rights risk assessments (HRRAs) and *human rights impact assessments* (HRIAs) constitute a necessary component of a company's due diligence process in accordance with the UN Guiding Principles on Business and Human Rights (see Section 2.1), based on the company's responsibility to respect human rights.

HRRAs and HRIAs should complement, and can be integrated into, the company's pre-existing impact assessment and due diligence processes and should be used across all stages of the project life cycle to inform project design and planning, monitor risks and impacts in development, and evaluate human rights risks and opportunities throughout operations and beyond mine closure.

HRRAs and HRIAs encourage consideration of a broader range of issues than standard SIAs, and touch on cross-cutting themes relevant to every aspect of the business.

1.6 Monitoring and evaluating cumulative impacts

Primary and secondary impacts can be obvious or well known, such as the construction of roads or large infrastructure, while other activities can be smaller but when considered together or over a certain period they can become concerning to stakeholders. While advances are being made, many practitioners are still developing techniques and ways to adequately incorporate cumulative impacts and effects into their research and impact assessments (IFC 2013).

Cumulative effects and impacts arise from different sources, inputs and activities occurring in combination, and the resulting impact is potentially larger than the simple sum of the impacts predicted to arise from each of the sources alone. Cumulative effects can occur when impacts are:

- additive (incremental)
- interactive
- sequential, or
- synergistic.

In the mining context, cumulative impacts on society, the economy and the environment can arise from compounding activities of a single operation or multiple operations. Cumulative effects impact assessments are typically conducted at the scale of human communities, regional landscapes, catchments or airsheds and require monitoring data to quantify all of those aspects (DEAT 2004; Franks et al. 2013).

The IFC has produced extensive recent guidance for conducting cumulative impact assessments for emerging markets and economies (IFC 2013). This guidance notes that:

cumulative impact assessment is evolving and there is no single accepted state of global practice. What is important is that during the process of identifying environmental and social impacts and risks, developers or project sponsors (a) recognize that their development may contribute to cumulative impacts on valued environmental and social components (VECs) on which other existing or future developments may also have detrimental effects, and (b) avoid and/or minimize these impacts to the greatest extent possible. (IFC 2013)

Complementing the guidance produced by the IFC is the *Sustainability reporting guidelines and Mining and metals sector supplement* produced by the Global Reporting Initiative (GRI 2011).

A recent contribution from Australia to addressing the potential conflicts that arise between multiple land uses and associated impacts, including mining, is the COAG Energy Council's Multiple Land Use Framework (MLUF) (SCER 2013). The framework has been developed to address challenges arising from competing land uses, land access and land-use change, with a focus on the mining industry. The aim of the MLUF is to enable government, community and industry to effectively and efficiently meet land access and use challenges, expectations and opportunities. The framework supports the ability of local and regional communities, industries and governments to maximise land use in a flexible, environmentally sustainable manner over time. The Strategic Framework for Managing Abandoned Mines in the Minerals Industry (MCMPR–MCA 2010) encourages managers to gather data to create jurisdiction-wide inventories as a basis for risk assessment and management.

Good practice requires that, as a minimum, the developers of a mining project assess whether their development may contribute to cumulative impacts on valued environmental and social components (VECs), may be at risk from cumulative effects on VECs they depend on for future viable operation of the project, or both.

Cumulative impact assessment can be applied over multiple scales—from a single operation to large parts of states or provinces. For example, the potential effect of an individual operation on the sustainability of a region may initially need to be addressed as part of the EIA process, with subsequent reporting against performance objectives required following approval and the start of mining. Equally as important is ongoing stakeholder communication and engagement to test and validate whether continuous improvement is occurring and company resources are adequate. Increasingly, however, the concept of cumulative impact assessment is being applied across regions in which there may be multiple existing, new or proposed mining developments. Such regional assessments are typically required when there are multiple mines affecting an economically and/or environmentally important river catchment, or where there are laterally extensive mineral deposits on which multiple mines exist or are being established.

A good recent international example of a regional cumulative impacts study addressing social, economic and environmental aspects is provided by the Ministry of Mines and Energy in Namibia. This strategic environmental assessment was conducted to address the possible consequences of a large expansion in the mining of uranium in that country (MME 2010). The assessment provided a big-picture overview and advice to the Namibian Government on how to avoid negative cumulative impacts, as well as how to enhance opportunities and benefits within the uranium sector and between mining and other industries. While the individual EIAs for the new mines and the EMSs in place at the existing mines deal with the impacts caused by the individual mines, the strategic environmental assessment considered the cumulative spatial and time-crowding effects of various possible uranium mining expansion scenarios. This provided the framework for being better able to develop synergies between operations in the context of integrated environmental, social and health management.

In Australia, the extensive iron ore deposits in the north of Western Australia and the major coal deposits in Queensland and New South Wales are the clearest examples of where the effect of multiple mines of the same type in relatively close proximity is requiring the effects of cumulative impacts to be addressed. In these cases, the impacts of multiple operations on the quantity and quality of groundwater and surface water and the ecological and human systems that depend on them have been the primary concern. The coalmining industry has been a particular focus in recent years after the inclusion of a ‘water trigger’ provision in the Australian Government’s EPBC Act. This change to the Act required all new coalmining and coal seam gas projects that are likely to have a significant impact², including cumulative impacts, on water resources to be assessed under the provisions of the Act. In addition, proposed expansions of existing mines may be subject to assessment under the Act. Comprehensive guidance is available on approaches to address cumulative impacts from coalmining (DERM 2009; Franks et al. 2010a, 2010b, 2013); the most extensive report on this subject was produced with funding from the Australian Coal Association Research Program (Franks et al. 2010). The concepts discussed in these publications should be readily transferrable to the broader mining industry.

A world-leading practice example of the application of cumulative impacts monitoring and analysis to the management of river water quality is provided by the Hunter River Salinity Trading Scheme (NSWEPA 2015; Vink et al. 2013). This scheme is a collaboration between the coalmining and electricity generating industries and regulators in New South Wales. Its purpose is to minimise the impacts of discharges of saline water into a high-value river system that supports competing mining, agricultural and urban uses. A network of 21 flow-monitoring and electrical conductivity stations along the river transmits data at 10-minute intervals. A river model then calculates the allowable increment of discharge from each mine in response to changing rainfall and flow within the catchment area.

It is currently being proposed that a similar cumulative salinity trading scheme be established for the Fitzroy River in Queensland, which has the second largest catchment area of rivers in Australia (Vink et al. 2013). Like the Hunter River catchment, the Fitzroy River catchment contains many large coalmines that coexist with a diverse regional agricultural industry (and many more mines and an expanding coal seam gas industry are proposed over the next decade). Cumulative impacts from active and abandoned mines resulting from controlled and uncontrolled discharges of contaminated water were highlighted as being matters of concern in the report produced by the Queensland Floods Commission of Inquiry (Chapter 13, 2012; http://www.floodcommission.qld.gov.au/data/assets/pdf_).

² For the definition of ‘significant impact’, see Australian Government (2013).

Case study: Strategic management of cumulative impacts of coalmine wastewater releases in the Fitzroy River Basin—a regulatory perspective

In order to develop an understanding of the cumulative impacts of economic development within a river catchment, a temporal and spatial perspective on all the current and potential future developments in the catchment is needed. Immediately, it would seem obvious that good strategic planning is required if sustainable water quality is to be achieved in a catchment where multiple activities are contributing contaminants to a river. Unfortunately, this has rarely occurred, and approvals are usually assessed on a case-by-case basis with limited information or assessment of other catchment inputs. The regulation of wastewater releases from coalmines in the Fitzroy River Basin is one example where regulation has significantly evolved to keep up with the rapidly changing water-quality issues downstream of multiple mining activities.

The Fitzroy River Basin includes six major rivers that constitute Australia's largest east-draining river system. The Fitzroy catchment contains more than 40 currently operating coalmines that have the potential to contribute significant saline discharges to the basin's waterways.

In 2008, unusually high rainfall caused flooding in a number of mines in the basin. The subsequent release of flooded mine pit water between February and September 2008, mainly from one coalmine, led to an increase in salinity in downstream drinking water supplies and many complaints about water quality. In response, the Queensland Government commissioned a review of the cumulative impacts of mining activities on the water quality in the Fitzroy Basin (DERM 2009).

The review provided a risk assessment for the most sensitive environmental values within the freshwater reaches of the Fitzroy, including aquatic ecosystems, crop irrigation and drinking water. On the basis of the volumes of water released from the mines and the salinity of downstream receiving water after releases, the review identified a potentially high risk from cumulative salinity, particularly in the Isaac River in the North Fitzroy, where there is a high concentration of mines. As a consequence of the 2009 cumulative impact study, standardised model conditions were developed and the environmental authorities for each of the Fitzroy mines were reviewed by the regulatory authority, which is currently known as the Department of Environment and Heritage Protection (DEHP).

The Queensland Government's model water conditions for coalmines in the Fitzroy Basin (more recently revised as the 'model mining conditions' (DEHP 2013), provide a consistent strategy for releases of mine-affected water from coalmines such that saline waters are to be released only at times of high natural flow (that is, following heavy rain) to ensure adequate dilution, whereas water of comparatively low salinity can be released at times of base or medium natural flow. The intent was to protect environmental values downstream of the mines, including sensitive aquatic ecosystems and areas of high ecological value.¹

¹ An ecosystem of high ecological value is the highest ranked ecological condition defined in ANZECC-ARMCANZ (2000). It is effectively an unmodified or other highly valued ecosystem.

Also developed was a release calculator that could allocate a proportion of the downstream assimilation capacity to several different mines, thereby reducing the potential for cumulative impacts. Substantial work has also been done in the catchment since 2008 to develop local water-quality guidelines and scheduling environmental values and water-quality objectives within the Queensland Environmental Protection (Water) Policy.² Although water-quality objectives are not imposed end-of-pipe, this information has been essential for developing standardised conditions and approaches for assessing cumulative impacts in the region, and is used to assess outcomes in the environment.

Despite the adoption of the model mining conditions approach, many coalmines in the Fitzroy Basin have been unable to reduce volumes of retained flood waters, either because they have not been able to exploit high-flow opportunities when they arose or because subsequent high-rainfall events have exacerbated the problem. Therefore, in 2012, in a further response to continuing issues involving stored saline water, the Queensland Government initiated a pilot program in the Isaac River that would allow some mines to release saline water outside of the model conditions framework. This pilot program was subsequently expanded throughout the Fitzroy Basin in 2013 (DEHP 2013). Ongoing monitoring of water quality and biological integrity has been, and will continue to be, used to ascertain whether the rates and volumes of wastewater released under this policy successfully protect all downstream environmental values.

The experience in the Fitzroy Basin highlights the need for:

- strategic future planning for all mining operations, particularly where multiple operations are likely to occur within a single catchment or subcatchment
- basin-wide assessment of water quality and assimilative capacity modelling to allow an equitable distribution of river usage among all activities and stakeholders, including aquatic ecosystems, agriculture, mining and human consumption
- greater emphasis on water management plans at the environmental impact statement stage of coalmine development applications to ensure that there is minimal build-up of saline waters over time, as a consequence of either onsite water management or extreme weather
- ongoing monitoring and assessment of water quality and environmental values by approval holders and broader catchment managers.

² The Environmental Protection (Water) Policy (2009) is subordinate to the Environmental Protection Act. Details on the policy and its environmental value and water quality objectives are at <http://www.ehp.qld.gov.au/water/policy/index.html>.

Case study: Integrated water management by Anglo American's Metallurgical Coal Business Unit

This case study describes stewardship actions adopted by Anglo American's Metallurgical Coal Business Unit to better manage risks associated with water management at its open-cut coalmines in the Fitzroy River catchment in central Queensland and to improve monitoring to meet the requirements of new regulations, introduced after the 2010–11 floods, to manage water stored on site (DEHP 2013). The historical background to the development of the regulations is provided in the 'Strategic management of cumulative impacts of coalmine wastewater releases in the Fitzroy River Basin' companion case study in this handbook.

The highly variable climate of the Fitzroy River catchment creates dual challenges for mine operators: from lack of water in dry years and excess water in wet years. During and after the major 2010–11 floods, the ability of mines to rapidly release stored water into highly diluting catchment flows was often delayed as a result of issues with both available water management infrastructure and the nature of the approvals process in place at that time. By February 2011, 80% of the coalmines in the Bowen Basin had restricted operations due to excess water (QFCI 2012, Chapter 13). Excess water can close roads, inundate pits, damage infrastructure and compromise safety.

Following the 2010–11 wet season, the Queensland Government initiated a review of release conditions for mine water and proposed a framework that allows mine-water releases as long as there is sufficient flow in the surrounding environment to dilute the water and maintain environmental values. This framework recognises that, in times of large flows in creeks and rivers, the controlled release of mine-affected water at appropriate dilution ratios poses a greatly reduced risk to the environment. For the mines that adopted the framework, meeting those conditions for discharge required precise real-time measurements of both flow and water quality.

Anglo American's Metallurgical Coal Business Unit consequently took action to adopt better forecasting of rainfall, real-time monitoring of stream flows and water quality, and better coordination between engineering and environmental teams. While mines already had monitoring systems in place, they were further refined to provide the data needed to meet the new requirements. Requirements for a high standard of monitoring and rapid-turnaround data analysis capability are becoming features of the modern mining sector.

Anglo's operations have adopted a fully integrated approach to monitoring and managing onsite water. The expected benefits from the investment include:

- reduced risk of mine pits being flooded
- reduced safety risks to employees
- reduced impacts on roads and machinery from flood damage
- the ability to store as much water as is safely possible for future use onsite, while still providing contingency storage capacity for high-rainfall events.

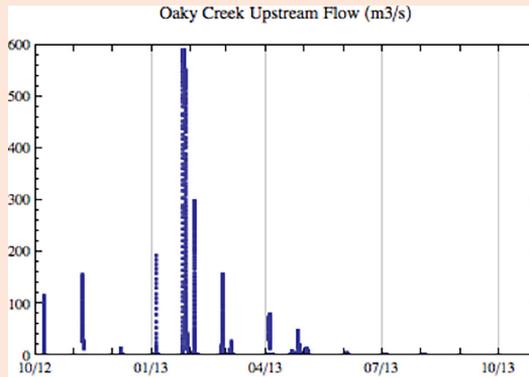
The adopted strategies were:

- exploring options to better anticipate rainfall and run-off through tracking and responding to medium-term (monthly) and longer term (1-5 years) forecasts
- automated monitoring and real-time communication of upstream creek flows and levels of salinity and turbidity
- daily data uploads into a state-of-the-art data management system for in-depth data analysis to address circumstances that can lead to more effective release conditions
- monitoring mine-water levels and quality, and the establishment of visual dashboards in the environmental database for easy and effective communication of risks related to mine-water storage
- detailed analysis of landforms and the design of levees and drains to divert excess water from mine infrastructure, where possible
- upgrading roads and particularly creek crossings to maintain access during high-rainfall events
- upgrading infrastructure to allow water to be rapidly moved around and managed (28 additional pumps and 135 km of new pipes at the Dawson and Capcoal mines)
- improving the communication and coordination of site teams to better integrate engineering and environmental water management.

The business case for Anglo American's \$120 million investment in improved water monitoring and management was supported by substantially reducing the number of production days lost due to wet weather. The collateral environmental benefits included reducing the volume of floodwaters that enter pits and ensuring compliance with release conditions, monitored in real time, designed to ensure the protection of the receiving waterway.



During the 2010–11 floods, substantial volumes of legacy water accumulated in storage pits.



Real-time monitoring of stream flows provides an effective tool with which to control and manage mine-water releases.



The location of Anglo American's operations in the Fitzroy River catchment.

While metal mining in general is not subject to the water trigger provisions of the EPBC Act, there is an increasing expectation by state regulators that the cumulative effects of existing or proposed multiple mining operations in a region (such as the impact on water resources in a river catchment) be addressed as part of the approvals process. The simplest example of the need to consider cumulative impacts on water quality occurs when a proposed operation is located downstream of an existing operating or legacy site. In this case, there is a need to establish the upstream (that is, upstream of the new operation) baseline against which the performance of the new operation can be assessed and managed (for example, deriving a waste discharge licence and development of local water-quality criteria in collaboration with regulators).

It will not be practical to analyse the cumulative effects of a new or existing mine on every environmental receptor or social indicator. Hence, the focus of the assessment and reporting process needs to be on those indicators that must be protected and/or those for which meaningful monitoring or measurement results can be produced. A good starting point for identifying what needs to be monitored and assessed is the list of agreed environmental and social values for the area in which a mine is located. In a regulatory context, government will often assist in determining the requirements and the scope of the assessment. Overall, the scope of the assessment should be set (by agreement) so that the impact assessment is not attempting to measure effects on everything. Upon the completion of the impact assessment, an impact management plan can be implemented for ongoing monitoring and evaluation of management responses. Implementing an impact management plan will ensure a greater likelihood of obtaining high-quality monitoring data for the key identified attributes.

2.0 SUSTAINABLE DEVELOPMENT

2.1 Guiding principles

The application of sustainable development principles to mining has undergone rapid evolution in the past decade, in concert with the global trend in commitment to sustainable development generally. Many of the formation guiding principles documents are still relevant.

The Mining, Minerals and Sustainable Development Project report *Breaking new ground* (IIED 2002) explored in detail how mining could further contribute to sustainable development. The Minerals Council of Australia (MCA) developed *Enduring value: the Australian minerals industry framework for sustainable development* to articulate and implement sustainable development within the Australian mining industry (MCA 2004). The International Council on Mining and Metals (ICMM) has also developed a sustainable development framework covering principles, public reporting and independent assurance (ICMM 2006; the principles directly relevant to this handbook are 4, 5, 6, 7, 9 and 10). While not all mining companies are signatories to these values and principles, they provide useful guidance on what leading practice means.

A core principle in sustainable development is the precautionary principle, which is simply stated in the 1992 Intergovernmental Agreement on the Environment as:

Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. (DEWHA 1992)

Monitoring and auditing are critical tools for demonstrating the effective implementation of sustainable development principles. The information they provide is crucial in assessing and managing the extent of impacts and hence supporting the application of the precautionary principle. This chapter describes the main methods and standards that provide guidance for incorporating sustainable development principles into performance evaluation programs, and hence the attainment of a leading practice approach.

2.2 National and international standards

Government policy and corporate policy are becoming increasingly committed to sustainable development. In general, while both sectors might commit to high standards and the use of available international protocols, they often leave implementation to individual companies or mining operations. For example, ICMM members are committed to responsible mining practices (as described in the ICMM 'good practice mining' resources available through www.icmm.com), but ICMM does not provide detailed, prescriptive guidance. Rather, it recommends an approach that is flexible and able to be tailored to meeting the specific local requirements of companies or mining projects.

Many standards or protocols seek to facilitate the operational implementation of sustainable development principles. They include voluntary industry protocols such as the ICMM principles or MCA's *Enduring value*, as well as numerous relevant standards from the International Organization for Standardization (ISO) and Australian/New Zealand Standards (AS/NZS) for various aspects of monitoring.

The World Bank's International Finance Corporation has developed a series of performance standards on social and environmental sustainability, as well as environmental, health and safety (EHS) guidelines for

mining and general EHS guidelines, which are relevant to environmental and social monitoring and auditing (IFC 2006, 2007a, 2007b). In addition, an increasingly popular protocol is the Global Reporting Initiative (GRI), which was established by the United Nations in conjunction with governments and civic and industry groups specifically to facilitate consistency and transparency in sustainability reporting (GRI 2006), and which is now in its fourth iteration (see sections 1.3 and 4.16). Although these protocols are essentially voluntary, compliance is increasingly being expected as evidence of good corporate governance.

2.2.1 Legislation and regulation

Australia

A range of Australian state and federal legislative requirements are relevant to monitoring, auditing and performance assessment for mining, such as the requirements for EIAs, surveying and monitoring of species or ecosystems listed under the EPBC Act, and regulations for monitoring air or water quality, pollutant discharges and so on. Many of the requirements are commonly included in mining leases and other statutory licences and conditions. In relation to the EPBC Act, consistency between state and federal government requirements is also increased by the fact that the process can be delegated so that only one set of environmental and social impact assessment requirements has to be met to comply with all federal, state and territory legislation and local government requirements.

However, the EPBC Act does not protect biodiversity of national significance from the impacts of abandoned mines; nor does state environmental protection legislation address the environmental impacts of abandoned mines (see, for example, QFCI 2012). In the absence of abandoned-mine legislation and policies, ambiguity remains over responsibilities, standards and processes to achieve beneficial post-mining land uses.

State governments have the primary constitutional power to manage the environment and to issue mining titles and environmental or pollution control licences. While different states have different requirements and expectations for monitoring, auditing and performance, the overarching philosophy applied in Australia is that of principle-based regulation. In practice, this means that mining companies have considerable flexibility in the practices they may use to meet specific performance targets (for example, water-quality guidelines that apply to their individual situation). This kind of regulatory regime is well suited to the implementation of leading practice principles by the mining industry, since it can more readily accommodate and recognise the development and implementation of better ways of meeting environmental performance targets. Leading practice helps to ensure continued improvement across all jurisdictions by aiming for performance outcomes that are beyond those that represent current industry best practice. Federal legislation has encouraged companies to undertake research by enabling them to take advantage of tax incentives for the implementation of innovative and systematically planned research studies. Monitoring is an integral part of sustainability research, since the monitoring data is needed to measure and document the effectiveness of new solutions to environmental management issues.

Under the Australian Government's National Pollutant Inventory, specific pollutants emitted above minimum thresholds are required to be monitored (or estimated) and publicly reported.

Recently, the National Environment Protection Measures have undergone changes that must be applied in the management of contaminants (SCEW, n.d.). The concept of such measures is unique to Australia and is provided for under the national environment protection Acts.

Although compliance with the legally required measures does not, by itself, represent leading practice, companies recognised for leading practice consistently meet regulatory requirements for monitoring, auditing and reporting. They also tend to have more productive relationships with their community stakeholders as a result of being able to communicate robust monitoring and audit outcomes. In the event that a leading practice approach results in superior environmental performance more cost-effectively than had previously been considered practicable, the implementation of the practice is more likely to be considered favourably by regulators as part of future approvals processes or for applications for major changes to scope at already operating sites.

Having operated beyond the compliance requirements, operators who are proactively addressing knowledge gaps and integrating new knowledge into progressive rehabilitation and closure plans are more likely to successfully close their mine and be able to relinquish their mining tenure (see, for example, the ‘Monitoring to improve the quality of rehabilitation’ case study in Section 3.6). Those who do not operate beyond compliance may run the risk of having to manage site impacts such as contaminated water in perpetuity.

International

In the international sphere, monitoring and reporting are becoming increasingly important not only for demonstrating successful environmental management, but also for illustrating the company’s strategic approach to business continuity and sustainable growth (see Section 4.16.2, ‘Integrated reporting’).

The legislative and international basis for emissions accounting and reporting continues to evolve rapidly, along with ongoing global commitment to climate change mitigation. In anticipation of the shift to a low-carbon economy, companies are under increasing pressure from investors to demonstrate a move to low-carbon business models that effectively respond and adapt to increasing regulation and the swing in consumer sentiment. Demonstrating how the business is adapting not only to the physical risks but also to the financial and regulatory risks associated with climate change is critical, particularly as governments prepare to commit to the next round of targets under the Kyoto Protocol.

In 2012, following the expiry of the first commitment period of the Kyoto Protocol, by which 37 industrialised countries and the European Union committed to reducing greenhouse gas emissions to an average of 5% against 1990 levels, the Doha amendment to the Kyoto Protocol was adopted. The amendment set out:

- new commitments to reduce emissions by at least 18% below 1990 levels in the eight-year period from 2013 to 2020
- a revised list of greenhouse gases to be reported on in the second commitment period.

In September 2014 at a UN summit in New York, countries under the Kyoto Protocol are expected to make pre- and post-2020 carbon reduction pledges, after which the monitoring and reporting requirements for companies may increase and performance standards become more prescriptive and demanding as governments endeavour to meet their new and ambitious reduction targets.

Trade restriction is also a critical area of focus in the international sphere. The European Commission’s 2006 regulation concerning the registration, evaluation, authorisation and restriction of chemicals (REACH) aims to provide for detailed assessment of the potential impacts of pollutants of products balanced against the desire for protecting human health, the environment and industry competitiveness. For example, elevated arsenic levels in metal concentrate or technologically enhanced naturally occurring radioactive material may preclude export to Europe under the REACH regulations. Therefore, a company exporting products to Europe must ensure that it monitors product quality and associated aspects to ensure that they comply with the regulations or risk being excluded from a key economic market.

For more information, see the leading practice handbooks *Risk management* (DIIS 2016a) and *Stewardship* (DIIS 2006).

The Minamata Convention, signed by Australia and many other nations in 2013, requires a commitment to a reduction in mercury in the environment due to the health impacts of exposure.³ For example, where goldmines have historically used mercury, the removal of mercury from soils and aquatic environments is required. Monitoring and evaluation of performance are essential to demonstrate the achievement of objectives.

2.2.2 Community expectations

It is normal for local communities in the vicinity of mining or mineral processing projects to want to stay informed about environmental aspects, social investment, economic contributions, statutory obligations and the like.

Historically, the mining industry has at times failed to provide timely information to stakeholders and the broader community about all aspects of particular mining operations. To achieve leading practice in this area, companies are becoming aware of what the community expects to know about mining operations and are setting up frameworks to identify stakeholders and their expectations, collect monitoring and auditing data over the life of the project, and report regularly to the affected community. This is part of a company's social licence to operate, as noted in the MCA's Enduring value framework.

Stakeholder engagement at the regional or catchment scale is emerging as an important tool. The multi-stakeholder Fitzroy Partnership for River Health is one example.⁴

³ <http://www.mercuryconvention.org/>.

⁴ <http://riverhealth.org.au/>.

Case study: PanAust in Laos—working with communities for sustainable livelihoods

Mining companies seeking to support community livelihoods via supply chain opportunities must be prepared to adopt flexible and adaptive procurement systems. Procurement needs to be responsive to local entrepreneurial capacities and informed by robust participatory monitoring and evaluation that ensures continuous improvement in locally based partnerships. Australian mining company PanAust faced this challenge. PanAust operates Phu Bia Mining, a Lao-registered company owned 90% by PanAust and 10% by the Government of Laos. Phu Bia Mining operates the Phu Kham copper–gold operation and the Ban Houayxai gold–silver operation in Laos.

Phu Kham, which is around 120 km north of the Lao capital, Vientiane, is directly adjacent to two villages—Nam Gnone and Nam Mo, which are home to 713 households with a population of 4,095 residents. The population is made up mainly of ethnic Lao, Khmu and Hmong people with a traditional economy historically based on subsistence agriculture.

Since the commencement of the operation in 2005, PanAust has undertaken regular socioeconomic and health survey monitoring as part of its operational and sustainable development activities. Aimed at enabling the company and the community to understand change as it unfolds, the surveys have shown a shift towards a cash-based economy, with household assets increasing in both villages and with fewer households exploiting natural resources through hunting, fishing and the collection of non-timber forest products.

The data from the socioeconomic monitoring surveys is used to provide a clearer picture of development needs and help prioritise both PanAust's and the community's development decisions and actions. The company has facilitated participatory community planning in local communities to better understand villagers' own perspectives on development challenges and priorities. Both approaches are used to provide a balanced community development program.

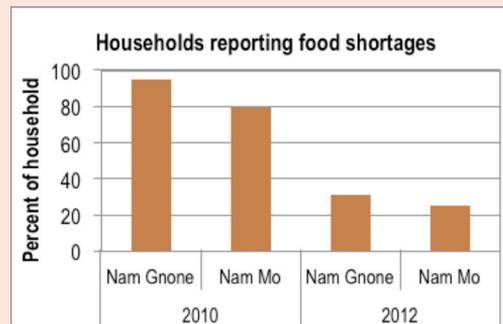
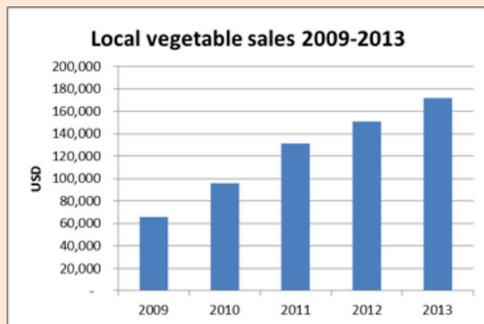
With the support of a company-sponsored community development fund, village development committees have worked with the company to identify and implement development activities that build upon local skills and capacities and provide the community with sustainable enterprise opportunities.

As a result, in 2009 PanAust partnered with the Lao Women's Union from the district (now province) of Xaysomboun to introduce and promote village savings and credit funds. These village banks provide microfinance services, including secure savings and flexible loan facilities to support enterprise development. In 2013, the funds had 487 registered members in the two villages and were providing US\$7,500 in micro loans on average each month. The day-to-day management, monitoring and reporting of outcomes for the microfinance program is managed by the community with ongoing technical support from PanAust.

Building upon the opportunities, villagers in Ban Nam Mo and Ban Nam Gnone formed a cooperative in 2009 to coordinate the production and sale of vegetables. The Phu Kham camp, as a large consumer of fresh vegetables, was identified as a potential vehicle to support a market garden enterprise and livelihood development program. Building on the community's traditional agricultural base, PanAust community officers helped the village development committee to identify and register participants, establish a farmers cooperative, prepare agricultural land and provide training to enable improvements in the quality, quantity and variety of produce. Market gardeners were able to borrow from the newly established village savings and credit funds.

The program grew rapidly, and by 2013 the camp was buying an average of 12,000 kilograms of vegetables from about 120 local farmers each month. Produce is delivered to a weekly point of sale in the village where it is sold under the monitoring and supervision of the village development committee and company staff. Total sales volume reached US\$172,000 in 2013, providing an average of US\$119 per month to each participating household, or \$1,430 per year. This represents a significant cash income, considering that GDP per capita in Laos stands at about the same level (US\$1,417).

The initiative has proven to be especially beneficial for local women, who comprise 98% of program participants. Land-poor households have been assisted by being prioritised in the allocation of newly developed market garden land. The program's indirect effects are also significant, leading to the production of larger quantities and varieties of vegetables for local markets and contributing to improved nutrition for participating families. Socioeconomic survey data shows that the proportion of households reporting food shortages reduced between 2010 and 2012 by a factor of four.



Source: 2012 Socio-economic survey, p. 41.

Regular meetings are held at which PanAust, the community and other key stakeholders monitor and review market gardening and microfinance data and outcomes in order to maximise opportunities to alleviate poverty through small business development.

This monitoring and review process has resulted in many program enhancements. For example, an analysis of company food supply requirements against local production capabilities identified several crops suitable for local production but for which local experience was lacking. Therefore, farmer training was organised to introduce several new varieties of vegetables (potatoes, carrots, tomatoes) not previously grown in the area.

The company has also adjusted to local capabilities. For example, the camp menu has been modified to use more seasonal local vegetables in place of imported produce. And locally grown mushrooms now feature on the menu more often, after villagers were trained in mushroom cultivation.

The lessons learned from the livelihood programs at the Phu Kham copper–gold operation are being incorporated elsewhere in PanAust’s operations. The combination of local vegetable procurement, agricultural training and village banking has been replicated at the Ban Houayxai gold–silver operation, and there is potential for replicating it at the company’s exploration sites in Laos and Chile.

From experience, the company and community recognise that through a combination of training, microfinance and the development of small business opportunities, broader outcomes such as food security and nutrition can be addressed hand-in-hand with livelihood development.

The combination of sustainability reporting guidelines and the ease of publishing through the internet is facilitating a revolution in the ability of mining companies to demonstrate their successes and challenges and to meet increasing community expectations for performance evaluation. For many community members, leading practice requires a comprehensive, up-to-date and transparent website with current online monitoring data. For specific projects, it is important to develop communication strategies which are technically appropriate and relevant to local community needs and expectations as well as cultural practices, especially in impoverished or indigenous communities, as described in the leading practice *Community engagement and development* handbook (DIIS 2016b).

2.3 Risk planning, management and mitigation

The ongoing process of risk assessment and the development and refinement of risk management plans is an integral component of ensuring that sustainable development objectives are met. Potential risks need to be identified and evaluated against relevant criteria, and control measures need to be designed and implemented, based on standards such as AS/NZS 4360:2004 *Risk management*.

Given the wide variety of risks that a mining project faces, including economic, environmental, social, reputational and even political risks, it is vital that there is clear alignment between monitoring and auditing and risk management. If a specific risk is identified (for example, a potential for tailings dam failure), appropriate monitoring (for example, groundwater pressures, underdrainage rates and so on) must be done to allow the risk to be appropriately managed. An associated program of regular audits should be scheduled to ensure that the required monitoring is being carried out and that performance evaluation is being done at a level commensurate with managing the risk. The incorporation of risk assessment and management procedures into monitoring design is discussed in more detail in Section 3.1.

3.0 MONITORING: DESIGN

Key messages

- Monitoring will be most effective if it is based on reassessment of the key environmental and stakeholder risks, and changes to the community asset base, for each phase of operations over the life of the mine.
- Regular review of the risks and associated monitoring are needed to ensure that objectives are met and findings are used to inform improved management decisions and practices.
- Monitoring is the means by which mining companies and stakeholders can assess the effectiveness of management or control measures, verify or adjust predictions made early in the project, and develop improved management practices.
- Leading practice mining project monitoring programs comprise environmental, social, cultural and socioeconomic aspects, in addition to routine operational monitoring requirements.
- The dataset relating to environmental and community risks is less well developed and, for many aspects, harder to quantify, than that for safety and health, making it more important to share information and benchmark with leading practice companies and sites.

3.1 Planning to manage risk

Leading practice monitoring extends beyond the base level of effort that may be required for assessing compliance with current licence or operating conditions. Leading practice monitoring is designed to be sensitive enough to detect trends in key parameters well before they go out of compliance, and to enable prompt responses to concerns or allegations of impact from third parties. In short, leading practice monitoring is risk based and proactive. It needs to be focused on the key environmental risks for the site, which will include operational and compliance risks as well as other potential stakeholder concerns. It also needs to adapt to the changing nature of those risks at each stage over the life of the mine, from exploration to closure (and beyond, for some aspects). A leading practice monitoring program can also be a valuable resource planning tool, helping to define the skill sets needed to manage the identified risks and to assist in adjusting to change during the life of the mine.

Monitoring that is only able to detect changes after a substantial impact has occurred cannot be used to manage systems to prevent impacts and minimise liabilities. A common misconception is that monitoring for compliance is all that is needed to prevent and to manage impacts. If the first measurement of change is one that fails compliance, it is too late to prevent the unwanted impact, as most compliance standards are set at the point where, if compliance is not met, impact is likely to occur.

Risk-based planning for monitoring involves understanding the nature and relevant sensitivities of the project, including environmental, political, socioeconomic and cultural contexts, and the processes by which mine operations could affect them. This enables appropriate and sufficiently sensitive parameters and end points to be selected and to be used to detect underlying trends before detrimental impacts occur.

The leading practice *Risk management* handbook (DIIS 2016a) includes examples of risk assessment that are applicable to risk planning and provides useful examples that can be adapted to suit a specific operation and context.

Risk planning maturity models (DIIS 2016a) are a useful framework that can be applied to other risks, such as health risks (Hancock 2010) and jurisdictional abandoned mine programs (Unger et al. 2012). Maturity models define characteristics of vulnerable through to resilient programs and are used to both evaluate progress and provide guidance on the next steps towards leading practice.

One method of integrating risk planning into the monitoring program is to develop a risk register that incorporates life-of-mine risks and associated monitoring with the performance criteria relevant to each. Separate risk registers can be developed for each phase of operations, from exploration to closure, and updated as the operation progresses. A risk register can provide both a framework to identify significant risks and the control measures to mitigate those risks (it is recommended as part of an EMS under ISO14001:2004, for example).

An environmental and social impact assessment (ESIA) will need to include a risk register with likelihood and consequence assessments and, ideally, a designed monitoring system to track changes in sensitive indicators of those risks. Some research may need to be carried out, either as a desktop study or in the field, if there is insufficient information to define or quantify potential impacts. The monitoring commitments made during the ESIA process need to be adhered to and revisited periodically in case changes are required (see Section 3.3). It is expected that the forthcoming revision of the Australian and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines documents will place strong emphasis on the development of conceptual models that will highlight those risks and the selection of multiple sensitive indicators. Additionally, a weight-of-evidence approach to assessing the outcomes of monitoring of those indicators is also expected to be emphasised. Importantly, the water quality management framework will emphasise reviews of the indicators used, the conceptual model that the risks are identified from and the management systems in place so that monitoring is continuously improved and optimised (note that these principles are equally applicable to risks other than water quality).

The risk register can be developed through a number of mechanisms—for example, assessments by panels of experts with diverse skills, stakeholder consultation, or quantitative and semi-quantitative risk assessments. Effective leading practice risk assessment must have the appropriate skills–knowledge mix in the team developing it and high-level commitment to implementing the control measures once they are identified, supported by the budget and resources to take necessary actions.

The *Risk management* handbook in this series provides examples of each type of risk assessment. Further guidance is in the Australian and New Zealand Standard AS/NZS 4360:2004 *Risk management* and the Standards Australia handbook HB 203: 2012 *Managing environment-related risk*.

Standards Australia also provides guidance on managing specific risks in handbooks such as:

- HB 205:2004 OHS *risk management handbook*
- HB 231:2004 *Information security risk management guidelines*
- HB 294:2006 *National post-border weed risk management protocol*.

The risk planning approach minimises monitoring effort that does not target the potential liabilities of the operation at each stage, but provides more than adequate warning of potentially detrimental trends, ensuring that appropriate datasets are available when issues arise and minimising the chance of being unable to defend claims for damages. The key is to have monitoring that facilitates managing risk for all stages of the operation.

There are risks associated with the gathering of appropriate information to solve problems and answer key questions. Additionally, there are risks associated with data management to ensure the continuity and accessibility of historical monitoring data. Both aspects must be addressed as part of the overall risk assessment and management processes.

Leading practice monitoring requires the risk assessment process to recognise and address implementation risks associated with the conduct of monitoring, such as the possibility that:

- baseline monitoring is not carried out over a sufficiently representative time period or at an appropriate location to provide good-quality data upon which to base subsequent assessments
- monitoring installations or equipment are destroyed by vandalism, fire, flood or feral animals, causing loss of data at critical times
- unexpected changes to mining operations affect monitoring installations, equipment databases used to manage and interpret data change over time and old data becomes irretrievable
- personnel who understand the critical elements of the monitoring program do not document procedures and, when they leave the company, new personnel are unable to manage the monitoring system to the standard required
- monitoring data is reviewed annually but not over longer periods, so cumulative impacts go undetected
- monitoring focuses on indirect measures of impact and therefore fails to detect the specific impacts that need to be measured (for example, focusing on monitoring particular fauna species when they may be affected by impacts on riparian vegetation caused by changes in stream hydrology and when the primary cause and all links need to be understood)
- insufficient data points are obtained to conduct the necessary analyses and interpretation with an adequate degree of confidence, which can result in a misrepresentation of trends
- good-quality monitoring data is not used for the purposes of adaptive management, continuous improvement, or both
- meta-analysis of data is not carried out.

3.2 Life-of-mine planning and management

Life-of-mine planning for monitoring requires a predevelopment impact register to be formulated and risk assessment procedures to be carried out, as described in Section 3.1. Once all potential future impacts have been anticipated, monitoring systems can be designed and put in place to take account of them.

3.2.1 Baseline monitoring

Where it is possible to incorporate baseline monitoring (for example, in greenfield projects and expansions to mines), such monitoring is a critical component of leading practice monitoring programs. Baseline monitoring should commence at the pre-feasibility stage and include all relevant environmental, economic, and social issues identified in risk planning. Typical elements of monitoring programs are listed in Appendix 2.

In most cases, the baseline monitoring system will become incorporated into later monitoring over the life of the mine so that repeat assessments can have a consistent basis of comparison. This will provide essential data on several aspects that are not necessarily related to impacts of the operating mining project but serve as a reference such that:

- the extent of natural system variability can be quantified over time and space
- the extent of pre-existing impacts from previous or current mining projects can be used to place the contribution of the operation into context
- the effects of other causes (such as urban or agricultural inputs) can be distinguished from those of the mining operation.

Baseline data, together with ongoing monitoring of reference (or control) sites, is essential for being able to correctly interpret the results from monitoring programs that have been designed to assess the extent of mining project-related impacts during mine life and the extent of recovery or improvement following control of the impact or rehabilitation.

3.2.2 Design principles for monitoring

A common and recommended approach for assessing impacts and recovery is the use of the 'before-after-control-impact' (BACI) approach to monitoring design (Quinn & Keough 2006) and derivatives of it (such as modified BACI). The 'before-after' component refers to measurements conducted before and after any change that might cause an impact. 'Control-impact' refers to measurements conducted in areas assumed to be unaffected ('control') or potentially affected ('impact') by the project. It is important to note that impacts can include direct impacts, secondary impacts and cumulative impacts.

The principle of the BACI design is that the operation's effect on the environment is assessed by determining the difference between results measured before and after the impact at sites potentially at risk, and comparing this with similar sites not likely to be at risk. It is focused on the relative differences of the control and impact sites before and after operational changes occur, not on trends at individual sites. This approach provides much-improved statistical power to differentiate project-caused environmental responses from other sources of variability in the measured indicators.

Note two points:

- While the 'control' and 'impact' sites should be similar in their physical and ecological characteristics, it is not necessary and not always possible for them to have identical attributes. However, the differences between the sites must be able to be measured both before and after the possible impact.
- When comparing before and after data, if there is an increase in the differences between the 'control' sites and the 'impact' sites, that may indicate that the project has had an impact. It is this difference that can be measured and used to statistically determine whether an impact has occurred. Ideally, this should include the measurement of baseline differences before the mine is developed, but the principle can be adapted to later assessment of any changes in the differences between 'control' and 'impact' sites.

In practice, the BACI monitoring design that is needed for a specific project can sometimes be more complex than this, although the principles remain the same. Further details for the design of a conventional BACI monitoring program are given in Quinn & Keogh (2006) and Underwood (1991), while design of the modified, multivariate BACI approach is described in Humphrey et al. (1995), Humphrey & Pidgeon (2001) and Faith et al. (1995).

Although well established as a robust, statistically based monitoring approach decades ago, BACI remains underutilised in most monitoring programs despite its clear analytical advantages. It remains the leading practice monitoring design where it is feasible. However, where practical, using conceptual models, as opposed to relying only on statistical models, can also prove very useful.

Other impacts that are not necessarily directly related to mining operations, but that may subsequently occur as a result of increased population in the vicinity of the mine, may need to be taken into account in monitoring design. They can include slash-and-burn agriculture and artisanal alluvial mining (both of which may increase sediment load upstream of the mine); other industrial development; dust storms, bushfires or forest fires affecting air quality; or previous logging, hunting or clearing activities affecting biodiversity. Consideration of these impacting processes will require some type of comparison with control and/or reference sites, even if not in a formal BACI framework.

Regardless of whether or not the BACI approach can be used, leading practice monitoring programs should be designed to be cost-effective and be based on sound statistical and social science research principles. The key to good monitoring design is to base the design on statistical principles, rather than trying to fit statistics to the design (but note comments above on the role of conceptual models in some instances). This will help to avoid bias in sampling and enable appropriate sample sizes and sampling frequencies to be calculated and optimised in advance. Leading practice monitoring programs commonly take statistical power into account, thereby ensuring that, if an effect occurs, there is a high probability that it will be detected at a meaningful early-warning effect size—not only after substantial environmental detriment has occurred.

While parametric statistical analysis using normally distributed data is preferable when determining whether impacts have occurred, high variability or low sample sizes (such as when monitoring rare or threatened species) may prevent its use in practice. In such cases, the monitoring program may be designed according to non-parametric analysis procedures, making use of modern robust, generalised or Bayesian statistical procedures that are more able to reliably analyse limited datasets and datasets that otherwise do not comply with the underlying assumptions of standard classical parametric statistical analysis procedures. In all cases, visual inspection of trends in data is very important, and in some instances it may be possible to do no more than observe trends graphically using a control charting approach.

However, this can prove to be a very useful practical tool in understanding what is happening, initiating management action and communicating the results of monitoring to the community. The development of R as a free statistical analysis tool and the wider availability of Bayesian analysis tools have made the adoption of more advanced statistical analysis of monitoring data a relatively simple matter.

Whatever the case, it is essential to include consideration of what analyses will be carried out when designing the monitoring program. Green (1979) provided a list of 10 principles that should be taken into account (see Appendix 1) and noted that ‘if you have delayed seeking expert advice until you can only ask “what can I do with my data”, you richly deserve, at that point, any answer you get!’ This remains true three decades later. Consideration of data analysis requirements at the design stage can result in much more cost-effective monitoring programs by providing guidance on sampling locations; the intensity, frequency and duration of sampling; the amount of replication; and other key aspects. Importantly, it will prevent wastage of funds spent on monitoring that has low statistical power.

Mine planners must be consulted when designing monitoring programs, and in some instances they should participate in the design of the monitoring that is required (where it is part of mine operations).

The environmental monitoring program and the resulting output data should be linked to the mine’s spatial or geographic information system (GIS) and should be accessible and highly visible on the system. In this way, when mine plans change (as they frequently do), those responsible for the monitoring system have early notice and can take action to ensure that impacts due to changes in mining operations continue to be appropriately monitored and managed. A particularly important example of this is where monitoring sites are damaged or destroyed by mine development and continuity of the data record is lost. Good knowledge of the importance of such sites ensures that it might be possible to maintain them by proactive mine

planning or, if not, new sites of similar monitoring effectiveness can be established as soon as possible. Ideally, the new sites should be established and running before the original sites are lost so that it is possible to have a period of monitoring overlap. A good GIS should not only store locations of monitoring sites, but also be capable of displaying overlays of monitoring trend data.

At some sites, operators decide (or are required) to develop or modify a monitoring program without the benefit of baseline monitoring and a predevelopment risk register. This can happen when a company acquires an existing operation that does not have that data, when mining operations recommence in the vicinity of old abandoned mines, or when a decision is made to significantly modify or upgrade the existing monitoring program in line with current regulatory and community expectations. In these instances, careful thought will need to be given to the design of the monitoring program using the principles described above where possible. Approaches such as monitoring nearby reference and/or control sites, monitoring upstream versus downstream, and determining whether previous owners or regulators have conducted monitoring can help in designing an appropriate monitoring program. In situations where a number of mining operations are present, including closed or abandoned mines for which no company has ongoing management responsibility, monitoring in conjunction with regulators may be needed to distinguish the impact of the active mining operation from those other (cumulative) sources.

The monitoring program should carry on through the entire life of the mining project, including rehabilitation and closure (as discussed above, the detailed content of the program will change through time). Post-closure monitoring will also be required where impacts have the potential to be high risk, long term, or both (for example, where drainage from the mine may be acidic or contaminated with metals).

The design and duration of post-closure monitoring and responsibility for conducting it should be determined by agreement with relevant regulators. Once the mining company has demonstrated that the rehabilitation has been completed satisfactorily and is performing as required, it usually requests the relinquishment of the lease back to the state (note that Western Australia and the Northern Territory have introduced levies that may partially contribute to remediating existing and future mining legacies). Once relinquishment has occurred, post-closure monitoring may be carried out by regulators rather than by the mine or consultants, provided an agreed source of funding is available.

Overall, it is essential that monitoring programs be designed according to the defined risk and potential impact of the project, and be capable of detecting all relevant impacts, including those that are positive. They must have clear objectives and, where possible, should be quantitative or else incorporate qualitative data that complies with sound statistical design and analysis principles and is in a form that can be replicated in each stage of the mine's life.

For social performance monitoring, objectively measurable datasets, such as local employment statistics, changes in regional health profiles or surveys of household income and expenditure, may be complemented by well-designed qualitatively focused monitoring. For example, monitoring could include tracking career progression for indigenous employees and the factors that influence employment outcomes, the essence of which cannot be captured in quantitative data or statistical analysis alone.

3.3 Adjustments for changes in the mine plan

Monitoring programs need to be planned and documented in such a way that, when changes occur to an operation and new or altered impacts are possible or former risks are mitigated, it is a straightforward matter to adjust the monitoring program.

Ideally, individual monitoring tasks are defined within both a medium-term time frame (such as one year or five years) and a life-of-mine plan for a particular project. The medium-term plan documents all phases of monitoring and indicates the lead times required, particularly when a scope-of-works statement needs to be defined for a monitoring project and subcontractors/consultants are required to develop proposals prior to commencement.

Specifically, the following aspects should be addressed.

Throughout the mine's life, from baseline to post-closure, leading practice monitoring should be based on a detailed, annually revised monitoring plan. This is developed or revised using a risk assessment that identifies the monitoring needs and tasks that require attention during the coming year and their interrelationships. It revisits and updates the less detailed medium-term and life-of-mine monitoring plans.

The following apply for individual tasks within the annual plan:

- Objectives are defined and documented in a scope-of-works statement with supporting information.
- If external expertise is needed, the scope of works is used as a basis for seeking proposals.
- If monitoring is to be undertaken internally, managers commit to resourcing the task and the expectations and commitments are documented.
- In the evaluation and selection of an external contractor, agreements are defined for key elements of monitoring; responsibilities for data management, interpretation and storage; and responsibilities for progress and final reporting or recommendations.
- An internal or external project coordinator or manager takes ownership of ensuring the continuity and success of the monitoring. This role ensures that the correct activities are undertaken in the right locations, appropriate stakeholders are engaged during the process, and all relevant supporting information is made available to the consultant. The coordinator reviews all draft reports and ensures that they are finalised and circulated to key personnel, and that data is managed in accordance with any agreements.

For a medium-term monitoring plan, it is important that the link is made to medium-term construction or production plans so that any change in production or infrastructure enables adjustments to be made to the monitoring programs. For example, if the annual production rate is to increase, then pre-clearing monitoring may be needed over much larger areas than previously planned and so more resources will be needed. There is also a need to review the findings of annual monitoring programs to determine whether there is any need to change management practices or alter the monitoring.

The life-of-mine plan for monitoring needs to be reviewed at frequencies that reflect the rate of change of the operation. In the early stages, when the rate of change may be greatest, there may be a need for an annual review of the monitoring program in the context of life-of-mine or closure planning. When the project accelerates or decelerates, there is a need to review monitoring programs frequently. For example, towards the end of the mine's life there is a risk that early closure or handover to another operator (change of ownership) may cause a shift in the focus that means that certain information (for example, completion criteria, community impacts due to closure, socioeconomic studies of local business impacts) is needed sooner.

For abandoned mines and mines that have suspended operations and are in a care and maintenance phase for an extended period, having a record (no matter how old) of past monitoring plans, data and maps showing monitoring sites is invaluable. Such information provides a sound basis for risk assessment focused on developing a closure or rehabilitation plan. In summary, the key element is to ensure that monitoring programs are aligned to operational changes or the development of the project and, where relevant, to cumulative impacts at the regional scale. While many monitoring components may be defined through the ESIA process and formalised through regulatory documents (such as licences and authorities),

other components are internally driven to develop site-specific methods and datasets for other purposes (such as using water and energy more efficiently). The documentation of overall monitoring plans is essential if continuity is to be maintained between successive monitoring program managers so that, even if changes in ownership occur, the momentum of monitoring programs is maintained and data gaps at critical stages are avoided or minimised.

3.4 Community involvement in monitoring design

Building and maintaining community trust and the social licence to operate are essential ingredients of sustainable development (the leading practice *Community engagement and development* handbook addresses these concepts in detail). Including communities in the design and implementation of monitoring programs is one way organisations can strengthen relations with key stakeholders and build trust through transparent information exchange and inclusive decision-making on issues that affect them.

Including the community also allows the organisation to tap into local or traditional knowledge of social and ecological systems.

Community involvement in monitoring design can include working with:

- indigenous communities and traditional owners on identifying and monitoring species that have cultural, food or medicinal significance
- adjacent communities in the design of air and water quality monitoring programs
- farmers or other land users on monitoring impacts of mining on current or potential land-use options
- naturalist groups on the current or previous known presence of rare or threatened species
- community leaders on matters relating to historic and traditional cultural heritage.

The starting point for conversations and the inclusion of the community in monitoring design and implementation is often the environmental and social impact assessments; however, leading practice companies seek to engage the community at all stages, even for already operating mines. The ICMM's *Community development toolkit* provides useful tools to assist organisations to plan, design, and implement inclusive monitoring and evaluation processes (ICMM n.d.).

Case study: Co-management of impacts of below-watertable mining on culturally significant and ecologically sensitive Weeli Wolli Springs and Creek system by traditional owners and Rio Tinto

The Weeli Wolli Springs and Creek is a unique hydrological and cultural feature in the Pilbara Region of Western Australia. The area is listed as a Priority Ecological Community (PEC) by the Western Australian Department of Parks and Wildlife. It is also an area of high cultural significance to the traditional owners of the land who believe that the spirit of Yurduba, the rainbow serpent who is guardian of permanent waterholes, is in the creek.

Hope Downs Mine, a joint venture operation between Hope Downs Iron Ore and Rio Tinto, is about 5 km to the west of the springs. Operations at the mine are managed by Hamersley Hope Downs Management Services. Mining commenced in 2007.

Because the developing pit went below the watertable, the mine required dewatering and the discharge of large volumes of groundwater. A considerable section of Weeli Wolli Springs is within the cone of depression from the dewatering, so most of the groundwater is subsequently discharged into the springs and down the creek. Dewatering and discharging could have an impact on the hydrology and ecology of the Weeli Wolli ecosystem.

Comprehensive environmental and heritage management plans and wide-ranging monitoring and evaluation mechanisms have been developed by Rio Tinto in cooperation with traditional owners. The cooperation goes back to July 2006, when traditional owners and company representatives held a bush meeting at the creek to discuss managing environmental and heritage issues and to identify culturally appropriate ways to include the traditional owners in issues relating to mining operations and the creek. An outcome was the formation of the Interim Weeli Wolli Creek Co-Management Board, which comprises five members each from the Nyiyarparli and Banyjima peoples and four Rio Tinto representatives.

Notwithstanding that the traditional ownership of the Weeli Wolli Creek area has not been fully resolved, the co-management board has had periodic composition reviews to ensure that traditional owners are appropriately represented.

The role and the objective of the board is to oversee and provide advice and guidance to Hamersley Hope Downs Management Services and conduct leading practice environmental and heritage monitoring and management for water discharges from Hope Downs Mine and their effects on Weeli Wolli Creek and its environs. Meeting every three months, the board discusses emerging and ongoing issues in relation to the ecological and cultural values of the springs and creek. The board members also evaluate progress made by Rio Tinto in monitoring and managing the identified threats and review the findings of independent scientists. The feedback from the board plays an important part in the development of adaptive management plans for the area. The board members and others from the two traditional owner groups participate in ecological monitoring of the springs and the creek system. The program is known as the Living Water Survey and is held twice a year. It involves monitoring and measuring a wide range of parameters, such as the water quality, biota (algae, macro- and micro-invertebrates, fish, other animals and plants found in the water and creek bed).

The board also oversees several subcommittees that deal with specific issues, and the findings and recommendations of the subcommittees are ratified at the meetings of the full board. More broadly, the board sponsors a wide range of projects aimed at conserving the traditional knowledge and values of the creek system and informing the wider community about them.

This is one of the first instances in the Pilbara of a large mining operation and traditional owners working together to mitigate environmental impacts associated with important aspects of mine development. The concept of co-management, in which all parties learn from each other and work collectively towards achieving sustainable outcomes, is emerging as a leading trend among mining operations in the region.

3.4.1 Elements of a socioeconomic monitoring framework

Coinciding with the emergence of sustainable development reporting requirements such as the GRI and voluntary codes such as *Enduring value*, there is increasing recognition among leading practice companies of a need to develop robust and transparent social performance monitoring. This should be rigorous, context driven, socially engaged and locally relevant, and should:

- provide systematic and consistent information that can be a basis for the assessment or quantification of community change and development at various stages of a project's life cycle
- inform both operational and community decision-making and feed into key community investment and development programs
- integrate with broader operational strategic planning and management frameworks, thereby making it easier to include community considerations in a whole-of-operation approach to sustainable development
- include external stakeholders at all stages of the development, implementation and reporting of the framework
- engage community aspirations for regional development and benefits transfers
- acknowledge, identify and respond collaboratively, where that is locally appropriate, to the broader cumulative impacts and benefits arising from mining or other local industrial activity.

3.4.2 Monitoring framework for indigenous (traditional owner) communities

Particular consideration should be given to ensuring that monitoring systems adequately address the impacts of mining operations on indigenous (traditional owner) communities. Historically, the economic and development benefits that accompany mining have often failed to have substantial positive flow-on effects for indigenous communities. In the past two decades, there have been moves to redress the imbalance. In Australia, mechanisms such as Indigenous land use agreements, community investment and development funds, and employment and training programs are now providing opportunities to formalise mining companies' commitments to Indigenous communities and meet their development aspirations. The aim is to ensure long-term, sustainable and culturally appropriate outcomes for Indigenous people.

For these initiatives to be successful, understanding the changes that can take place in Indigenous communities affected through mining and community development programs is important for both mining companies and the affected communities. Timely, rigorous and transparent social performance monitoring has an important role in providing stakeholders with the capacity to influence, steer and promote development programs in a culturally appropriate and responsive manner.

The leading practice handbook *Working with indigenous communities* (DIIS 2016c) gives detailed guidance on indigenous engagement and economic development.

3.4.3 Criteria for selecting socioeconomic indicators

Socioeconomic indicators should be selected with the goal of providing a consistent, reliable and valid dataset that can be sustained over time. Ideally, indicators should comply with the general principles of:

- validity—logically measuring what they are supposed to measure with appropriate sensitivity
- reliability—remaining consistent over time and involving consistent community engagement in data collection
- simplicity—not being overcomplicated, particularly if the community is to participate in data collection (which will also need to be manageable to maintain reliability)

- comprehensiveness—encompassing all the complexity likely to exist in the sampled population
- availability—being easy to collect
- practicality—not being onerously resource intensive (adapted from Black & Hughes 2001).

However, in a real-life operation, where there are many competing demands on time and resources, the rigid application of these criteria can be too constraining. Socioeconomic frameworks therefore need to be developed with considerations of cost and availability firmly in mind. Rather than developing a suite of purpose-built indicators, it is sometimes more effective and practical to use information that is already being collected by other, preferably locally operating, agencies (for example, local environmental surveillance groups, local or state government bodies or community organisations) or can easily be generated from the operation's standard operating procedures (for example, employment or procurement data for sources of hired labour or for local spending and benefit transfers).

Furthermore, rather than relying solely on 'objective' quantitative measures, the inclusion of qualitative feedback from local experts or community groups, collected in a consistent and replicable format, can substantially enhance the usefulness of the information obtained. This approach, which might not always lend itself to conventional statistical analysis, nevertheless has the substantial advantage of being practical and capable of capturing a range of community inputs and voices. Finally, using multiple indicators for each of the primary mine domains or community assets also minimises the risk of misreading or ignoring significant trends.

3.4.4 Monitoring for social performance over project stages

As indicated elsewhere in this handbook (sections 3.2 and 3.3) and other handbooks in this series, planning and development for an effective monitoring framework should occur as early as possible in a project's life cycle. The earlier the operation is able to establish the regional socioeconomic starting point, or baseline, the more that operation will be able to clearly delineate, track and understand the changes that take place in a community as a result of the project.

It may be necessary over the course of a project to adjust a monitoring framework and enable indicators to take into account shifts in operational circumstances, such as major transitions from construction to operations; expansion programs; changes in workforce delivery mechanisms, such as the introduction of fly-in/fly-out; or unplanned contraction. For projects with a long life, such as 25 years or more, or operations established in a greenfield environment, the indicators of high importance during construction may diminish in importance as the operation matures and the community adjusts to changed circumstances, and will certainly differ from the suite of indicators of importance during closure. While the fundamentals of a monitoring framework may remain intact for the life of the mine, elements of a framework must be adjusted where necessary to accommodate shifts in project life cycles and community perceptions and drivers, as well as expansions and contractions.

3.5 Elements of the monitoring program

Typical elements of environmental and socioeconomic monitoring, and indicative frequencies of monitoring throughout all stages of project development, are outlined in Appendix 2. Operational monitoring is not specifically addressed in Appendix 2, although some operational monitoring parameters, including water balance, ore and waste production rates and composition, have direct relevance for other aspects of monitoring, such as discharge water quality and acid and metalliferous drainage management.

As noted in Section 2.2.2, each project has specific regulatory monitoring requirements. However, the incorporation of additional monitoring parameters and performance evaluation criteria is essential to the identification and proactive management of environmental, social and work health and safety issues during the project's life. Leading practice methods go beyond regulatory requirements and aim to further investigate potential high-risk aspects, quantify and mitigate impacts before substantial incidents occur, and develop solutions and assess the success of control measures. As noted in Section 3.1, a risk-based approach is recommended to ensure that, regardless of the size of a mining operation, site-specific monitoring programs incorporate appropriate monitoring elements, parameters, frequencies and applicable performance criteria on which to assess the monitoring data.

Appendix 2 should be considered 'indicative' of a leading practice monitoring program. It is intended to provide a basis for establishing a detailed program that is relevant to site-specific sensitivities and the nature and scale of potential impacts. The elements outlined in Appendix 2 are not necessarily exhaustive for all mining projects; nor is each element and suggested frequency of monitoring relevant to all projects.

Further guidance on the identification of suitable monitoring parameters, frequencies and performance evaluation criteria is in other leading practice handbooks.

3.6 Links to research and investigations

Often, at some point during the operational life of a mine, the need emerges to develop more cost-effective methods, taking into account local conditions, for assessing and minimising impacts, restoring environmental values or rehabilitating degraded sites. A major reason for this is that all sites are different and change over time. While the approach and process used by other projects may have developed leading practice methods of addressing knowledge gaps, specific characteristics of the project site may require modifications to the procedures developed and optimised elsewhere, or the selection of new indicators.

This requires a leading practice approach—that is, a willingness to do research, trials or whatever other investigations are necessary to monitor, assess and manage impacts to an extent acceptable to all stakeholders.

Baseline and subsequent surveys can identify the need for research and investigations. For example, they may reveal:

- endemic species whose sensitivities or ecological requirements are not known
- floral species for which propagation methods are not known
- faunal species whose habitat requirements are not well known
- specific flora–fauna interactions that are not well understood but may be important for ecosystem sustainability
- topsoil characteristics that need specific remediation or other treatment to ensure successful revegetation
- characteristics of overburden material that need specific procedures to ensure the successful construction and long-term stability of waste dumps or tailings storage facilities
- unusual water, soil or sediment characteristics that alter the bioavailability risks of minerals or contaminants suitable for post-mining land uses, decision tools and knowledge management frameworks
- community subgroups with differing economic and land-use requirements and aspirations
- gaps in local skills, education or other employment-related capacities
- limited business diversity, which restricts opportunities for economic benefits to flow to the local community.

Ongoing monitoring through all phases of the mining project can also reveal problems that need addressing, such as:

- problems relating to the establishment or growth of rehabilitation plantings
- invasive species that alter the ecosystem's form or function, altering its value or sensitivity
- unexpected water-quality impacts arising from specific site characteristics and environmental values
- difficulties associated with managing dispersive spoil material, together with characteristics, such as variable soil salinity, that indicate a need for different handling procedures
- inappropriate distribution of financial benefits from the mine throughout the community
- social structures that do not represent generally accepted social norms for human rights, women's rights, vulnerable groups and the like.

In almost all cases, it is much better to discover issues that require further investigation earlier rather than later. This gives more time to develop solutions, which may reduce the duration or extent of impact and be more cost-effective. In the case of rehabilitation, the earlier problems are identified and rectified, the less the area of suboptimal rehabilitated land that, in the worst case, may need to be reworked. Well-designed and targeted research can result in more cost-effective rehabilitation, for example by discovering better ways of doing things and fixing rehabilitation problems while mining equipment is still on site.

Some issues might require detailed research programs, whereas others might be resolved using simple field trials, such as those used to finetune fertiliser and seeding rates in rehabilitation programs. Depending on the work involved and the skills and resources required, research and investigations may need to be done by external consultants or universities or other research institutions.

A commitment to leading practice monitoring, and, where necessary, to research investigations, can result in significant improvements in overall environmental performance. A good example of this is the mine rehabilitation program conducted by Alcoa in Western Australia (see case study). It has resulted in the attainment of a very high standard of rehabilitation as a result of a process of continuous improvement over a period of more than 30 years (Koch 2007a, 2007b; Grant et al. 2007; Majer et al. 2007; Nichols & Grant 2007).

Case study: Monitoring to improve the quality of rehabilitation

Alcoa operates two bauxite mines in the jarrah forest of south-west Western Australia. Around 600 hectares of forest are cleared, mined and rehabilitated each year. The published objective of the rehabilitation is 'to restore a self-sustaining jarrah forest ecosystem planned to enhance or maintain conservation, timber, water, recreation, and other forest values'.

The success of the rehabilitation is assessed by using several different monitoring systems, each targeting a different aspect of rehabilitation quality. To fulfil the conservation component of Alcoa's rehabilitation objective, it is considered essential to restore the floristic diversity of the forest in rehabilitated areas, so a botanical richness target has been developed: 'The average number of indigenous plant species in 15-month-old restoration is 100% of the number found in representative jarrah forest sites, with at least 20% of these from the recalcitrant species priority list.' Recalcitrant species are typically fire resprouters that are common in the unmined jarrah forest but are difficult to re-establish and are historically absent or under-represented in the restored mined areas. The resprouters give the jarrah forest a high resilience to natural disturbances, particularly fire and grazing, and hence are a crucial component of the ecosystem.

Progress towards this target is monitored when rehabilitated areas are 15 months old, using about 150 randomly located 80 square metre plots. At fixed intervals (6, 15, 30 and 50 years of age), a subset of the monitoring plots is repeat-monitored, which provides long-term data on plant succession and vegetation development. Identical plots are monitored in the unmined jarrah forest to provide reference site data.

The pattern of plant succession in rehabilitated bauxite mines tends to follow the 'initial floristic composition' model, in which the first plant species to establish on the sites dominate the vegetation for at least several decades. Long-term monitoring has shown that species richness shows little change over time and, in fact, can decrease as short-lived annual species and disturbance-opportunist species, such as the acacias, senesce over the first few decades. Accordingly, Alcoa's strategy is to restore the highest level of species richness possible in newly rehabilitated areas.



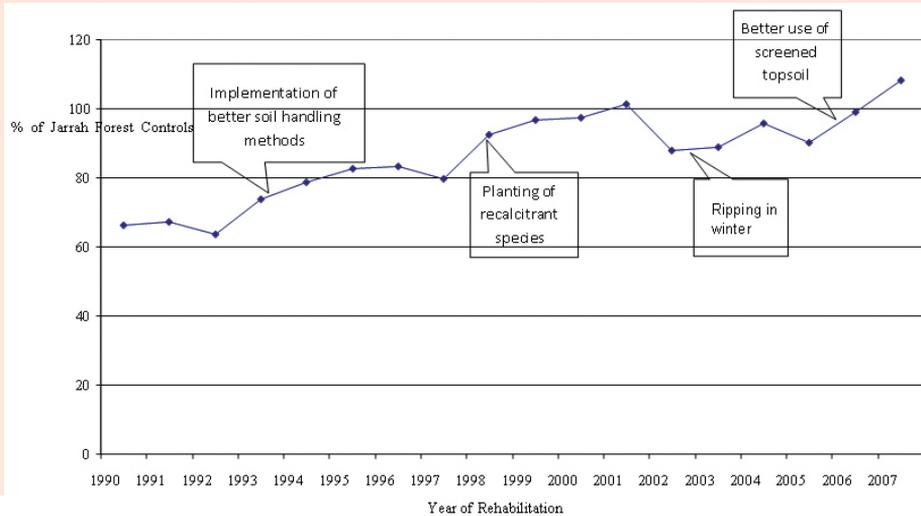
The photograph shows a 15-month old rehabilitated bauxite pit being monitored. Each year, approximately 150 plots, each of 80 square metres, are assessed.

In rehabilitated areas, plant species establish from three main sources: the natural seed in the returned topsoil, seeds that are collected and broadcast onto those areas, and planted greenstock (mostly the recalcitrant species described above). Natural recruitment by native species is slow; if areas are left bare, they are usually colonised by exotic weeds, which have strong dispersal and recruitment characteristics. Research has shown that correct soil-handling practices optimise the return of native species from the natural soil seed bank, which can contribute 70% of the species richness of a restored bauxite pit. Hence, the quality of the rehabilitation establishment procedures is closely reflected in the number of native plant species that establish in the first two winters; in other words, better rehabilitation procedures lead to higher native plant species numbers.

For example, carrying out the final ripping operation during dry soil conditions in summer (the dry season in the jarrah forest ecosystem) results in more plants and species establishing. By contrast, ripping the sites well after winter rains have begun significantly reduces the number of plant species by killing the newly germinating seedlings. In addition, the natural soil seed bank in summer is double the density of the winter seed bank, so summer is by far the best season to use this important resource.

Each year, the data collected during the 15-month monitoring program is compared with records of rehabilitation activities, which are stored in a GIS that includes the original source of the topsoil, the date of clearing of the source site, the date of removal of the topsoil, whether the topsoil was stockpiled or directly returned to the rehabilitated area, the location and duration of stockpiling, the date of respreading of the topsoil, the date of final contour ripping, and the date of seed application. This enables rehabilitation practices that lead to high returns of plant species, as well as those that result in poor rehabilitation, to be identified.

At a feedback session held each year, mine planners, environmental staff and rehabilitation operations staff review the monitoring results and discuss improvements to rehabilitation practices. Approved enhanced practices are then implemented. This intensive monitoring and plan-do-check-act cycle has enabled Alcoa to measure progress and make changes and improvements to its rehabilitation program over a 22-year period.



This graph shows the 15-month monitoring results for newly rehabilitated areas from 1990 to 2012. Identical plots are assessed in unmined forest controls, and the mean native species richness in the controls is nominally set as the 100% improvement target. The graph shows the effects of several different rehabilitation practices on the monitoring results obtained each year, including a decrease in plant species richness due to winter ripping in 2002-03. Source: Matthew Daws, Alcoa of Australia.

While monitoring per se can identify the need for research or trials, in some cases there are no effective methods available to monitor a particular variable. In such cases, research will be needed to develop an appropriate method. A good example of this is the ACARP-funded study by Dunlop et al. (2011) that developed the first locally relevant ecosystem protection guideline for sulphate for the Fitzroy River system—the first such development of an ecosystem water quality guideline for sulphate in Australia. This research arose from reduced freshwater consumption by coalmines in the region, which resulted in increased salinity of water stored onsite, and sulphate was a key parameter in that water.

It is important for companies operating in Australia to develop research plans compatible with AusIndustry R&D requirements, by engaging registered research agencies, in order to gain the benefits of R&D tax incentive arrangements while developing solutions to site-based challenges

4.0 MONITORING: IMPLEMENTATION

Key messages

- A leading practice approach to monitoring is essential for achieving consistently good performance outcomes and for facilitating continuous improvement.
- Community participation is a decisive element in the design and implementation of leading practice socioeconomic and environmental monitoring.
- Readily accessible and transparent data management systems are critical to ensure maintenance of quality assurance and quality control standards, and for the utilisation of the data to the maximum advantage of all involved with or affected by the project.
- Monitoring, auditing and research all play a critical role in the development of achievable operational performance and mine completion criteria.
- Leading practice monitoring systems are subject to regular review and are revised to take into account audit findings, changes in mine planning and operation, improvements in monitoring technology, and other relevant aspects.
- Improved automated monitoring technology can increase cost-effectiveness and improve data collection and analysis.
- Reporting systems for monitoring and auditing must be accurate and timely and address the information needs of all stakeholders. Feedback from monitoring programs should inform operational planning and decision-making.

4.1 Overview of leading practice monitoring procedures

This section describes what are generally accepted as leading practice monitoring procedures. Inevitably, there is some overlap between what is regarded as routine monitoring and more 'cutting edge' procedures. However, mining companies identified for their leading practice inevitably fulfil their routine monitoring commitments as required, on time and to the highest practicable levels of quality control, and treat even routine monitoring as an opportunity for learning and achieving continuous improvement.

All procedures described in this chapter are believed to be practicable and cost-effective in the situations in which they have been applied. Further details are in Appendix 2 and the leading practice handbooks *Preventing acid and metalliferous drainage* (DIIS 2016d), *Mine closure* (DIIS 2016e), *Biodiversity management* (DIIS 2016f) and *Mine rehabilitation* (DIIS 2016g).

4.2 Open pits

Open-pit operations involve both the creation of a mine pit and the placement of waste and sub-economic materials either on the adjacent ground surface (out-of-pit) or within the pit (in-pit). Monitoring of the waste rock types removed from the pit and their selective placement in dumps or as backfill in mining voids is part of an effective management plan for minimising acid and metalliferous drainage (AMD).

Other key aspects requiring monitoring are the geotechnical stability and safety of pit walls, groundwater ingress and drawdown, and groundwater quality. Geotechnical stability and safety are monitored by daily inspections by qualified geotechnical personnel, controlling access to the pit, and the use of slope stability monitoring equipment such as radar scanning and survey prisms to monitor wall movements. The website <http://www.smenet.org/store/mining-books.cfm/Slope-Stability-in-Surface-Mining/194-O> contains relevant information on pit slope design, case studies of pit slope stability, and the stability of waste rock dumps and tailings dam stability, and in each case includes monitoring. Performance assessment and monitoring are also discussed in Read & Stacey (2009).

Groundwater ingress is monitored and controlled by in-pit pumping, and groundwater drawdown is monitored by piezometers installed in boreholes around the perimeter of the pit and beyond. Boreholes are sampled to monitor groundwater quality surrounding the pit.

Prior to mining, the impacts on water of creating an open pit are quantified using various modelling tools, as described in the *Water management* leading practice handbook (DRET 2008a). The modelled parameters enable pit dewatering requirements and associated impacts to be predicted before mining so that mitigation measures can be planned and implemented. The extent of interactions between surface water and groundwater and the pit are based upon assumptions about the staged development of the pit and adjacent landforms scheduled in the life-of-mine plan.

As a consequence of the limitations of modelling, leading practice requires the model, as well as the dataset and assumptions that are used as a basis for modelling, to be verified and amended according to data collected during the operational phase (Kuipers et al. 2006). Modelling should not be limited to its use as a once-off tool that is run only with initially limited input data. It should instead be regarded as an iterative process; monitoring should focus on the collection of data to which the model is particularly sensitive, and for which there is initially less data than needed to produce a well-calibrated and robust model. This will enable the model to be revalidated and recalibrated, and its reliability and accuracy as a predictive tool to be continually improved.

The requirement for predictive modelling goes beyond estimating likely water inflow rates to include predicting water quality based on key geochemical characterisation parameters, as well as monitoring the effectiveness of various control measures (such as seepage barriers). Where open-pit mines are close to water resources with identified beneficial values (such as potable drinking water supplies, grazing and groundwater-dependent ecosystems), additional attention is required in relation to the lateral extent of groundwater drawdown and the potential for contamination.

Post-mining objectives for the open-cut pit also influence which key investigations and what data gathering are needed during the operational phase. Operational monitoring, efficiently combined with life-of-mine pit management, enables timely and effective closure strategies to be developed in consultation with regulatory and community stakeholders. Questions to be considered include the following:

- Will there be impacts on nearby rivers and groundwater resources during or after mining?
- Will dewatering or stream diversions around pits and underground workings affect groundwater-dependent ecosystems?

- Will the water in a flooded open pit be of adequate quantity and quality to enable access and use by others for grazing, recreational or urban use?
- How will the water levels and seasonal fluctuations in those levels affect pit wall stability?
- Could valuable water resources drain to the final void and become contaminated, rather than remain accessible and usable for downstream and adjacent water users?
- Could contaminated water from a flooded pit contaminate adjacent groundwater and surface water systems? The contamination of groundwater could occur if the flooded pit level rises above the surrounding groundwater level to become a source, rather than a sink, for contaminated pit water; the contamination of surface waters could occur if the contaminated pit water overtops the pit.

After mine closure, geotechnical slope stability and safety must be maintained and groundwater recovery and surface water inflows to the pit must be assessed following the cessation of dewatering. Geotechnical slope stability and the safety of pits generally require a minimum of perimeter bunds and fences around the pit, and usually the flattening of pit edges down to the estimated final low water level. Pit water quality should be estimated using data gathered during operations and by the use of the refined hydrological and hydrogeological models that have been developed using that data. Groundwater monitoring will be needed to verify predictions and, if objectives are not met, intervention with control measures will be required. Mine operators therefore have a strong imperative to undertake leading practice rehabilitation, which minimises or eliminates the need for ongoing inspections and maintenance (of course, this should apply to all domains).

At the very least, monitoring will be needed to provide input into predictive modelling of the chemical limnology and water quality of a future pit lake. Further details on the assessment and monitoring of seepage water quality are in the leading practice handbooks *Preventing acid and metalliferous drainage* (DIIS 2016d), *Mine closure* (DIIS 2016e) and *Mine rehabilitation* (DIIS 2016g).

4.3 Waste rock dumps

Waste rock typically emerges from an open pit in a relatively dry condition. Once placed in a surface dump, it is exposed to wetting and degradation influenced by:

- the magnitude and intensity of rainfall
- rainfall infiltration and evaporation losses
- the height and slopes of the waste rock dump (WRD)
- the nature of the waste rock, including its chemical and physical characteristics.

4.3.1 Geochemistry of surface waste rock dumps

Monitoring must verify the geochemical characteristics and model assumptions that guide waste rock dumping plans in order to continue to protect adjacent water values throughout the life of the operation. Contaminant load predictions made during exploration can be checked and adjusted and more complete operational datasets compiled to help plan water-quality and other control measures as part of rehabilitation and to determine whether covers are required (see Appendix 2).

Where soil or benign waste rock covers are found to be needed to reduce future risk from mine drainage, cover designs should integrate what has been learned from monitoring waste rock hydrology and geochemistry, and the covers should be monitored for erosional stability and performance so that covers designed for new landforms can continually improve.

In some instances, metal-tolerant plants (metalophytes) may be useful for reducing soil concentrations of particular metals via phytoremediation (Baker et al. 2010). A proactive leading practice approach to phytoremediation would be to investigate the presence and unique characteristics of site-specific metalophytes during pre-mining ecological surveys to identify species suitable for remediation and to run operational research trials to evaluate their performance. The monitoring data can be used to inform the choice of rehabilitation species mix and establishment methods when integrated with other aspects of rehabilitation planning.

4.3.2 Water monitoring of surface waste rock dumps

On wetting-up by rainfall infiltration, WRDs have the potential to generate base seepage into the underlying foundation and to topographic low points around the toe of the dump. The seepage is likely to be contaminated if the dump contains reactive waste rock. As the dump wets up, the amount and rate of base seepage increases, and the trigger rainfall necessary to initiate base seepage and the time lag before base seepage occurs following triggering both decrease.

In order to design control measures to manage WRD base seepage and potential contamination and assess the performance of those measures, monitoring is needed before, during and after the construction of dumps to enable the prediction of their hydrological and geochemical behaviour.

The quantity and rate of production and the quality and fate of surface run-off and base seepage from a surface WRD are all important in assessing the extent of potential environmental impacts. The balance between rainfall infiltration and run-off depends on the geometry and construction of the dump, the physical nature of the waste rock and the rainfall regime (climatic conditions in the monsoonal tropics are very different from those in semi-arid or temperate zones).

Seepage to the foundation often results in groundwater mounding beneath and around the WRD. The extent of mounding should be monitored by means of borehole piezometers. Since it is very difficult to install piezometers directly beneath an existing WRD, they are typically located around and just outside the WRD footprint. Piezometer installation involves placing a screen at the depth of interest down a borehole and sealing the borehole above and below that depth. Water levels in the borehole may be monitored manually using a down-hole dip meter or electronically using permanently installed pneumatic or vibrating wire piezometer tips connected to the surface by electronic cables. Borehole water sampling should be used to monitor groundwater quality.

The rate of the surface expression of WRD base seepage at topographic low points around the toe of the dump should be monitored using V-notch weirs and samples collected for water quality monitoring.

In view of the relative difficulty of obtaining representative and reliable direct measurements of rainfall infiltration into WRDs and base seepage from them using localised lysimeters,⁵ monitoring should preferably be directed at understanding the overall water balance and wetting-up over time for the dump. Automated weather stations installed on WRDs provide primary input data for the water balance. The stations should be equipped with metrological sensors, including solar irradiance and evaporation pans, so that actual evaporation can be calculated and estimates can be made of rainfall infiltration and run-off. The volume of surface run-off should be measured in flumes located in run-off drains designed to capture the bulk of the run-off to provide this component of the overall water balance and provide a cross-check of the infiltration estimates.

⁵ The limitation of lysimeters is that they only give spot values of a highly variable parameter and need to be extremely well designed, constructed and maintained.

Following the closure of a surface WRD, it is necessary to monitor rehabilitation to assess whether closure performance targets have been met. These include targets related to surface stability, such as erosion due to rainfall run-off; soil erodibility; rock mulch/vegetation covers; the water quality of seepage and run-off; dust generation by wind; the performance and stability of drainage works and vegetation establishment; and the sustainability of post-mining land uses. Further details are in the leading practice handbooks *Preventing acid and metalliferous drainage* (DIIS 2016d), *Mine closure* (DIIS 2016e) and *Mine rehabilitation* (DIIS 2016g).

Case study: Erosion monitoring for stable landforms

The key requirement in monitoring erosion is to ensure that the data obtained provides the specific information needed by the site. In some instances, it may be sufficient to demonstrate that erosion rates are declining. In others, there may be greater concern about potential off-site impacts.

Minara Resources Ltd operates the Murrin nickel operation in the north of the Western Australian goldfields. Initial rehabilitation works conducted at the site on constructed landforms showed good vegetation establishment but high rates of erosion.

Consequently, the site engaged expert consultants to design landforms with lower erosion potential. The Water Erosion Prediction Project (WEPP) model was chosen to provide erosion simulations for design purposes. This model requires complex soil erodibility data and a range of assumptions about landscape condition and performance. For that reason, there was considerable interest in obtaining erosion data from constructed landforms to refine the modelling and generate even more cost-effective landform designs.

Therefore, the erosion monitoring objectives were:

- to demonstrate that erosion rates were consistent with site targets
- to enable validation and more precise calibration of the erosion modelling used in landform design at the site, thereby enabling continuous improvement in the design process.

For a range of designed concave slopes, measurements of rill frequency and volume were used to estimate cumulative erosion on landforms constructed in 2004 and 2005. Those measurements were compared with predictions of erosion based on the original design simulations. Actual erosion potential for the periods of interest was assessed by using data on actual rainfall to provide a comparison against predicted long-term averages. Calculated erosion potential for the periods of interest was found to be considerably higher than the predicted long-term average, illustrating the importance of considering rainfall records when assessing measurements of erosion.

In general, cumulative erosion measured in late 2008 showed good agreement with calculated erosion potential. Of great value was data collected in situations where flow patterns, soil condition and/or landform construction clearly did not match the assumptions used in the initial design. That data was used in evaluating the accuracy of the initial design assumptions.

In one or two cases, the observed variations led to slight changes in construction and rehabilitation methods, rather than refinement of the modelling process. In general, the observations made during the measurement of rill volume were extremely useful, demonstrating that data without associated interpretation or qualitative observation and verification is of significantly reduced value.

LANDFORM	LOCATION	POTENTIAL CUMULATIVE EROSION SINCE CONSTRUCTION	MEASURED CUMULATIVE EROSION SINCE CONSTRUCTION
2/3	Upper slope (not corner)	37.4	28.3
	Lower slope (below tree debris)	37.4	31.9
7/2 concave	Upper slope	37.4	0
	Lower slope	37.4	0
7/2 back	Upper slope (not corner)	30	30.1
9/4 west ^a	Upper slope (30 m from crest)	100-150	102.5
	Upper slope (20 m from crest)	100-150	156.6

^a*Landform not constructed to specification and expected to exceed design erosion rates.*

The erosion monitoring undertaken at the site has provided:

- validation of the landform design process used
- confidence in the stability of existing landforms that have been constructed to specification
- refinement and improvement in the design process.

This has led to changes to landform design, including the elimination of flow-concentrating structures such as berms, more effective containment of run-off on the tops of the landforms, and the use of computer simulations of run-off and erosion to develop lower gradient concave slopes.

Subsequently, assessment of erosion relative to model predictions has been carried out for landforms on other mine sites, and the data was reported by Howard & Roddy (2012). The level of agreement between predicted and observed cumulative erosion was extremely strong, provided the initial simulations used experimentally measured erodibility parameters.



Reference:
Howard, E.J. and Roddy, B.P. (2012b)

Monitoring seepage as well as surface run-off water quality and volume is also crucial for understanding risks to wildlife, grazing cattle or sheep and nearby communities. Animals often interact with or drink from seepages or soaks at the toe of WRDs, seepage channels and containment ponds. Risks to wildlife are a function of the extent of interaction, species behaviour and water quality. Wildlife monitoring may be required, complemented by monitoring seepage chemistry, to gain an understanding of ecosystem sensitivity to key water-quality parameters.

It is also necessary to monitor sediment or seepage interception dams to ensure that they capture mine water (not clean water, which should be diverted around disturbed areas) and have sufficient capacity over the life of a project to perform as required. Water quality in streams and natural water bodies down-gradient from mine run-off and seepage areas also requires monitoring to assess downstream risks to aquatic fauna and flora. Stream conditions and the diversity and abundance of biota change considerably through the seasons, so seasonal monitoring programs may need to be implemented. Remote sensing can be used to detect changes over time at a landscape level (see Section 4.14.2).

Ecotoxicology evaluations enable the aquatic impacts to be assessed. Effective monitoring can also distinguish between chronic and acute impacts and help to evaluate the performance of landforms and water management systems.

If wetland filters are used as a treatment of run-off water with low-level contamination and suspended solids or for tertiary treatment of water discharged from a water treatment plant, they need to be monitored to ensure that they can manage and treat water at the rates required (for example, taking into account variation in rainfall) and that the water they release meets water-quality discharge requirements for the site. The concentrations of metals that accumulate through time should also be monitored to provide an indication of whether or not the wetland may ultimately need to be either cleaned out and re-established or remediated in the future.

4.3.3 Monitoring of in-pit waste rock dumps

For an in-pit WRD, the monitoring-related issues are essentially the same as for a surface WRD. However, if a partially backfilled pit will be actively or passively flooded at closure, there are specific monitoring requirements that will need to be addressed to ensure that final water quality in the flooded pit meets closure targets.

4.4 Tailings storage facilities and heap leach piles

4.4.1 Hydrology of surface tailings storage facilities

Surface tailings storage facilities (TSFs) generate high rates of base and/or embankment seepage and groundwater mounding during operation because of the large volumes of water discharged with the tailings. In dry climates, the volume of tailings water discharged to the TSF will be many times the volume of rainfall. Leading practice shows that thickened or paste tailings yield less water to the TSF and thereby mitigate many water-related problems.

Rates of base seepage generated during operations depend on:

- whether or not the base of the TSF is lined, and the thickness and effective permeability of the liner and natural foundation
- whether the TSF embankment is designed and constructed to seep with an interception system or to be water-holding
- the particle size distribution and particle shape of the tailings and their potential to consolidate and to cement on desiccation, affecting their permeability
- the rate of production and removal of supernatant water
- superimposed incident rainfall and rainfall run-off (clean run-off should be diverted so it does not enter the TSF) (Williams & Williams 2007).

By understanding the key factors influencing the hydrology of TSFs, it is possible to plan appropriate monitoring programs.

Monitoring of the physical consolidation (including draining and drying) of the tailings during the life of the TSF enables the prediction of the final strength of the tailings surface to identify the types of equipment the tailings surface can safely support during rehabilitation, and the extent of ultimate post-closure consolidation so that the amount and distribution of required cover surcharge can be calculated.

Surface seepage can quickly attract wildlife, particularly in dry environments. Surface seepages and soaks also often produce lush vegetation that attracts more wildlife. The water quality of seepages and soaks needs to be assessed to identify risks to wildlife, for example from elevated cyanide or arsenic concentrations. The absence of carcasses around a TSF is not necessarily indicative of lack of impact or risks to wildlife, because the continuous deposition of tailings slurry often buries them and nocturnal scavenging animals remove them. Monitoring impacts on wildlife is difficult, but monitoring the water quality of seeps is much easier and should form the basis of a frequent and simple monitoring regime. If water quality suggests a possible risk to wildlife, further investigations into the extent of the impacts are warranted.

Vegetation that is growing on the surface of TSFs can also be a potential source of metals to animals that graze on it, so consideration should be given to periodic monitoring of metal uptake by vegetation such as grass.

4.4.2 Geochemistry of surface tailings storage facilities

Monitoring of tailings geochemistry during the life of a TSF, as well as water quality of intercepted seepage and monitoring bores, enables the potential future performance of the TSF to be evaluated and the most appropriate rehabilitation strategy selected.

Prevention is preferred over mitigation or treatment. For example, where tailings contain sulphides, the sulphides can potentially be largely removed by in-plant flotation. Comprehensive geochemical characterisation and monitoring of the hydrological and water quality performance of a TSF during operations will indicate whether the tailings can be directly revegetated or whether a cover system will be needed to meet rehabilitation objectives. Post-mining land uses having been defined during the planning stage of a mine (see *Mine closure* (DIIS 2016e) and *Mine rehabilitation* (DIIS 2016g)) and agreed in consultation with stakeholders, those uses must then guide the planning of the final rehabilitation of tailings.

A proactive leading practice approach requires the investigation of the potential for plants to take up metals by conducting pre-closure research trials to inform the final design plan. If covers are required, cover designs for TSFs should integrate what has been learned from monitoring and modelling of the hydrology and geochemistry of the tailings to achieve post-mining land-use objectives. Contaminant uptake by plants growing on the rehabilitated tailings may also need to be monitored to define potential impacts on grazing animals or humans eating bush food; for example, extensive grazing trials on tailings at Kidston showed insignificant uptake of metals and arsenic by cattle eating grass, although there was some uptake from ingesting dirt attached to the grass and roots (Bruce et al. 2002, 2003). Conversely, in some instances, metallophytes may be useful for reducing soil concentrations of particular metals (see Section 4.3.1). A proactive leading practice approach would be to investigate the potential for plants to take up metals by conducting a pre-closure research trial to inform the final design plan.

'Store and release' covers are not necessarily applicable in all situations. Other options include the use of wet covers and rock mulch for dust control in dry climates. In all cases, monitoring to assess their effectiveness and whether objectives are being met (or likely to be met) is critical.

4.4.3 Stability and water monitoring of surface tailings storage facilities

The slope stability of a TSF is most at risk during its operation. Hence, during its operation, monitoring of the stability of the TSF embankments is of key importance.

Monitoring to ensure geotechnical stability should include the use of piezometers within the embankments and tailings deposited against them to record the phreatic surface. Settlement plates are used to record embankment deformations. Visual inspections are an important TSF monitoring tool and should focus on critical embankment sections. They should identify seepage points, particularly those that are elevated on downstream embankment faces; obvious signs of embankment deformation or erosion; ponded water against sections of the embankment; and the condition of emergency discharge spillways.

Seepage monitoring will rely on data from an automated weather station (ideally installed on the TSF embankment). The volumes of tailings water input to and returned from the TSF should also be monitored to provide the data needed to calculate overall water balance. The volume and quality of base seepage should be monitored, particularly from low points around the TSF toe, since this will report directly to the surrounding surface catchments and into the foundation, where groundwater resources may be affected. A TSF may have a seepage collection trench installed along the outer foot of the embankment and wells installed with pumps to return the seepage to the TSF. Some TSFs have underdrainage systems that report to a seepage sump. Monitoring of the quality and volume of this seepage is essential. Borehole sampling should be employed to monitor groundwater quality upstream and downstream of the TSF. This data is also important for closure planning (DIIS 2016e; ANCOLD 2012).

Comprehensive geochemical characterisation and monitoring of the hydrological and water-quality performance of a TSF during operations indicates whether the tailings can be directly revegetated or whether a cover system will be needed to meet rehabilitation objectives. Once tailings deposition ceases and rehabilitation is undertaken, it may be necessary to also monitor erosion loss due to rainfall run-off, dust generation by wind, the stability of drainage and spillway works, the time-series evolution of seepage water quality, and vegetation establishment and sustainability, to verify when the works meet closure objectives (see Appendix 2). Further details are in the leading practice handbooks *Tailings management* (DIIS 2016h), *Mine closure* (DIIS 2016e) and *Mine rehabilitation* (DIIS 2016g).

Many wildlife species, such as microchiropteran bats and waterbirds, use TSFs as wetlands where they seek food, water and resting sites. The solution and slurry quality of operating TSFs can be poor, and the exposure of wildlife to such solutions can be, but is not necessarily, detrimental. Wildlife monitoring regimes for TSFs should be established, and can be simple and inexpensive to implement. Further details are in the *Cyanide management* handbook (DRET 2008b).

4.4.4 Monitoring of in-pit tailings storage facilities

In-pit tailings disposal can be designed so that there is no additional impact on the surface. However, the geochemical nature of the tailings and composition of process solutions need to be monitored through time to provide input to groundwater models that are used to predict the extent of interaction of the pore water in the deposited tailings with surrounding groundwater flows. The other critical parameters that need to be measured relate to the consolidation of the tailings, since this will determine the final settled level of the tailings and hence the depth of any ultimate pit lake, the depth of the final tailings surface below ground level if no surface water is intended, or the volume of backfill required in the event that the pit is to be backfilled to the original ground surface. Further details are in the leading practice handbooks *Tailings management* (DIIS 2016h), *Mine closure* (DIIS 2016e) and *Mine rehabilitation* (DIIS 2016g).

4.4.5 Monitoring of heap leach piles

Monitoring required for heap leach piles is somewhat similar to that required for TSFs and WRDs. Physical stability and leachate containment should be the focus of operational monitoring. However, gold heap leach operations use cyanide at concentrations toxic to wildlife, and copper heap leach operations use acidic leachate solutions that are also toxic to wildlife. Operational monitoring of such facilities must therefore also include recording the presence of ponded leachate solutions on the surface and seepage at the base. Wildlife is particularly attracted to surface ponds and toe seeps. Also, scavenger species have easier access to carcasses on heap leach pads compared to TSFs. Even small pools can attract large numbers of animals, so the position (in relation to native vegetation, and height compared to the

surrounding terrain), and environmental conditions (drought), are more critical than the size of the pool. The irrigation of heap leach pads is dynamic, and surface pools can form and disappear rapidly during the course of operations. Heap leach pads are well suited to automated wildlife monitoring techniques, such as motion-triggered and infrared cameras (see Section 4.14.3).

Monitoring of disused heap leach pads will be needed to determine whether they are able to be rehabilitated in place once mining and processing cease, or whether the materials will need to be returned to a mine void or encapsulated in a dedicated waste storage facility (such as a WRD) to minimise environmental risk.

4.5 Contaminated land

Minimising land contamination during operations and rehabilitating areas affected by mining remain the goal of leading practice mining. The post-mining land use will determine to a large extent the nature and type of contaminated land management and associated monitoring that is required.

The surface of an operating mining lease inevitably becomes impacted to a greater or lesser extent by mineralised material derived from the stockpiling of concentrates, ore, waste rock and mineral processing residues (tailings) on the site. Contamination of the surface and at depth may also occur as a result of spills or leakages of petroleum products (petrol, diesel, kerosene) or process chemicals (xanthates, cyanide). To address the latter two issues at source, there needs to be regular mass balance monitoring of inventory held in storage so that leakage can be detected and repairs effected as soon as possible.

Monitoring of shallow groundwater bores in these areas will indicate whether there has been contamination of groundwater. Best practice for storage of these materials requires that tanks be located on impermeable pads bounded by bunds high enough to contain the volume of the tanks.

A site assessment will be needed to determine the extent of contamination and to quantify the human health and ecological risks associated with it. The outcomes from the assessment inform rehabilitation or management plans needed to maintain or restore the current or future condition of the land. In this context, the metal content of material used to produce the final surface layers of rehabilitated landforms also needs to be consistent with the final land use. When considering the area of land that needs to be assessed, the propensity of mineralised dust to be carried considerable distances downwind should be taken into account.

A fundamental requirement for contaminated-land assessment is to do detailed site mapping that shows the distributions and levels of contaminants. Conventional soil sampling with post-collection analysis constrains the number of sampling points (because of cost) and potentially reduces the resolution of the assessment.

The development and ready availability over the past decade of field-portable metal and organics analysers with good detection limits have revolutionised the conduct of contaminated site assessments at mine sites. Handheld X-ray fluorescence analysers (Hall et al. 2012), in particular, can be used to screen for concentrations of relevant metals at dozens of grid points in a day. Thus, areas with metal concentrations above environmental screening thresholds can be rapidly identified and the initial sampling grid refined as the survey is being conducted, resulting in substantial increases in efficiency, a reduction in overall cost and a more rigorous assessment. Any relationships between concentration and depth can also be rapidly assessed by digging shallow holes, which is especially useful for estimating the areal extent of surface contamination from dust fallout.

This approach contrasts with past practices in which samples were collected and then sent for analysis in a laboratory, with weeks often elapsing before the results were obtained. Repeat infill sampling was then often needed to fill in gaps in the coverage introduced by imposing a relatively coarse random grid over the area to be sampled.

A leading practice mine site determines the baseline concentrations of metals in the surface soil before starting operations in order to provide the basis for developing robust closure criteria. It is especially important to do this in mineralised areas, where shallow outcrops of mineralised material could later be wrongly attributed to contamination from mining-related activity. Some of this baseline information may be available from the exploration database, but a purpose-commissioned survey may also be needed to complete the coverage required. Longitudinal surveys through time enable any trends in contamination to be determined. Such surveys are especially important in areas likely to be affected by metal-containing dust.

A leading practice mine site also minimises the extent of surface contamination by avoiding or minimising the use of mineralised material to construct roads and other infrastructure, such as water diversion bunds or the embankments of tailings dams.

The framework that has been accepted in all Australian jurisdictions for the assessment of site contamination is the National Environment Protection (Assessment of Site Contamination) Measure (NEPM). While not specifically developed for assessments of contamination by mining, the framework contained in the NEPM is directly applicable to the design, conduct and interpretation (in both human and ecological health risk contexts) of a mine site assessment. The most recent version of the NEPM and associated schedules (2013) is available for download through the Standing Council on Environment and Water. The most significant changes in the latest version of the NEPM that are relevant to mine site assessments are summarised below.

The 1999 NEPM ecological investigation levels (EILs) have been expanded and cover a range of soil types and constituents that apply for fresh and aged contamination in soil. The current NEPM requires that both the potential effects to human health and the environment (ecology) of metals and metalloids be fully evaluated.

The NEPM (SCEW 2013) now defines the EIL as the concentration of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values is required. The EILs are calculated using EC30 or lowest observed effect concentrations toxicity data. EILs are the sum of the added contaminant limit and the ambient background concentration, and the limit is expressed in terms of total concentration. EILs depend on specific soil physicochemical properties and land-use scenarios and generally apply to the top 2 metres of soil.

The methodology used for deriving the EILs used in the ecological risk assessment framework is described in schedules B5b and B5c of the NEPM. Because the toxicity of some contaminants is affected by soil physicochemical properties, empirical relationships are used to model the effect of soil properties on toxicity so that soil-specific EILs can be developed. A supplied EIL calculation spreadsheet provides step-by-step guidance to enable the derivation of EILs specific to the site.

The tiered ecological risk assessment approach used in the latest framework facilitates the:

- identification of the ecological receptors of concern
- estimation of the concentration of a contaminant of concern to which the ecological receptors are exposed
- consideration of the toxicity-modifying or toxicity-enhancing capacity of the receiving environment (whether that be soil, sediment or water)
- determination of whether the ecological receptors and ecological values may be at risk
- application of a multiple-lines-of-evidence approach to assess risks.

The tiered approach screens out those sites where the environmental risk is minimal and enables resources to be focused on those locations that pose the greatest potential risk.

4.6 Groundwater

There are many references in the sections above to the need to monitor groundwater. What surface water and groundwater monitoring have in common is the need for good baseline (pre-mining), operational and closure data. The type of monitoring required (water level, water quality, aquifer yield, macro-invertebrates) and the locations of monitoring systems (close to the mine, and both upstream and at downstream compliance points) invariably need to evolve through time to address the different requirements at each of these stages in the mine's life. In all cases, the key receptors (surface ecosystems, drinking or irrigation water, groundwater ecosystems) need to first be identified to ensure that the monitoring program is well targeted both to detect changes that may affect the receptors and to meet compliance targets.

The occurrence of macro-invertebrate organisms (stygofauna) in groundwater is increasingly being recognised and, depending on location, the monitoring of them should be included in site environmental monitoring and management plans. The strongest and earliest push for this in Australia was in karst and paleo-channel environments in Western Australia, but leading practice mining operations take stygofauna into account more broadly. Leading practice guidance on identifying and monitoring groundwater ecosystems is provided by WAEPA (2013) and Richardson et al. (2011.)

In contrast to surface water monitoring, a groundwater monitoring program needs to address multilayered hydrogeology created by changes in geology as a function of depth (Sundaram et al 2009; OOW 2014). Several aquifer formations may need to be monitored to assess both environmental impacts (such as groundwater drawdown and contamination of aquifers) and mine safety aspects (such as the stability of open-pit walls and underground workings). Commonly, there is a need to place monitoring bores at different depths at the same location so that the extent of vertical connection between aquifer systems can be determined. Another point of difference from surface water monitoring programs is that access to sampling points requires the installation of bores, which are usually substantially more costly to establish than a surface water monitoring site. Hence, the cost of access is more likely to limit the coverage of the groundwater sampling site network. That cost must be balanced against the need to undertake sufficient monitoring of groundwater to address both environmental and site safety performance aspects.

Detailed consideration of near-field hydrogeology is needed to produce a design specification for a monitoring borefield that will provide timely data cost-effectively. If monitoring systems are located too far away, or in hydraulically inappropriate locations, a developing cone of depression or contaminant plume may go undetected for so long that it will be too late for mitigation of the source to be effective in preventing the impact. A leading practice groundwater monitoring program needs the spatial and

temporal resolution necessary to detect change so that management action can be taken before the extent of that change causes irreversible damage.

In summary, the groundwater monitoring network must be sufficient to:

- identify groundwater yields in the exploration stage
- establish the extent of hydraulic interactions between aquifers and surface water sources
- detect impacts on water quality and quantity
- measure or allow the prediction of impacts on identified sensitive receptors
- enable the safe construction and ongoing operation of open-pit and underground workings and waste storages.

The number and location of groundwater monitoring bores is determined on a case-by-case basis, as every site is unique in its combination of geology and environmental receptors. Open-hole monitoring bores allow both the measurement of groundwater levels and the sampling and analysis of groundwater for quality (Sundaram et al. 2009). When only water level is needed, appropriately installed and calibrated pneumatic or vibrating wire piezometers can be an alternative to manual dipping of conventional open bore holes for monitoring groundwater levels within a geological formation.

One issue of key practical relevance is that the near-field monitoring bores installed at the beginning of a mine's operating life may be subsequently destroyed as a result of the expansion of open pits, WRDs, or both. The consequences can be the loss of continuity of the baseline water-quality record needed to monitor performance and develop site closure criteria for groundwater. If one or more bores are lost, new bores should be installed far enough in advance that a period of parallel monitoring can be done to establish continuity of the monitoring record. In the case of bores that are encroached on by expanding WRDs, it may be possible with care to vertically extend the bore casing.

Specialised drilling, well construction and monitoring techniques and water sampling methods are needed to ensure a high degree of reliability in the monitoring data that is produced (Sundaram et al. 2009). The reliable measurement of groundwater quality requires special care and differs from surface water monitoring in several aspects. The installation of a monitoring bore, and the process used for the retrieval of water samples from various depths within the bore, need to be optimised to minimise the risk of sample contamination or chemical changes (such as those caused by oxygenation). Commonly, multiple, specially cleaned samplers need to be prepared for each bore sampling round. This is necessary both to minimise the potential for sample contamination and to account for the fact that different sampling methods may be needed, depending on the depth or recharge rate of each bore. The requirement for several different types of sampling device or multiple cleaned devices increases sample collection costs compared with surface water monitoring.

The groundwater monitoring program developed for a site should describe the location and depth interval of all monitoring bores and the frequency required for groundwater level and quality measurement (OOW 2014). In dynamic situations, the use of automatic data loggers should be considered the standard for groundwater level measurement. Instances where loggers may be required are at the groundwater – surface water interface, or when assessing the shorter term impacts of groundwater pumping on nearby bore users. Predictive numerical groundwater models are regularly used to assess the likely future impacts of mining on groundwater, and are increasingly being required by regulators as part of the performance assessment process (Barnett et al. 2012; OOW 2014). Model calibration requires groundwater-level data to be collected on a monthly basis as a minimum.

4.7 Heritage values

The Burra Charter (Australia ICOMOS 2013) is the leading practice reference for the management of potential and listed heritage features in Australia and is therefore not covered in detail in this handbook. The monitoring and evaluation of performance should be aligned with this guidance document for all elements of conservation principles, processes and practices where mining heritage values are integral to the current post-mining landscape and land uses.

4.8 Radioactive minerals

Globally, uranium mining is expanding to help meet the increasing demand for supplies of raw material for use in electricity generation. Australia has the largest proportion of the world's identified uranium resources, including the largest known single deposit, which is at Olympic Dam in South Australia. Specific radiation-related issues are associated with uranium mining and with some other mining operations that deal with naturally occurring radioactive material (NORM), such as mineral sands, phosphates, rare earths, oil and gas (see, for example, IAEA 2002, 2003abc, 2013; ARPANSA 2005, 2008). The increased exploitation of these minerals, many of which are associated with emerging technologies, has led to a greater awareness of the need to assess and monitor radiological risks in their mining and processing and in mine site remediation.

Although most current world production of uranium uses the in-situ leach method, in the medium term it is likely that most Australian production will be by underground mining. For open-pit mines and associated WRDs, environmental monitoring must cover surface water, groundwater and the air to ensure that there is no unacceptable risk to mine personnel and the general public and that the movement of radioactive contamination away from the mine is minimised. For underground mines, environmental monitoring of the groundwater in and adjacent to the mining area is obviously of extreme importance, especially to be able to ensure that the movement of radioactive contamination away from the mine is minimised. For the same reasons, environmental monitoring of TSFs in both open-pit and underground operations must cover surface water, groundwater and the air.

In-situ leaching of uranium ore bodies minimises surface disturbance and contamination. A leaching solution is injected into a confined aquifer located in a permeable uranium-bearing rock formation and pumped through the rock to dissolve uranium before the uranium-enriched solution is returned to the surface and treated to recover the uranium. There are no pits, WRDs or TSFs associated with in situ leaching. However, environmental monitoring of the groundwater in and adjacent to the mining area is extremely important, especially to be able to ensure that there are no excursions of the solution away from the mining area.

Whichever production method is used, uranium mining is similar to mining other metals. The most significant risks and issues associated with potential environmental impacts from uranium mines are rarely associated with radioactivity. All environmental protection rules and monitoring procedures required for heavy metal mines need to be applied, as well as those specifically related to the radiological aspects of the operation. The community generally maintains an extremely close watch on uranium mining operations, so monitoring programs are expected to be nothing less than leading practice.

In these circumstances, monitoring at a uranium mine needs to pay special attention to radiochemical and radiological parameters in addition to the standard suite of physiochemical monitoring parameters that are collected for metal mines. Such radiochemical and radiological monitoring is recommended by international and Australian guidelines and codes of practice, irrespective of the fact that the most significant risks and issues associated with low-grade uranium mines in Australia are rarely associated with radiological exposure (in contrast to the situation in very high grade underground uranium mines in Canada).

Radiation protection issues are primarily related to the work health and safety of people who may be exposed to radiation in the mine and processing areas for long periods. Their exposure is monitored through radiation management plans that are required by regulatory authorities and refer to international safety standards and limits that are incorporated into Australian law. Environmental radiation monitoring is usually done at the boundaries of working areas to ensure that fugitive dust and atmospheric emissions, if present, are below the internationally agreed limits and are kept 'as low as reasonably achievable'. The elements of such monitoring programs are listed in Appendix 2.

From an environmental monitoring perspective, some social and environmental issues specific to uranium mines need to be considered. For example, food-chain issues may be of concern if the post-mining landform or adjacent areas are used as a source of food supplies. Indigenous people, in particular, may traditionally rely on bush foods sourced from the local environment as part of their diet. In situations where mine remediation and traditional indigenous culture intersect, potential doses via the bush food ingestion pathway should be considered and assessed, taking into account the type and amount of bush foods typically consumed. Environmental monitoring to facilitate this dose assessment should include sampling and radionuclide analysis of the foods to establish transfer factors. Baseline studies are essential for understanding the naturally occurring pre-mining radiological levels, as they will be the basis for developing acceptable radiological closure criteria as specified by Australian and international guidelines.

Cover design, the selective placement of a topmost layer of material with low radioactivity levels, or both, are methods used to address food-chain and other public exposure issues during the operational and post-remediation phases, but their effectiveness requires assessment to ensure the radiation doses are within prescribed limits and as low as reasonably achievable. Post-remediation monitoring should be aimed at understanding aspects such as these and facilitating the management of risks to the general public, other land users, and flora and fauna.

Australian (ARPANSA 2014) and international (ICRP 2007) recommendations for radiological protection now specifically recognise the environmental exposure of wildlife (flora and fauna) to ionising radiation as a distinct exposure category to which assessment and protection considerations apply. Environmental exposures of wildlife should be assessed using a reference organism approach to estimate above-baseline absorbed dose rates to organisms from mine-related radionuclides in environmental media (typically soil or water) and from radionuclides accumulated in the organisms themselves. The estimated dose rates should then be compared with a protective screening level to determine the potential radiological risk to wildlife. Relevant radioecological data is necessary to assess environmental exposures, including data on the bioaccumulation of radionuclides by wildlife. A recent ARPANSA technical report (Hirth 2014) provides some general reference values on bioaccumulation factors for Australian organisms inhabiting uranium mining environments.

Current International Commission on Radiological Protection recommendations that have been adopted in Australia specify that total exposure of the general public to radiation throughout the operation of a uranium mine, as well as from a remediated uranium mine site, should be no more than 1 millisievert per year above pre-mining levels and should ideally be constrained to a lower value ('dose constraint') by applying the principle of optimisation of protection. To be able to demonstrate that this target has been achieved by the remediation practices that have been implemented, it is essential to conduct a robust assessment of the pre-mining radiological levels. A case study from the Wismut uranium mine remediation program in former East Germany illustrates how remediation works targeted radiation protection standards and how monitoring programs were applied to demonstrate the achievement of these goals.

Case study: Integrated monitoring program for a former uranium mining region in Germany

Wismut GmbH operates one of the largest environmental monitoring networks in Europe, taking roughly 30,000 samples per year and making 300,000 database entries (95% water samples). Water monitoring covers more than 1,400 investigation points for the observation of groundwater, surface water, seepage and processing water at seven former uranium mining and milling sites. The monitoring program is the backbone for performance evaluation for multiple former uranium mine and mill sites.

Brief history

Successful prospecting for uranium immediately after World War II prompted the Soviet occupation forces to establish the Soviet company SAG Wismut in what was then the German Democratic Republic in 1947. The company, which was initially run by the Soviet military, had the sole aim of exploiting German uranium deposits for the Soviet nuclear program. In 1953, Wismut became a jointly owned Soviet–German company. By 1990, Wismut had produced 231,000 tons of uranium, making it the world's fourth largest producer.

The environment around Wismut was adversely affected by more than 40 years of unrestrained mining and processing of uranium ores. The mining legacy included 1,400 km of underground adits and shafts, 311 million cubic metres of waste rock and 160 million cubic metres of radioactive tailings in densely populated areas.



Following German reunification in 1990, WISMUT, GmbH (limited liability company) referred to here as 'WISMUT' became a federal government-owned company, (www.wismut.de). Its principal business is the decommissioning, clean-up, and rehabilitation of uranium mining and processing sites, specifically:

- mine decommissioning and flooding
- disassembly and demolition of contaminated buildings and structures
- remediation of mine dumps and tailings ponds (shaping and covering)
- treatment of ascending flooding water, collected seepage and pore water.

Wismut has been mandated to ameliorate the environmental situation by eliminating or at least reducing adverse impacts to an acceptable level.

Performance evaluation

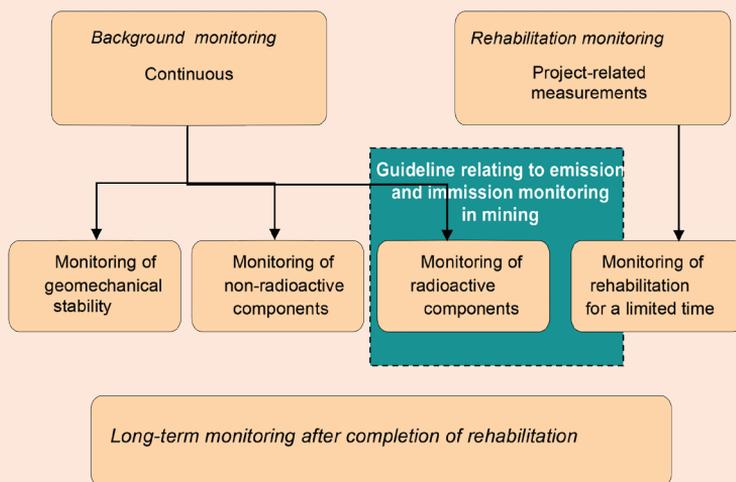
The objectives of the Wismut monitoring program are to:

- acquire data to plan and design remedial actions
- ensure compliance with legal and regulatory standards
- provide feedback on rehabilitation
- document remediation performance
- provide evidence of the efficiency of the remedial activities.

The Wismut monitoring program includes both environmental and operational monitoring. Parameters monitored include concentrations of radionuclides (such as U-238, Ra-226, Rn-222) as well as of non-radiological parameters (salinity, trace elements and so on). The program also gathers data on hydrological and meteorological parameters.

Wismut makes a distinction between background monitoring and rehabilitation monitoring (see Figure 2). Background monitoring involves long-term atmospheric and water pathways monitoring using a network of fixed monitoring locations and measurements that occur independently of remedial actions. Rehabilitation monitoring assesses the performance of the rehabilitation project. After the end of physical rehabilitation, a long-term monitoring program provides evidence on the performance of the remediation process. Final land uses include sheep grazing, greening, solar parks and golf courses. The monitoring conducted depends on the land use and the particular site (such as covered stockpiles and tailings and open pits). Parameters measured include plant growth and cover, soil characteristics and hydrological properties.

Figure 2: Structure of the Wismut monitoring program



Note: Includes requirements of the German Government to control, summarise and report all natural radioactivity outflow and effects on the environment. The term 'immission' refers to the receiving point where emissions are monitored.

Integration of monitoring and spatial data

The huge amount of data collected requires efficient data management and stringent quality assurance. Quality-assured data is stored in a central environmental database. The environmental database is linked to a geographical information system (GIS) that allows the interpretation, presentation and goal-oriented analysis of environmental data.

How monitoring data is used to evaluate the success of rehabilitation: an example

- Many waste rock dumps cause elevated concentrations of radon in the air near residential areas around the Schlema-Alberoda site. Figure 3 shows dump #366 after intensive reshaping and the construction of a 1-metre thick radon barrier over the reshaped landform. Figure 4 shows how remediation has resulted in significantly diminished radon concentrations in ambient air. Taking a background level for radon (Rn) of 20 Bq/m^3 into account, the measured concentrations of 70 Bq/m^3 (that is, 50 Bq/m^3 from the dump) correspond to an effective dose of 1 mSv/a for local people. This dose value serves as a criterion for the remediation success.

Figure 3: Dump #366 at Schlema site after remediation with measuring

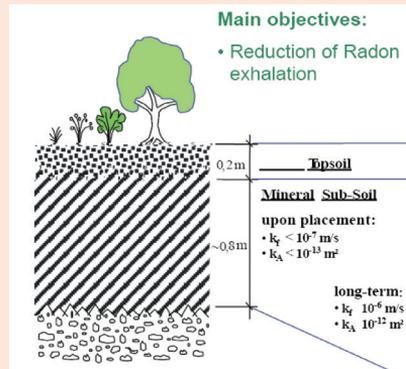
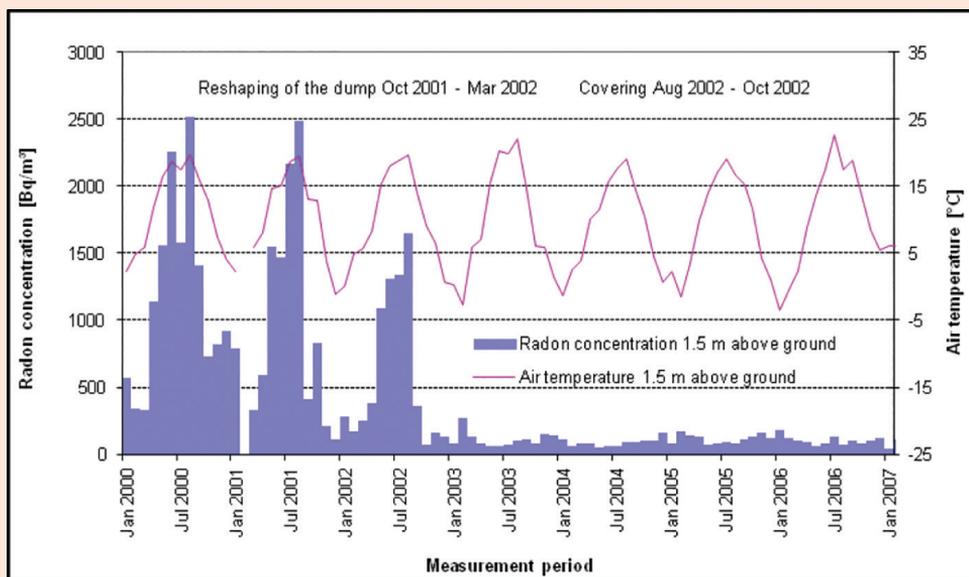


Figure 4: Time series of radon concentration measured (at the red star) and the limit of additional dose



Conclusion

Managing such a vast regional mine closure monitoring program requires clear monitoring program objectives for both background and rehabilitation monitoring measuring a range of parameters from remote data sources. Such a program would not be possible without the leadership and continuity provided by a well-qualified and experienced monitoring team ensuring quality assurance of all elements; data gathering, storage, interpretation and reporting of data over very long time frames. This project provides leading practice principles which can be applied to complex monitoring programs.

Legacy mine programs may require the development of site-specific limits to be derived as part of the remediation activity, in accordance with accepted international leading practice for what is described as an 'existing exposure situation', as opposed to a planned exposure situation (IAEA 2011). An existing exposure situation is one that already exists when a decision on the need for control needs to be taken. Such situations include exposure to natural background radiation that is amenable to control, exposure due to residual radioactive material that arose from past practices that were never subject to regulatory control, and exposure due to residual radioactive material arising from a nuclear or radiation emergency after the emergency has ended.

Similar concerns to those expressed about uranium mining are often expressed about other operations dealing with NORM, such as mineral sands or phosphate processing facilities. Again, the main concerns for public and biota protection usually relate to chemistry rather than radioactivity. Where applicable, workers in NORM-producing industries are monitored by a radiation management plan operated in accordance with regulatory requirements.

Comprehensive discussion of the above issues is in reference documents produced by the IAEA and the ARPANSA (see the 'Further reading' section of this handbook). A best practice guide for in-situ leach mining of uranium in Australia has been produced by Geoscience Australia (2010).

4.9 Community involvement in monitoring implementation

4.9.1 Environmental monitoring programs

With greater emphasis on sustainable development and increasing stakeholder involvement in decision-making, it is expected that communities will have a more active role in monitoring programs.

The principle of consulting community stakeholders in setting environmental monitoring and management objectives, as well as in selecting water-quality indicators to monitor and water-quality objectives to assess them against, is embodied in the ANZECC-ARMCANZ (2000ab) framework for water quality management. While it has not been widely adopted, leading practice operations have taken this approach. The Rum Jungle case study provides an example.

Case study: Rum Jungle Environmental Values Project

Acid and metalliferous drainage at the former Rum Jungle copper and uranium mine in the Northern Territory has led to significant impacts on local groundwater and on the aquatic environment of the East Branch of the Finnis River. Although rehabilitation was undertaken in the 1980s, it was not to a level that meets current leading practice for mine closure. In addition, the works were done without input from the traditional Aboriginal owners of the area.

The Northern Territory and Australian governments have been working under a partnership agreement to improve site maintenance and environmental monitoring and to develop an improved rehabilitation strategy for the site that is beneficial to stakeholders and consistent with the views and interests of the traditional owners. As part of this project, in early 2013 the territory's Department of Mines and Energy (DME) completed a study of the environmental values downstream of Rum Jungle. The aim was to describe the receiving environment's key ecological and geomorphological characteristics, identify environmental values of importance to the stakeholders, particularly the traditional owners, and set appropriate water-quality objectives for the rehabilitation of the mine based on those values. An environmental monitoring plan was then designed so that improvements in water quality could be measured as further rehabilitation of the site went ahead.

The study was done by a team of scientific experts with a range of relevant technical skills and a detailed knowledge of the area. The team carefully reviewed historical data and scientific reports, conducted a field inspection and held consultations with stakeholders, including the four main traditional owner groups. The team discovered that, while a substantial amount of monitoring data had been collected over the years, focused mainly on waters within the mine site, there were substantial data gaps for environmental quality in the river and riverbank habitats downstream of the mine.

An important part of the fieldwork was to identify cultural values through meetings with traditional owners. Their contribution helped the team identify the cultural values that needed to be considered as part of the ANZECC-ARMCANZ (2000b) method of identifying environmental values and setting water-quality objectives. The team learned that the health of the river, its ability to flow freely, and the abundance and wellbeing of totem and other culturally and spiritually significant organisms and traditional foods were particularly important to the traditional owners. Because many of those cultural values were closely linked to aquatic ecosystem health, it was possible to use water-quality trigger values as surrogates for cultural value protection. This approach was agreed to by the traditional owners.

The study found that the 1980s rehabilitation of the mine site greatly improved the quality of downstream flows, reducing contaminant loads in the East Branch by factors of three to seven on an annual basis (Jeffrey et al. 2001). However, water quality in the branch is still at times well above applicable trigger values for aquatic ecosystem protection. Sediments along the branch also contain metal concentrations above the sediment quality guidelines.

Studies during the 1990s documented the status and recovery of water quality and aquatic organisms following the start of rehabilitation in 1983, indicating that substantial recovery had occurred in the main Finnis River, but that aquatic ecosystems remained degraded in the East Branch. However, there had been very little investigation of riparian vegetation during the pre-mining, mining and post-rehabilitation periods despite extensive riparian vegetation dieback during operations. While there was some recovery in the East Branch, some parts of the riparian corridor remained highly affected. The riparian condition of the main Finnis River (downstream from its junction with the East Branch) was generally much better, improving with distance downstream.

Near the coast, the Finnis River flows through the Finnis River Coastal Floodplain Site of Conservation Significance, which supports a number of listed threatened species. However, very little was known about the status of riparian and aquatic rare and threatened flora and fauna within or near the mine site, despite the cultural importance of several of those and other more common species.

To identify environmental values and develop water-quality objectives from them, the downstream river system was divided into nine zones (four in the East Branch between upstream of the mine and the branch's confluence with the Finnis River and five in the Finnis River from upstream of the East Branch confluence to the estuary, including the site of conservation significance). This was undertaken because existing ecosystem health, environmental values, recovery potential and therefore targets differed along the river system. The environmental values considered for each zone were aquatic ecosystems, cultural/spiritual, wildlife habitats, primary recreation, secondary recreation, visual recreation, industrial usage, aquaculture, drinking water, irrigation, stock water and farm supply. Only aquatic ecosystems and cultural/spiritual environmental values were important for all zones.

Water quality objectives were developed for each zone for each water-quality parameter by selecting the lowest trigger value identified for any of the environmental values that applied to that zone. The objectives have subsequently been incorporated into rehabilitation planning and design to ensure that any future rehabilitation works address them.

For the highly affected zones in the East Branch within the mine lease area, it was considered that rehabilitation was unlikely to be capable of providing water quality that would afford the same level of protection of aquatic ecosystems selected for zones further downstream. Higher concentration trigger values were therefore nominated for those zones. Because they were selected in terms of the percentage of species protected, it was possible to convey to the traditional owners what was implied by these reduced levels of protection and reach agreement on the water-quality objectives for those zones.

The recommended monitoring program developed from the study aims to provide a sufficiently robust current baseline against which to assess rehabilitation success. It comprises water quality, aquatic biota, aquatic and riparian tetrapoda (vertebrates other than fishes); channel processes (such as erosion and sediment deposition); riparian vegetation; and bush foods identified by traditional owners. Monitoring locations include upstream reference sites and sites as far downstream as impacts had historically been detected or might be expected to occur in the future.

The assessment team recommended that routine monitoring should be supported by targeted studies in the first instance to help develop locally derived water-quality objectives, and that the findings should be regularly reported to the public and directly to the traditional owners.



Rum Jungle mine when operating.



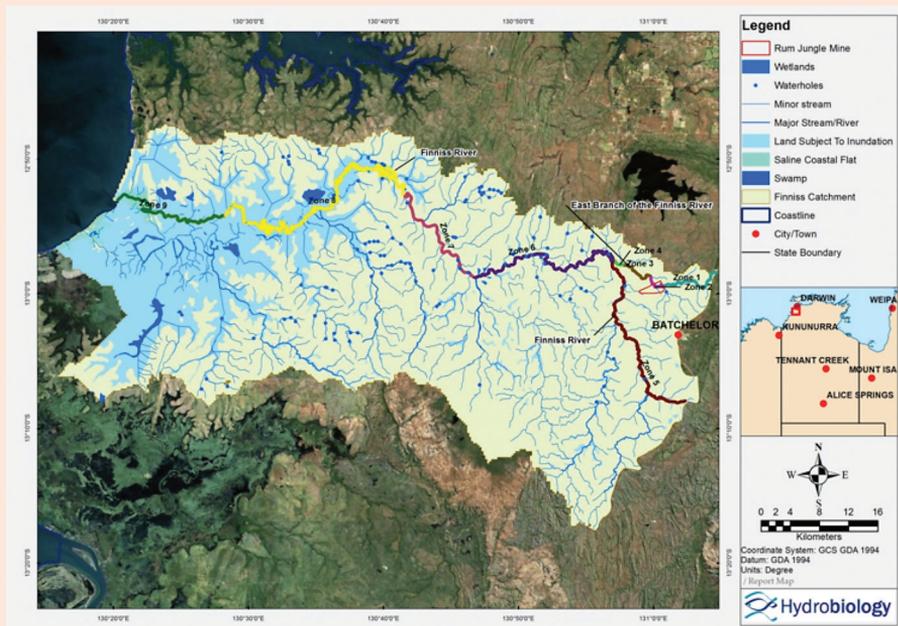
Dr R Smith of the study team testing the water quality of a pool in the East Branch.



Pools in the diversion channel at Rum Jungle affected by contaminants from the former Rum Jungle mine.



Sandy sediments fill the channel in the lower East Branch.



Map of the Finnis River system showing the zones used for setting water-quality objectives.

Community engagement in the collection of environmental monitoring data requires consideration of the training and skills needed for community participants and data quality management to ensure the validity and utility of the monitoring results. Nonetheless, it can and has been adopted with considerable success. Streamwatch (www.streamwatch.org.au) is an example of a successful community-driven environmental monitoring program outside the resources sector that demonstrates the real value that can be realised by community environmental monitoring. In the mining industry, there are many examples of community involvement, such as volunteer helpers in field programs, landowners hosting and helping to maintain automatic weather or gauging stations, local student internships, and community members providing anecdotal accounts of species presence or absence and historical changes to landscapes and habitats.

Leading practice adopters of community engagement realise the benefits of better community understanding of environmental monitoring results and the constraints on collection of monitoring data. In areas where environmental monitoring engages with communities with subsistence economies, income earned by participating in monitoring can be a substantial boost to the local economy, providing additional positive community sentiment.

Web-based consultation is an increasingly popular way for community members to have input to various stages of a project. It is well suited to engaging young people and those unable to attend meetings and can help to reduce 'engagement fatigue' among community participants.

4.9.2 Socioeconomic monitoring programs

As noted in Section 3.4.3, socioeconomic monitoring in the mining industry should ideally involve mechanisms for community input at each stage of the monitoring framework's development and execution, potentially including data collection and the validation of outcomes.

Clearly, the capacity of a community to participate in data collection depends on the form and context of the data in question. Nevertheless, a well-designed socioeconomic monitoring framework that incorporates a mix of data types and sources should seek to include some degree of community participation at each stage of the monitoring program. Community groups that could facilitate that participation include community liaison groups, schools and local associations. It is also essential to consult and include local indigenous people (traditional owners) on a wide range of socioeconomic, cultural and heritage issues, as many issues are interrelated.

Socioeconomic monitoring programs that fail to include a cross-section of community interests may ultimately prove to be deficient as an organisational or community reference point. Tools to guide companies in identifying primary or secondary stakeholders include the ICMM *Community development toolkit* (ICMM n.d.).

Case study: Indigenous community involvement in monitoring for improved land management

Rio Tinto Alcan's (RTA's) Weipa bauxite operation is on the west coast of Cape York Peninsula in Far North Queensland. The operation runs community engagement programs, driven by obligations in RTA Weipa's Indigenous land use agreements that include ongoing consultation with traditional owners to identify potential land management impacts and opportunities before expanding the mine into new areas. The programs are developed by the RTA's community relations, heritage and environment teams to address each team's specific responsibilities.

The teams have begun to develop programs that facilitate the involvement of Indigenous communities in monitoring compliance responsibilities to improve land management across the site. The environment team developed the Deriving Cultural Values community consultation project in collaboration with traditional owners to capture their thoughts, values and aspirations relating to rehabilitation sites on the company's mining leases. This project facilitated the input of Indigenous values into rehabilitation objectives and practices on site, identified the priority plants for traditional owners and described the cultural framework that defines the significance of the plants. This knowledge will help RTA to target appropriate plant species for rehabilitation and take into account other traditional owner values and aspirations for country after mining ('country' is the Aboriginal concept of land and includes their spiritual, physical, social and cultural connection to it).

The cultural heritage team collaborated with traditional owners to develop a proactive management approach to cultural heritage that identified the values and importance of cultural heritage places to them. This allows appropriate management and monitoring strategies for places and sites across the mining leases to be defined if and when they are affected by mining.

In 2013, RTA looked to expand mining activities into the areas east of the current East Weipa mine. This area had not been substantially affected by mining, and the land management of the area required significant community engagement with the traditional landowners, the Wathayn and Peppan peoples. Lessons from rehabilitation and cultural heritage workshops found that approaches to land management should be more holistic and deal with country, rather than engaging separately with community relations, heritage and environment.

The RTA teams and the Wathayn and Peppan traditional owners are developing a plan that collectively deals with all land management obligations for the area. The plan will be developed through a series of on-country workshops and meetings to detail RTA's legal obligations and agreements for land management and identify traditional owners' values and aspirations for the land. The plan will inform the way RTA implements its land management obligations on country to meet its legal and agreement requirements and the values and priorities of traditional owners. Through this process, RTA will develop a clear understanding of what traditional owners want the company to be telling them about its land management and how its activities should be conducted, and identify opportunities for engaging in land management activities. The Communities, Heritage, and Environment Land Management Plan will detail the ongoing management and monitoring of the area, allowing for early detection of negative impacts to land, clear assessment of the effectiveness of RTA's land management, and the development of effective remedies in collaboration with traditional owners.



4.9.3 Handling disputes and community grievances

Disputes between mines and communities, or particular groups within a community, are not uncommon. If handled well, engagement over difficult issues can help to strengthen relationships and demonstrate the mining operation's willingness to address issues of concern (even when they cannot be fully resolved). Early engagement, community participation, impact assessment, risk analysis, and commitments to human rights and community development are pre-emptive leading practice strategies that aim to prevent conflict arising in the first place.

Nevertheless, issues will inevitably arise and operations should prepare for them by establishing effective grievance and dispute resolution mechanisms as early in the mine life cycle as possible, including during the exploration phase. Monitoring mechanisms should include processes to communicate, receive, log, assess, respond to and report on complaints. Trends in incidents and complaints should be analysed and used to achieve better outcomes and demonstrate improvement in performance.

Early and inclusive engagement will help determine the optimal design for the consultation mechanism. The needs and preferences of vulnerable, minority and marginalised groups should be considered, for example by providing means to lodge grievances for people with low levels of literacy. Complaints mechanisms, whether formal or informal, should be monitored and evaluated regularly, including evaluating people's satisfaction with the outcomes as well as with the process.

A recent study on mining and community grievances lists those elements of grievance mechanism recording and management that have worked and those that have not (see Appendix 3, from Kemp & Bond 2009).

4.10 Data management

Considering the cost and effort that goes into collecting it, monitoring data is commonly the most expensive asset of a mining project's monitoring section, so it is astonishing to see how little attention is often given to optimising data storage and management systems and the uses to which the data could be put. To realise maximum value from the investment in data collection, database management systems must be in place to ensure not only that the data is accurate and readily accessible, but also that adequate security exists to prevent tampering or unauthorised access. A leading practice data management and reporting system automatically alerts operations staff if key parameters approaching performance limit values, and facilitates the production of timely and fit-for-purpose reports. The monitoring data can also be used to support research effort and to identify previously unrecognised relationships between monitoring parameters. This is leading practice data management; storing monitoring data in a spreadsheet on a local hard drive is not.

Adequate data management is the first step in data quality control. As the *Australian guidelines for water quality monitoring and reporting* note, 'Once the "certified" data leave the laboratory, there is ample opportunity for "contamination" of results to occur' (ANZECC-ARMCANZ 2000b). Data insertions, deletions and repetitions, the mixing of units of measurement and the mis-assignment of sites or dates can readily occur. Such data errors can be very difficult to detect without regular detailed checking of new sets of data by personnel who are familiar with the monitoring program. Rigorous data entry quality assurance and quality control, using a database with appropriate authorisations for access and tracking of edits and internal consistency checks, can eliminate or minimise such errors, and are well worth the cost and effort.

Because most data storage systems are primarily electronic, it is critical that they are adequately backed up (both onsite and offsite). Ideally, hard copies of the data should also be maintained. As with any aspect of quality management, good housekeeping is the essential element. The adequacy and quality of the backups, and their locations, should be regularly checked. This applies especially where multiple networked systems are involved and where there is potential for parts of the system not to be backed up as a result of software error or hardware failure.

For operations with long lives, it is important to use data storage software that is widely used, allows easy data transfer to another system, or both. Software systems evolve, and there is no guarantee that the software used today will continue to be supported or that future hardware and operating systems will be able to run it. The same applies to mass storage media and internal formatting used for the archiving of data.

For larger datasets, relational databases are generally better futureproofed because the data structures can be maintained in future software implementations, and robust data transfer systems are generally well developed for them. For smaller datasets and projects of short duration, standard spreadsheet formats can provide adequate futureproofing, but they might not be the best option if they do not allow easy data quality checking. Online database options are available even for small datasets, and free relational database software is readily available.

A number of relational database packages tailored for storing and reporting monitoring data are available. The leading packages include the ability to automate some aspects of data quality checking (for example, the ion balance in the case of water sample analysis) and provide for data quality scores to be associated with the stored measurements. Such features are highly recommended for leading practice data management. In selecting a monitoring data management package, it is essential that its suitability and coverage of data types are matched to the requirements of the monitoring program. It is ill-advised to design monitoring information content to suit the capabilities of the software, as that may mean that a number of important components of the monitoring program cannot be effectively incorporated into the data structure or need to be downgraded or summarised to be stored, potentially reducing the future utility of the data.

Flexibility and adaptability in data management systems are necessities in the selection of a monitoring data management package. The sites, parameters and precision of monitoring may change over time in response to changing management needs. The data management system needs to be flexible enough to accommodate such changes and maintain the right balance between standardisation to facilitate data quality management and adaptation to facilitate the optimisation of the monitoring program. Usually this will entail a multi-level security system, so that only an authorised and technically competent system manager is able to make the changes necessary to adapt the database structure to changing needs.

Most modern monitoring programs include the collection of different types of data, such as datasets of different sizes, continuous or semi-continuous time-series measurements, and discrete samples of a limited number of parameters. Alternatively, they may include datasets of different levels of complexity, such as biological measurements of several parameters for different body parts of individuals of several species from different taxonomic groupings, collected using several different sampling methods at a number of sites on a number of occasions, as well as spot water-quality measurements once a month with a few parameters per sample.

Leading practice use of the different datasets includes comparison and synthesis of results to provide multiple lines of evidence to assess the impact of the mining operation. Where possible, this should be facilitated by the use of a single data management system. However, it might not be possible to effectively include all types of monitoring data in a single system. In that case, standardisation of the use of some data elements across datasets, such as the use of common site code descriptors, is essential to facilitate the analysis of data stored in different databases. Commonly, the location of a compliance site may change through time, and the same station name is retained for reporting convenience. In such a case, it is essential that a record be kept of the changes that have occurred in the location, as previously unrecognised differences in behaviour may subsequently be found. There may also be cases in which the same site has been assigned different names as a result of data having been collected by different teams for different purposes (such as water quality and taxonomic identification). In such cases, it is essential that the data management system is capable of matching the various site names (aliases) to the location, so that all of the datasets for that site can be collated and reported consistently.

The data systems must be accessible to those who need to use them and sufficiently intuitive so that new users are able to use them quickly and access the monitoring data as they need it. Clarity in data management systems should extend to data sources, their quality and their relevance. Remember that the person in charge of the data now may not be the person responsible for it in years to come. Leading practice data management systems facilitate transfer of the monitoring knowledge base and should be person-independent.

Maintaining corporate memory of monitoring and auditing results can also be a big issue for a mining project. Procedures must be in place to ensure that monitoring techniques, locations, data and reports are securely recorded in a manner that will enable new staff to continue to implement and report monitoring programs without any loss of information or quality control.

A robust spatial database is also an essential requirement for keeping a record of the location of all monitoring sites. A common problem relating to spatial data management is that of different mapping datums being used, making data conversion necessary. This is a straightforward task if the process is known or well documented, but it can lead to serious errors if there is a high turnover of staff or if data points are plotted onto base imagery using GIS without rigorous review and checking.

The use of spatial data acquired by portable global positioning system (GPS) units is standard and usually includes inbuilt translation to a range of datums, but once transferred to a database the selection of a common datum is essential for the accurate positioning of field points in the GIS and the relocation of sites by new samplers.

GIS software can also be used to point and click on specific monitoring details (contained in separate databases but linked to the GIS). Particularly large or complex sites may need data visualisation tools that provide a link between the spatial data and a range of conventional data sources in spreadsheets and databases. Leading practice requires good integration of monitoring data with GIS, web-based interface, site operational data and information management systems, or combinations of them. Increasingly, components of monitoring data are being made available to external parties (such as regulators and community groups) using web-based platforms. The availability of this facility should be considered when a data management and reporting system is being selected. Good data accessibility but secure data storage is the key.

4.11 Data analysis and interpretation

Although consistently meeting regulatory requirements in relation to monitoring results is an important component of leading practice, it does not, by itself, represent leading practice. Leading practice requires that analysis and interpretation of monitoring data commences early and remains an ongoing process, so that companies can identify and address problems as soon as possible, preferably before they become significant issues. For example, staff should be encouraged to note any unexpected readings as soon as possible while conducting field monitoring or when reports are received from an analysis laboratory—not days or even months later, when results are analysed in more detail for the preparation of a compliance report. Results should be assessed against ‘zones of comfort’ and ranges where risks of significant impacts could occur; this will help trigger action response plans and enable early preventive or remedial action.

As well as following routine monitoring procedures, staff should observe and report aspects that could help with subsequent data analysis and interpretation, such as the presence of:

- sick or dead fish, when monitoring water for heavy metals, dissolved oxygen and so on
- algal blooms, when collecting water samples for nutrient analysis

- tree-yellowing or other possible signs of nutrient deficiency or dieback, when monitoring rehabilitation plantings or unmined native woodlands.

Unusual or extreme events, such as floods, could be filmed or photographed to record visible quality indicators, such as turbidity. Anomalies in monitoring data compared with previously measured values may indicate problems with the maintenance or calibration of monitoring equipment, which need to be identified and corrected as soon as possible.

Leading practice monitoring and data analysis require a conscious effort to go beyond routine regulatory requirements in:

- collecting data, for example by including observational data and taking extra samples if required
- ensuring that samples are representative of what is really happening, by adapting the monitoring schedule to the nature of the event (which rarely occurs when routine prescriptive procedures are being followed for compliance monitoring).

Early analysis of monitoring data can also be very helpful in refining monitoring procedures. A leading practice approach is to run a pilot study and analyse the data so that any problems with sampling and analysis can be identified and rectified before implementing the monitoring program at full scale. This can include ensuring that the sampling design is compliant with the implicit assumptions in the preferred statistical analysis design, understanding variation, and using power analysis to optimise the amount of sample replication and other aspects of data analysis.

So, when sampling, how do we know when we have enough samples? Determining the optimal number of samples or replicates for a study to account for the physical and natural variation within a site ensures an adequate power to detect statistical significance, should it exist. If a study is underpowered, the results will be inconclusive and increase the risk of failing to detect a change when it has occurred. On the other hand, collecting too many samples is a waste of resources. Leading practice monitoring programs use power and precision analyses to ensure that they are providing adequate statistical power to detect meaningful effects in the most cost-effective way.

Typically, calculating required sample sizes using a power analysis requires particular information and parameters: the statistical test to be used, the sample size used, the significance level (alpha), power, effect size, mean and variance. These values are used to test the hypothesis, which is typically a statement of whether an effect exists or not. Power analysis is used to estimate the minimum sample sizes needed to detect a particular effect (see the case study on determining sample size), or the realised power for a statistical test that has already been conducted but where an effect was not detected (that is, whether the non-detection of effect was reliable).

Case study: Sample size estimated for monitoring impacts of undermining on a plant growing on damp rock faces

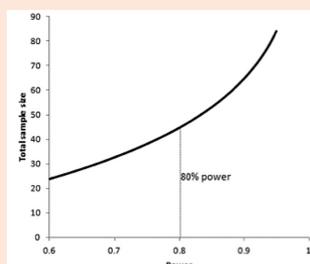
Epacris muelleri (family Ericaceae) is a weak, straggly shrub growing on damp, sheltered, sandstone faces in the western Blue Mountains in New South Wales where there is underground coalmining (Figure 5a). It occupies a habitat that may be sensitive to impacts related to subsidence, as well as sites where conventional sampling techniques might not be possible. Research staff from the University of Queensland's Centre for Mined Land Rehabilitation ran a short pilot test comprising forty 1 m² plots in a variety of locations to understand the variation in the population. This revealed an average density of 4.6 plants per square metre and a standard deviation of 4.3. From this, it was possible to develop the hypotheses for a theoretical decrease of 30% in the density in the population as an indicator of impact on *E. muelleri* as:

H (null): mean density at current levels (such as 4.6 plants per m²)

H (alternate): mean density with a 30% decrease in abundance
(for example, 3.2 plants per m²)

A power analysis revealed that a minimum of 45 sample plots would be needed to detect a decrease of 30% at 80% power (a conventional rule of thumb)—see Figure 5b.

Figure 5: (a) Sampling *Epacris muelleri* plants growing on damp rock faces using 1 m² plots
(b) Power analysis with calculated sample size at 80% power



With a small investment in field data collection (1 day), it was possible to calculate the minimum samples or replicates needed for certainty of impact detection. Provided the monitoring design is representative of the area to be affected, this approach can be used to evaluate and direct management practices as a project progresses. A practical example of how a power analysis can be incorporated into a monitoring design with quantified trigger points for management might read like this:

- Management objective: Allow a decrease of no more than 30% of the 2014 cover of *E. muelleri* in population sampling area A between 2014 and 2017, in comparison with a control/reference site.
- Sampling objective: Be 80% certain (power) of detecting a 30% change (effect size) in cover with a Type I error (alpha) of 0.10.
- Management response: A decline of 30% will trigger a study to determine the cause of change. If mining activity is determined to be the cause of the decline, it may be necessary to avoid or minimise the techniques used (such as void width, the location of mining areas or the orientation of mining layout) to prevent further impact. Remediation may also be required.

The parameters in a power analysis can be adjusted further, depending on the conditions, limitations and trade-offs required for designing a successful monitoring program. Elzinga et al. (1998) describe methods for changing parameters.

Alternatively, precision analysis can be used to determine the minimum effect size (difference from the control mean) that can be detected with adequate power with a given sample size. This can be particularly useful where the number of samples that can be taken is constrained by a limited budget or the availability of the monitoring target (such as rare organisms or rare habitat types). The methods used for calculating sample size or precision can be quite complicated, but fortunately there are a number of guides and free software online. Free online monitoring manuals with chapters on power analysis include Barker (2001), Elzinga et al. (1998), Harding & Williams (2010), Herrick et al. (2005) and Wirth & Pyke (2007). A very good overview of the importance of power analysis is provided by Fairweather (1995). Also useful is the online statistical reference McDonald (2009) and the free software G*Power and PowerPlant. Thomas & Krebs (1997) list over 29 software programs capable of undertaking power analysis.

Data should be analysed as soon as possible to ensure that rapid feedback is available to operators and stakeholders and that any identified problems can be addressed as soon as possible. Standard practice requires that the data be analysed and compared against agreed objectives and targets or standards. Leading practice goes beyond this and seeks to provide early warning of possible problems by analysing trends (either visually or using statistical analyses). Companies may choose to set more stringent internal trigger levels than required for compliance to initiate further investigation.

The use of agreed statistical procedures will often be needed to analyse and correctly interpret the data obtained using carefully designed monitoring programs. This can result in a more robust determination of whether objectives and targets have been met and help resolve situations where legal issues may be involved. However, even when statistical procedures have been agreed on, it is essential that exploratory data visualisation (such as graphs, tables and GIS plots) is done to examine patterns and trends and, if appropriate, that investigative statistical analyses are conducted to ensure that changes are detected early. This can also help confirm the applicability of the agreed statistical analyses.

In some situations, small sample sizes or other limitations may preclude the use of some conventional statistical analyses (such as analysis of variance). This applies especially to those cases in which there is a consistent trend through time. In such instances, analysis of trends and other procedures may be needed to detect changes. The use of Bayesian statistics has recently revolutionised analyses of small sample sizes, and several other robust classical statistical tools may be suitable.

Whatever the case, statistical methods are simply hypothesis-testing or hypothesis-generating tools and are no substitute for the examination of quality data from an informed environmental science viewpoint. Routine, mechanical, statistical testing of compliance may be standard practice, but leading practice requires data interpretation that takes into account an understanding of the processes in the receiving environment and the mechanisms of action of the stressors of concern.

Therefore, most leading practice monitoring programs and practices will include sound experimental design and statistical analyses, but can also include simple field trials and detailed observations that may help greatly in understanding the causes of impacts and the processes of recovery.

As well as being used in compliance checking, the analysis of the results from monitoring programs should also be used to investigate any trends that may be developing in the frequency of occurrence of, for

example, noncompliance with a water quality parameter. An increasing frequency of failure can point to a developing adverse condition. Incidents can range from near misses to spills with significant environmental or safety impacts. Recording the details, impacts and frequency of events and analysing this information in relation to operating procedures can be useful for both reporting and improving performance. It is standard practice to record these details in sites with AS/NZS ISO 14001:2004 compliant EMSs. Leading practice takes this a step further by analysing the data and acting on the results of the analyses.

As well as the obvious aspects of the interpretation of analyses, such as determining whether objectives, targets and standards have been met, leading practice includes a strong focus on continuous improvement. Leading practice companies clearly understand that monitoring provides the information needed to identify problems and to assess the effectiveness of mitigation measures. Procedures are set in place to ensure that the findings of monitoring programs are reviewed by company environmental and operations staff. Results are inspected in conjunction with records of events (such as a change in operating procedure) and actions taken (for example, to explain an unexpected rehabilitation outcome) in order to determine causes and explain results. In some cases, further investigation, monitoring or research, including root cause analysis, may be required. Modifications to the monitoring program may also be needed and should be considered on a regular basis.

Frequent objective analysis and interpretation of data, with a strong focus on continuous improvement, will result in better environmental, economic and social outcomes.

4.12 Completion criteria

Completion criteria (also known as ‘success criteria’) are critical elements of the mine closure process. The mining company requires completion criteria in order to demonstrate that rehabilitation and other objectives have been met, close the mine and relinquish the mining lease.

Leading practice mine completion criteria go beyond physical and biological rehabilitation and closure aspects to include social and economic criteria, in order to establish sustainable outcomes in communities that may have been negatively affected by mine operations, mine closure, or both. Governments need reliable measures of rehabilitation success to ensure that sites are stable and sustainable and the community is not inheriting an ongoing liability. The public wants to know that the rehabilitation will be successful; that the site is non-polluting, not having impacts beyond the mine boundaries and being safe for humans and fauna; and that sustainable land use will result. Examples of leading practice approaches to closure planning and design are in the *Mine closure* handbook (DIIS 2016e).

While completion criteria are a key requirement for demonstrating rehabilitation success, meeting regulator and other stakeholder expectations for mine closure also requires criteria relating to other parameters. They might include criteria relating to water quality (for a range of water bodies and downstream creeks or rivers), contaminated land, visual indicators linked to aesthetics or belief systems (such as landforms not visually detracting from significant landmarks), the agricultural productivity of farmland, or geotechnical stability. The need for each criterion should be defined during risk assessments undertaken as part of life-of-mine closure planning.

Procedures for developing completion criteria are described in a number of documents, including the *Mine closure*, *Mine rehabilitation* and *Biodiversity management* handbooks in this series (DIIS 2016e, 2016g and 2016f). Other key references describing important aspects of the process include the IMCC mine closure toolkit, *Planning for integrated mine closure* (ICMM 2008) and the ANZMEC–MCA *Strategic framework for mine closure* (2000). In the simplest terms, a clear closure objective is needed, accompanied by auditable measurement criteria that can be used to establish that the objective has been achieved. The criteria,

together with any associated targets and standards, must be clear and unambiguous, measurable using indicators and methods acceptable to regulators and other key stakeholders, and achievable.

Monitoring, auditing and research can play a key role in the development of completion criteria by demonstrating what impacts have occurred due to mining activities and the extent to which rehabilitation can replace (or is replacing) the values affected, as outlined in the agreed objectives. The results can be compared with stakeholder expectations, and the criteria, together with any associated targets or milestones, can be modified according to new information, subject to the agreement of stakeholders. A process for developing ecological criteria is described in Nichols (2006), where it is illustrated using a flowchart.

More recently, several Australian states have provided guidance on the development of completion criteria, such as Western Australia (DMP-EPA 2011) and Queensland (DEHP 2013). Both emphasise the importance of having clear objectives, using indicators to measure the development of rehabilitation, and closely linking completion criteria to both of them. They also provide examples of criteria.

When developing rehabilitation completion criteria and associated indicators, it is important to note that expectations are increasing. Simply using the area rehabilitated as a measure of performance is no longer considered sufficient. Several companies are now either using or developing more detailed measures (or metrics) of rehabilitation quality. They include measures of species richness and diversity (such as the numbers of native species in a defined area), as well as measures of cover and indicators of nutrient accumulation and cycling. In several instances, rehabilitation quality metrics (RQM) or similar measures that integrate several indicators are being used to assess rehabilitation performance, sometimes in conjunction with the assessment of offsets (for example, Temple et al. 2012; Rio Tinto 2008). These can be useful for determining whether objectives linked to no net loss of biodiversity are being met.

When assessing the establishment of native ecosystems, it is now generally required that monitoring include unmined reference sites. However, the reference sites might not necessarily be equivalent to pre-mined sites. Also, in most mines, even when leading practice rehabilitation methods are used, differences in pre- and post-mining soil structure and parameters exist. For that reason, it is not realistic to require that rehabilitation sites exactly match unmined sites in terms of key ecological parameters. Rather, the monitoring and comparison of rehabilitation with reference sites should give an indication of the replacement of ecological values over time and likely long-term sustainability.

For most projects, monitoring and auditing for performance evaluation have an important role in demonstrating that agreed completion criteria have been fulfilled and rehabilitation objectives have been met. Completion criteria can be derived from a number of sources, such as the conditions of an approval or an enabling agreement, agreements with individual landowners or regulatory requirements. The biophysical and social contexts of the mine also need to be taken into account. Often an operation commences with some broadly agreed closure objectives and associated completion criteria. They are generally easier to develop for mines that have a shorter life and clearly defined footprint than for longer lived mines with a more dynamic footprint. As the mine evolves, the objectives and criteria may be adjusted to reflect changing community expectations where they can be accommodated. The criteria may progressively become more refined and specific as mine closure approaches. Changes made to them, for whatever reason, may require altered monitoring procedures and auditing criteria.

Leading practice requires that, where practicable, mines implement progressive rehabilitation on an ongoing basis during mining operations. This can be linked to progressive sign-off through evaluations of rehabilitation performance and thereby increase stakeholders' confidence in final rehabilitation outcomes and the mine closure process. Where progressive rehabilitation is carried out, definitions of rehabilitation success may need to be modified to cater for specific aspects of the rehabilitation process. For example, if

progressively rehabilitated areas have poor connectivity with undisturbed areas, opportunities for the return of fauna and natural floral recolonisation may be more limited.

Completion criteria are usually developed for each 'domain'; that is, for each different operational area of the mine, including open pits, WRDs, TSFs, infrastructure and so on. The criteria include consideration of social, cultural, economic and environmental values, all of which will need to be measured or assessed in some way to determine whether the target or milestone has been met. It is important that criteria are 'SMART' (Specific, Measurable, Attainable, Realistic, Timely).

Completion criteria for the closure and rehabilitation of open pits, WRDs and TSFs commonly include consideration of the following elements:

- The final waste landforms are physically and chemically stable; they are safe for people and animals, blend with the surrounding landscape and are aesthetically and functionally acceptable.
- Open pits, surface WRDs and TSFs maintain geotechnical stability.
- Seepage to the receiving surface waters and groundwaters can be assimilated by the receiving environment and will not cause unacceptable harm.
- Open pits remain regional 'sinks' unless a flooded and flow-through pit is the objective. If the pit is backfilled, the need to remain a sink will depend on the geochemical characteristics of the backfill material.
- All drainage works remain functional and stable.
- Erosion loss rates do not cause unacceptable environmental harm or geotechnical instability or threaten the sustainability of vegetation communities.
- Downstream water quality will not be negatively affected by mine run-off and seepage.
- Stream flows are not permanently reduced in the post-mining landscape (such as by catchment diversions).
- Final void water quality matches the post-mining land-use requirements and community expectations.
- Dust generation does not cause unacceptable amenity or health impacts or unacceptable harm to the environment.
- Soil nutrient banks are established and soil chemical and physical parameters are suitable for the intended post-mining vegetation.
- Appropriate vegetation is established and sustainable and satisfies the agreed post-mining land use, which may be an agricultural system (cropping, grazing, or both) or a native ecosystem.
- Native animals are recolonising rehabilitated native ecosystems in adequate numbers and diversity.

It is important to demonstrate that completion criteria can (and will) be met over an extended period. The design of the monitoring and research programs discussed above must take into account the long-term sustainability of rehabilitation and how it is measured and demonstrated.

Socioeconomic completion criteria are usually whole-operation matters. Community baseline studies enable relevant information on the population and economy to be gathered and appropriate completion criteria to be developed. Criteria are influenced by the population and skills mix of the local community and by business activity either at the mine site (such as the adaptive reuse of buildings or interpretation of mining heritage through tours) or in neighbouring communities. An important part of mine closure is ongoing monitoring of the success of social and community development programs, for example through periodic household surveys seeking information on the health, education and economic status of the community.

It is important to monitor or audit the financial aspects relating to mine closure. The issue of funding for mine closure can pose challenges. While annual rehabilitation budgets are relatively easy to establish and monitor, the cost of closure to meet the completion criteria is more difficult to assess. However, those costs should still be modelled and should be reviewed at key milestones in an operation. Ideally, this should occur annually, but 3–5-year time frames may be adequate during expansion phases. Leading practice monitoring and auditing criteria ensure that internal funding is established to achieve both completion criteria and regulatory financial assurance requirements, verifying that sufficient funds are provided throughout the mine's life to allow for both planned closure costs and contingency costs for unexpected developments. Costing and provisioning for mine closure are discussed in more detail in the *Mine closure* handbook in this series (DIIS 2016e).

4.13 Safety of monitoring

Leading practice environmental monitoring includes leading practice management of the safety of the personnel involved. While mine operations are required by law to maintain high standards of safety, monitoring programs often involve activities that are otherwise atypical of mining project practices and might not be covered by the standard safety practices for the project. This can be especially true of short-term or one-off monitoring projects or tasks, such as spill responses or special investigations.

Environmental and social monitoring may require sample collection well outside the project boundaries, such as in reference or upstream areas. Standard mine site safety procedures or personal protective equipment (PPE) requirements may be inappropriate and even potentially hazardous in some circumstances. For example, water-quality monitoring may involve accessing sampling sites by boat, and wearing steel-capped boots, a standard mine site requirement, could substantially increase the risk of drowning in the event of a boating accident.

As many mine sites are in remote areas, monitoring at locations remote from the mine site can further increase the risks to personnel. Safe communication requirements and transport backup systems for monitoring staff can differ greatly from those required by other project staff. Monitoring staff may be exposed to hazards that are rare or simply do not occur in the main mining areas, such as aggressive animals or fast currents. For example, crocodile attack is a very real risk in environmental water sampling in many parts of northern Australia; crocodiles have even been recorded in open mine pits, water storages and tailings dams.

Weather conditions during some of the critical times for collecting monitoring data, such as when plants are shut down during storms or wet season floods or periods of extreme temperature, pose additional risks to monitoring staff. The data collected during these periods may be particularly valuable for environmental management, but must only be collected in a safe manner. Leading practice does not use 'safety' as an excuse for not collecting data at such times, but involves plans for collecting it safely.

These special safety requirements for monitoring need to be carefully considered for each monitoring program element, and ways to minimise and/or eliminate the risks need to be developed. Typically, this will require the development of standard operating procedures that are specifically developed for the monitoring tasks, the allocation and approval of specialised PPE for some tasks, and detailed task safety assessments for each new monitoring task. In all cases, it is important to address the real safety issues for the monitoring task and not rely on standard site practices that might not be appropriate.

4.14 Monitoring technologies

4.14.1 Real-time monitoring

Many mining operations use technology and communication platforms to operate their fleet of earthmoving equipment and their process plants. The use of telemetry networks for monitoring the environment is just an extension of this management technique. It saves the time and cost of manual data downloading and allows the monitoring staff to acquire information and act proactively, rather than reactively. The benefit is that the environment can be managed and operated in a similar manner to plant on the mine site. Telemetry networks can also provide cost savings by reducing the magnitude of the impact of incidents and the associated clean-up effort and by facilitating early intervention. They can also bring safety benefits and labour savings, as staff can limit visits to remote monitoring locations to maintenance inspections. The real value of data is realised when it is incorporated into the dataset and used to improve management.

When developing a telemetry system for a monitoring network, it is important to discuss requirements with a specialist. Apart from the immediate need to convey data from A to B, the design must consider the telemetry bandwidth, network support, communications protocol, power supply (preferably by solar panels, which are essential for remote locations) and consumption, data delivery, data storage, connectivity and data display.

Many system control and data acquisition (SCADA) packages for telemetry are programmed to store high-resolution data for only a short period—days or weeks—before the data is summarised. It is critical that the environmental data is stored at its original resolution before any summations are made. That being said, if the site SCADA package has the potential for environmental data transmission with the appropriate safeguards it can be of enormous benefit, as environmental staff will then have onsite support for back-end data receipt and management.

Leading practice requires the data to be delivered and accessible to the end user in a simple, usable format. This does not mean that the system has to have graphical displays; rather, it should deliver the data in a format that meets the program objectives. For example, some integrated GPRS (general packet radio service) data loggers can send an alarm out using voice messaging and SMS and an email of the dataset. This links field officers to their field instruments through smartphones. On the other hand, radio telemetry networks are normally site-based and have limited capabilities to transmit offsite.

To identify the appropriate technology, the project's objectives should be considered and, as a minimum, the following questions should be addressed:

- Is the data required in 'real time' for operational purposes or 'almost real time' for post-event management and alarm purposes?
- What is the quantity of data to be relayed over the network? Does the selected technology have adequate bandwidth to both manage the immediate data transmission needs and allow for future expansion?
- What infrastructure is in place that can be used for the telemetry network? Is the system to use site-based radio telemetry or publicly operated networks, such as mobile phone GPRS systems or satellite telemetry?
- Is there a transmission charge, such as when using commercial networks for GPRS and satellite transmission? What communication protocols do the field instruments use and can the telemetry unit accept their input?
- Has power consumption been considered?
- What is the geographical coverage required? Has consideration been given to vegetation (signal attenuation) and topography?

- Has climate been considered? Could heavy rainfall attenuate signals and cause signal loss? In hot climates, such as at arid or desert sites, can signals be distorted or blocked by heat mirages?
- If using the site SCADA and telemetry system, what is the back-end SCADA package? Can data at the correct resolution be saved and exported? What data connection is possible to allow the export of data from the SCADA package in a simple, accessible format?
- What requirements do the stakeholders have for accessing data?

The telemetry solution is not appropriate if the data is inaccessible or the data resolution is compromised by the telemetry platform. Field verification, calibration and maintenance are still required.

With rapid and constant change in technology, the demand to provide access to data now is growing. When designing a telemetry system, care must be taken not to leave out the data management requirements. The network will generate large amounts of data. At some time, false readings will need to be quarantined from alarms and dissemination to stakeholders. It is also important to ensure that the selected system has the ability to qualify the data either at the field monitoring station or by post-processing.

A leading practice telemetry system saves the environmental staff time, allows them to act on events in real time and is robust, reliable and cost-effective.

4.14.2 Routine and novel remote sensing

Aerial photography

Most open-cut mine sites have a standard set of remote sensing data that is collected on a regular basis to estimate resource and spoil stockpiles. Some of these data layers include annual site aerial photography (resolution ~50-cm pixels) and a photogrammetrically derived digital surface model. Both these datasets tend to be underutilised by staff responsible for site rehabilitation. Because rehabilitation objectives require a safe, stable and sustainable landform, this remotely sensed data could be used to check the overall progress of a site. A time series of aerial photos illustrating the progression of rehabilitation, when compared to rainfall, soil and other data, may be used to help determine why some areas of rehabilitation have had more successful vegetation establishment. Areas of bare ground can be derived from classification of the aerial photography using GIS. For example, using iso-cluster analysis in ArcGIS, aerial photos can be used to demonstrate areas of bare ground across a site's rehabilitation areas. Where the bare areas are persistent over time, this data can be used to guide soil surveys to determine whether there is an underlying substrate cause.

Slope angles of rehabilitation can be determined using the site digital surface model in GIS. If slopes are beyond suggested completion criteria or incompatible with the targeted post-mining land use, rework activities could be targeted, particularly where there is active erosion or unplanned ponding in geochemically active or risky material.

LiDAR

Airborne light detection and ranging (LiDAR) is commonly used to collect 3D point clouds of mine sites and is most cost-effective in more extensive areas, as long as good statistical analysis of the collected data can be done. LiDAR has the advantage that it collects multiple data points from rehabilitation vegetation and ground surfaces. If LiDAR datasets are available, the data from hard returns (for example, from the ground surface) could potentially be used over time to assess changes in the terrain beneath the vegetation and assess the development of gully erosion. Using change maps allows early intervention to

prevent expensive and time-consuming earthmoving at closure. This dataset could also be used to illustrate the stability of a site's rehabilitation before management applies for closure.

Unmanned aerial systems

The miniaturisation of sensors and the increased reliability of unmanned aerial vehicles (UAVs) controlled by GPS-guided autopilots allow the collection of hyper-temporal (several times a day) and very high resolution (~5-cm pixel) imagery across rehabilitation areas. This type of data can now be routinely collected by a number of organisations and, when processed, can generate highly accurate photogrammetrically derived digital surface models of individual rehabilitation areas. Additionally, the imagery allows high-precision vegetation maps to be generated, particularly if landscape features and plant species are targeted and marked by ecologists before images are collected. One example of this technology becoming a routine part of vegetation assessment is at Curragh coalmine, where UAVs collect imagery with a resolution of ~5 cm to monitor ground cover, rehabilitation success and erosional processes over time. UAV imagery has also been used in combination with targeted ground surveys to map the distribution of a rare shrub species on mine leases in the Blue Mountains (Fletcher & Erskine 2012).

Thermal cameras operating in UAVs can be used to identify rehabilitation areas with subsurface fires and spontaneous combustion issues. They ensure that rehabilitation can be assessed where noxious gases (such as carbon monoxide and nitrous oxide) limit access and are a risk to human health. Monitoring conducted with UAVs fitted with sensitive gas sensors could be used to map and model gas plumes.

Finally, UAVs with thermal cameras can track animals that are using rehabilitation areas and provide evidence that sites have created native fauna habitat.

Smart sensor technology

In the past decade, there has been steady growth in smart sensor technology, and particularly rapid changes over the past five years. These technologies range from simple water-level sensors that have inbuilt data loggers and GPS units with centimetre accuracy to scanning technology using UAVs and remotely controlled bathymetry vessels.

The benefits of these technologies are readily apparent, such as the additional information that they can provide. It is more challenging to effectively manage the vast datasets that are captured and the additional computer processing power required to manage and analyse the data and generate the final product.

Leading practice using remote sensing technology considers the selection of the most appropriate instrumentation as carefully as more traditional monitoring. To identify the appropriate technology, the project's objectives should be considered and, as a minimum, the following questions should be addressed:

- Are the data required in real time for operational purposes or 'almost' real time for post-event management and alarm purposes?
- What is the geographical coverage required? Has consideration been given to vegetation (signal attenuation) and topography?
- What is the quantity of data to be captured?
- What communication protocols do the field instruments use and what data formats will the field data be provided in?
- What software tools and analysis skills are needed for data processing? What output requirements do stakeholders have?
- How often should the study be replicated?

- Is the data required in real time for operational purposes or ‘almost’ real time for post-event management and alarm purposes?

Remote sensing can provide excellent datasets that can be used to identify even minor environmental issues. Leading practice takes into account the resolution of the study for both data capture and interpretation.

4.14.3 Limits of detection for monitoring parameters

When choosing the detection limits for monitoring parameters, it is important to consider the reasons for collecting the measurements and the timespan over which the measurements may be used. Analytical methods tend to improve over time, and the levels of detection achieved tend to improve as detection limits decrease. Corresponding with this, target standards and guidelines also tend to reduce as community perceptions of acceptability tighten over time. It is true that the current standard commercial laboratory analytical methods are not able to detect all the toxicants in the Australian and New Zealand guidelines for fresh and marine water quality (ANZECC–ARMCANZ 2000a) at levels below the trigger values (silver is an example relevant to mining), but commercial analysis methods are approaching this as routine for most parameters relevant to mining.

For these reasons, it is important in the earlier stages of a project to aim for the lower range of detection limits that are currently achievable and at all stages to regularly reassess the levels of resolution that are requested of the analysis laboratory or specified for field or site monitoring equipment purchases, in order to maximise the relevance of the monitoring data over time. As mentioned in Section 4.10, monitoring data is often the most valuable asset of a mine’s environment section, and built-in obsolescence should be avoided as much as possible.

This may mean that consideration should be given to using ‘cutting edge’ or more costly analytical methods rather than standard, mid-priced commercial analysis, at least for key parameters and sites. The acquisition of pre-mining baseline data can never be done again once a mining project starts, so it is worthwhile to consider paying for low levels of detection at the initial stage, even if later routine compliance monitoring does not have such stringent requirements.

For some parameters, extremely low levels of detection are possible but might not be achievable by non-specialist personnel or laboratories. The sample preparation, collection, handling, shipment and analysis quality control requirements for measurement of, for example, dissolved metal concentrations in the nanogram per litre range (important for some elements in some circumstances) are much greater than for levels of detection in the low microgram per litre range (more typical for aquatic ecosystem protection for most metals), which in turn are much greater than for measurement in the upper microgram per litre and milligram per litre ranges (more typical for human drinking water considerations). The fact that a laboratory instrument has specifications indicating that it can achieve a particular level of detection does not mean that reliable measurements at very low concentrations can be achieved in practice without specialists being involved at each stage, from container preparation, sampling and delivery to the laboratory through to laboratory analysis and reporting.

This has become increasingly evident as a result of the improved availability of low-level analysis. While analysis to the required levels of resolution is readily available from the better environmental analysis laboratories, the skill levels of samplers and sample collection quality assurance and control systems to reliably manage contamination below these levels are not as readily available. Even the selection of the sampling equipment for these low levels of resolution requires careful consideration, and not all manufacturers are able to provide equipment of an adequate standard. For example, there are no

commercially available water sampling poles that do not have metal fittings in the bottle-holding mechanism. Leading practice monitoring is able to achieve these levels of resolution and quality control and either has systems and training in place to ensure that they are achieved reliably or uses specialised consultants to achieve quality control of low-level sampling.

The key issue is that leading practice considers which analytical methods are appropriate for the project's data needs, both now and into the future, and selects methods that are appropriate to those needs.

Leading practice never selects methods on the basis of current laboratory pricing structures and the skill sets of low-cost sampling personnel.

Case Study: Pushing technology to meet expected future requirement—Tampakan Project baseline water quality monitoring

The proposed Tampakan copper–gold project is located around 65 km north-north-west of General Santos City, a major growth centre on the southern Philippines island of Mindanao. The project area straddles a steep north-north-east trending incised plateau that ranges in elevation from 1,000 metres in the south to 1,350 metres in the north.

The Tampakan Project will be a large-scale copper–gold mine with a measured, indicated and inferred resource estimated in November 2013 to total 2.9 billion tonnes of ore at a grade of 0.5% copper and 0.2 grams per tonne gold and containing 15 million tonnes of copper and 17.6 million ounces of gold using a 0.2% copper cut-off grade.

The area is politically complex, and the deposit sits in the headwaters of seven different catchments, most of which are heavily used by downstream stakeholders for irrigating crops, stock watering and drinking and sanitary water supplies, and as a source of aquatic foods and other resources, all of which contribute to a need for rigorous, defensible baseline environmental data. In April 2007, Xstrata Copper (now GlencoreXstrata, XCu) acquired a controlling interest in the project; day-to-day management of the operation was through Philippines-based mining company Sagittarius Mines (SMI).

Until April 2007, surface water monitoring at Tampakan was conducted at 71 separate locations in more than 10 catchments. It was done periodically from January 1995, largely by Philippines-based consultants, and was consistent with the national requirements for environmental monitoring and assessment. XCu and SMI determined that there was a requirement for further feasibility studies and that a more detailed environmental impact statement would be needed to meet XCu's international obligations. The project committed to an extended pre-feasibility stage to gather the necessary additional knowledge. A substantial extension of the baseline water quality monitoring program was part of that commitment.

The baseline water quality sampling and analysis program aimed to achieve leading practice by using rigorous quality control, clean trace-metal sampling techniques and then state-of-the-art analysis to low parts-per-billion levels. Laboratory analysis was initially sought from commercial environmental analysis laboratories in Hong Kong and Australia, both of which had a long-term history of high-quality environmental chemistry analysis for international mining projects. The water quality sampling was conducted under the stewardship of an Australia-based environmental consultancy. As a due-diligence exercise, initial rounds of the renewed sampling and analysis program included multi-element 'scans' of 70 elements to identify any unusual elements of concern. In addition, ultra-trace metals analysis was conducted in the initial two sampling rounds, as both a baseline data collection and a sampling program design assessment measure. As part of ongoing support and capacity building for local Philippines laboratories, analysis for selected parameters was undertaken at national environmental analysis laboratories on sample splits sent to the international laboratories for interlaboratory comparisons. It was intended to use Philippines laboratories in preference to international laboratories if suitable quality control and assurance could be established through cooperative capacity building.

SMI Environment Department staff were trained by international consultants in conducting water monitoring to high levels of quality control and assurance. This included requiring all laboratory parameters to be within 15% relative difference for triplicate samples taken during each monthly sampling round and field blanks to be below reporting limits.

The result has been two years of monthly and quarterly (depending on sampling site location) baseline water-quality monitoring data of high quality. The data is expected to provide a sound dataset that will be useful for the multi-decadal life span of the project. This has included achieving reliable trace metal analysis results to sub- $\mu\text{g}/\text{L}$ levels of resolution. Such a high-quality and extensive baseline dataset was well beyond the minimum requirements for the pre-feasibility stage of a mining project in the Philippines, and in terms of data quality, levels of resolution and quantity, beyond the typical international requirements. However, SMI and XCu considered it to be of substantial benefit to the project because it would serve as a defensible baseline for many years, provided high-quality inputs into environmental management planning for the project and provided skills training to international leading-practice standards for in-country staff and service providers.

Since 2009, the project has remained undeveloped, but laboratory analytical capacity has improved such that ultra-trace metal analysis is now routinely offered by the better equipped environmental analysis laboratories. However, the limits of detection offered have not reduced markedly and the limits of resolution of the Tampakan baseline sampling remain relevant and leading practice.

Greater experience in the use of ultra-trace limits of resolution of analysis by a broader number of monitoring teams has found that quality control of the sample collection and handling is now commonly the limiting factor in determining practical limits of resolution for metal concentration because of sample contamination at those low concentrations, not because of laboratory instrument detection limits. Therefore, the effort put into training staff in quality control of sample collection by Tampakan, and the incorporation of good-quality assurance protocols including the routine use of trip and field blank samples, were particularly important and provided the project with a robust baseline.



Bottles used for sampling.



Right: Filtering for dissolved metals and measuring flow.



Collecting water samples.



Flow in the Dalul being diverted into the irrigation channel.



Irrigation channel.



Local woman washing vegetables.

4.14.3 Leading practice fauna monitoring methods

General considerations for fauna monitoring are outlined in the *Biodiversity management* handbook (DIIS 2016f). Monitoring methods have continued to evolve, and a number of recent technological improvements are now routinely used in fauna monitoring at mining operations. They include automatic audio recorders for bats, frogs and birds. A number of different types of auto recorders are now commercially available and are relatively inexpensive. They allow for sample monitoring day and night and for extended periods. Audio recorders used in conjunction with voice recognition software have considerably improved cost-effectiveness in data collation and analysis. For example, vocal recognition using computer identification of species has been used successfully for the detection of threatened species. The cost-effectiveness of audio recording enables the processing of considerably more data and improved monitoring quality. Other benefits associated with audio recording include:

- removal of observer bias
- rapid collation of biodiversity present
- weatherproof construction and long battery life, allowing for extended periods of monitoring
- consistency when repeating surveys
- increased information gathering (for example, threatened and cryptic species detection)
- cost-effective increase of sampling frequency (to enable seasonal sampling)
- electronic generation of data, allowing for reanalysis at a later stage, verification of data quality and ease of storage
- concurrent monitoring (that is, surveying a number of locations in the same point in time)
- simplicity of use.

Infrared and motion-detection cameras are now commercially available and frequently used to survey fauna at mining operations. Such cameras enable day and night monitoring of discrete locations, such as water bodies, heap leach pad ponding and tailings systems. Where wildlife mortalities occasionally occur, they are very useful in carcass detection and, more importantly, in detecting carcass removal by scavenger species.

Although automated fauna monitoring technologies are readily available and now widely used, an understanding of the monitoring requirements, target species and how the technologies work is critically important for data integrity and subsequent analysis. For example, territorial species can be detected more frequently within their range using camera traps, and vocal birds are more readily detected with audio devices.

Abundance comparisons between species or even between age classes of a species are often not valid; such camera and audio devices typically measure species activity, not abundance. However, they are good at detecting rare, nocturnal and cryptic species.

Due to expense, fauna surveys are often conducted annually, usually at the same time of year to remove seasonal bias. Data analysis is used to determine any changes from the previous year. That might not be satisfactory, since impacts to wildlife may occur and remain undetected until the next annual survey. The cost-effectiveness of audio and camera surveying can enable quarterly or continuous monitoring at a similar cost to typical monitoring techniques. Importantly, the increase in frequency of sampling improves the timing and extent to which changes are detected.

Case study: Fauna monitoring to assess offsets and mine rehabilitation

Glencore's Mt Owen Mine is in the Upper Hunter Valley of New South Wales. The original 1994 mine development consent permitted the disturbance of 240 hectares of Ravensworth State Forest, while in 2004 a development authority allowed for the clearing of a further 94 hectares of the forest, subject to the implementation of a biodiversity offsets strategy including comprehensive flora and fauna management measures.

Ravensworth State Forest is a highly significant remnant on the local and regional scale, and is one of the largest remaining areas of woodland on the Hunter Valley floor. Impacts on flora and fauna are managed under the 1994 Mt Owen Mine Plan of Management for Revegetation and Wildlife and subsequent revisions. Together with the biodiversity offset strategy, the plan requires conservation values in areas of remnant woodland to be managed and protected, restoration and reforestation to be carried out on degraded and cleared areas, and targeted mined areas to be rehabilitated to woodland communities. The fauna monitoring and management programs are reviewed annually by the Mt Owen Flora and Fauna Interagency Advisory Group, which comprises representatives from the Department of Resources and Energy, the Hunter Environment Lobby, the University of Newcastle and the Mt Owen Complex (MOC).

Management actions to restore and enhance habitat for protected and threatened fauna include the permanent exclusion of grazing stock, modifications of water bodies to enhance habitat value, the installation of 300 nest boxes for hollow-dependent species in remnant, restored and rehabilitated woodland, the establishment of native woodland in offset and rehabilitated mine areas, the collecting and spreading of forest debris such as logs in rehabilitation, weed management, and feral animal control.

Flora and fauna monitoring are critical components of this management. An annual fauna monitoring program includes monitoring of both the effects of mining activities on fauna in remnant areas and the recovery and recolonisation of fauna in restored, reforested and rehabilitated areas. This provides information essential for understanding the habitat requirements of fauna and enables the development of the most cost-effective techniques for promoting fauna recovery and recolonisation. Monitoring data is compared across three forest sites, four regenerating (restored or reforested) sites, and two sites in mine rehabilitation areas. The fauna monitoring program is described in detail in FFSNI (2013).

Leading practice terrestrial vertebrate fauna survey techniques have evolved considerably in the past 10–15 years. Those used at MOC include conventional procedures and recently developed survey methods, including:

- conventional bird surveys (such as visual and bird calls) and mammal trapping
- pit trapping for reptiles, frogs and small mammals
- using infrared (heat) and motion-detection cameras to detect several feral fauna species (such as wild dogs and spotted-tail quolls)
- using other cameras for waterbird population counts on wetlands, for population estimates of larger mammals, and to document stock intrusions

- nest boxes that are checked using a camera mounted on a pole, which overcomes working-at-height restrictions and is a cost-effective alternative to trapping and spotlight surveys
- using harp traps and Anabat detectors to survey bats
- radio tracking of the spotted-tailed quolls using GPS collars and remote data retrieval via telemetry.

The project has helped to identify specific quoll habitat requirements, and also opportunities to improve habitat for the species, in the rehabilitation and revegetation areas of Mt Owen.

Several other recently developed vertebrate fauna survey techniques are used effectively in leading practice fauna surveys at other mines in Australia, but were not considered appropriate for the specific habitats and circumstances at MOC. They include song meters, which enable the passive monitoring of several faunal groups, including microbats, birds and frogs. They are also suited to long-term monitoring of several rare and cryptic species that would otherwise require intensive field hours by staff at considerable expense. They enable sampling during specific times of the day or during events such as summer storms when activity peaks for some species.

Fauna monitoring results at MOC have shown that colonisation of rehabilitated areas by vertebrate species, including a range of woodland birds and bats, is progressing well (for details, see FFSNI 2013). The rate of colonisation for some species has been enhanced by the installation of critical resources, such as rock and timber piles, frog ponds and nest boxes. However, as has been found elsewhere, there is variability between species as they recolonise rehabilitated and reforested areas at different rates according to their habitat requirements.

The MOC fauna monitoring program is a useful illustration of how leading practice flora and fauna monitoring and management programs can be used to help mines achieve biodiversity conservation, offset and rehabilitation objectives. More details of these programs are in Glencore (n.d.), which includes several relevant publications.



Spotted-tailed quoll radio-tracking study.



Australian owl-nightjar.



Bats in boxes.

4.14.4 Other technology considerations

Many leading practice monitoring methods have been or are being developed to meet particular needs. They include methods such as:

- improved sensor technologies, including biosensors
- specialist remote sensing methods:
 - on land, such as high-resolution satellite imagery of varying wavelengths and combinations of wavelengths
 - on water, such as hydro-acoustic sampling of aquatic organism position, density and size frequency; acoustic Doppler current profiling of water and suspended sediment movements; acoustic, including sonar, habitat mapping systems; automated video habitat and organism recording systems (for example, BRUVS or baited remote underwater video systems for fish); and water-quality drones
 - in the air, using remotely operated low-flying UAVs carrying cameras and multispectral detectors (Section 4.13.2)
- improved non-destructive animal sampling, such as frog recorders, bat detectors and DNA analysis of hair
- tube samples
- radio and satellite fauna tracking devices to assess habitat recolonisation
- instruments for measuring water uptake in vegetation.

Importantly, leading practice monitoring does not select standard default technologies or cutting-edge technologies because they are cheaper or provide cachet. Leading practice uses technologies that are appropriate to the monitoring program and address both its immediate and future data needs. In many cases, the pursuit of leading practice may accelerate the development of these technologies as a result of their adoption by the industry.

4.15 Long-term relevance

As pointed out in Section 3, planning for monitoring should always be carried out as a life-of-mine exercise, maximising the relevance of data collected in each phase for use in later phases.

Section 4.14.3 notes that this may require, for example, that chemical limits of detection used for baseline data collection be well below standard commercial practice at the time, to maintain relevance at later stages of projects with a long lifespan. It is essential that there is accurate and transparent reporting of data quality and continued access to datasets through the life of the project. As noted in Section 4.10, the future users of data are unlikely to be the original collectors, due to staff turnover, and the future users must be able to access the results, understand their provenance and be assured of their reliability. Leading practice addresses these life-of-project issues and ensures that data management systems and decisions on data collections maximise the continuing relevance of the data.

4.16 Public reporting and assurance

4.16.1 Recent developments in public reporting

The reporting of sustainability or environmental, social and governance (ESG) performance should be seen not as an isolated activity but as part of a larger process of sustainable company practice, stakeholder engagement and corporate accountability. When done strategically, reporting can help to manage sustainability resources within the organisation, identify gaps in sustainability information or data collection and generate momentum for environmentally and socially responsible practices in company operations and processes.

There have been some significant new developments in public reporting in recent times, including the arrival of two new frameworks that offer companies different ways to present performance data to their stakeholders:

- integrated reporting—an initiative of the International Integrated Reporting Council (IIRC)⁶
- G4 sustainability reporting—promoted by the Global Reporting Initiative (GRI).⁷

The two frameworks should be considered not as alternatives, but rather as complementary in reaching different audiences with different interests.

4.16.2 Integrated reporting

Integrated reporting provides a powerful framework for connecting social performance to broader business strategy and provides a means of demonstrating the business value of social investments over time. Identifying material issues affecting value creation in the short, medium and long terms promotes a more sustainable long-term outlook than other corporate reporting frameworks.

Integrated reporting is starting to gain the attention of Australian companies, and some have made their first attempt to produce such a report. Some stock exchanges, such as South Africa's JSE, are now mandating that listed companies produce one. However, there is a widespread misunderstanding in the marketplace about what constitutes an 'integrated' report.

Recent research by the GRI noted that 'the number of self-declared integrated reports in the GRI database that are explicitly titled "Integrated report" has grown in recent years ... but the majority—from 50–60%—are called "Annual report", followed by "Sustainability report" or "Sustainable development report".' (GRI 9999).

A closer look at the figures from GRI's research suggests that at least 70% of those reports claiming to be 'integrated' are not and, if we use a literal definition of 'integrated report', the actual figure is possibly closer to 90%.

This misunderstanding has created confusion in the marketplace about reporting options and directions, promoting a view that integrated reporting is the inevitable successor to sustainability and financial reporting. Some organisations believe that producing an integrated report will relieve them of the need for sustainability reporting in future.

⁶ IIRC, <http://integratedreporting.org/the-iirc-2/>.

⁷ GRI, <https://www.globalreporting.org/standards/g4/Pages/default.aspx>.

Now that both GRI's G4 and the integrated reporting framework are available to reporters, it is clear that sustainability reporting remains primarily focused on providing information for stakeholders wanting to understand an organisation's *key social, economic and environmental impacts* and how it is managing them, while integrated reporting is targeted at providers of financial capital seeking information that demonstrates how an organisation creates value across a range of interconnected capitals in a coherent and strategic way.

4.16.3 New sustainability reporting guidelines

Coinciding with the delivery of the integrated reporting framework has been the release of the next generation of sustainability reporting guidelines, called G4, developed by the GRI. Through G4, the GRI has sought to step up the level and quality of sustainability reporting. It is not simply an update of the previous set of guidelines, but has a clear intent to pull reporters up to the next level of accountability by enhancing key aspects such as disclosures of materiality, boundary setting, governance, supply chains, ethics and management.

Governance and supply-chain reporting are also strengthened in G4. Reporters now need to more fully describe their organisation's supply chain, including detail on the location of suppliers, changes in their relationships with suppliers, their selection and termination of suppliers, and the monetary value and volume of goods and services purchased directly from suppliers. Governance is covered in Section 4.18 of this handbook.

4.16.4 Energy and emissions reporting

Mandatory reporting

In Australia, the monitoring and reporting of greenhouse gas emissions, energy production and energy consumption by corporations is mandated under the *National Greenhouse and Energy Reporting Act 2007* (NGER Act).

The Act requires corporations that emit greenhouse gases or produce or consume energy above specified thresholds to register and report their emissions, energy production and energy consumption to the Australian Government.

Emissions data collected under the NGER Act is integral to the compilation of the National Greenhouse Accounts, and is used to fulfil international reporting requirements under the United Nations Framework Convention on Climate Change; to track Australia's progress towards targets set under the Kyoto Protocol; and to inform policymakers and the public.

Key documentation on reporting under the NGER Act includes the:

- National Greenhouse and Energy Reporting Regulations 2008
- National Greenhouse and Energy (Measurement) Determination 2008
- National Greenhouse and Energy Reporting Technical Guidelines.

The technical guidelines help corporations understand and apply the NGER Determination by outlining calculation methods and criteria for determining greenhouse gas emissions and energy data. They also contain a step-by-step guide for corporations on how they may register and report under the NGER Act.

The National Greenhouse and Energy Reporting System (NGERS) represents leading practice in the monitoring and reporting of greenhouse gas emissions and energy in Australia. As well as being underpinned by legislation, the NGERS is based on international reporting standards and methods, such as the World Business Council for Sustainable Development's Greenhouse Gas Protocol (see box), and methods prescribed by the Intergovernmental Panel on Climate Change. To ensure the accuracy of data reported under the NGERS, the NGER Act also contains a series of auditing, compliance and enforcement provisions.

Further information about the reporting obligations of corporations under the NGER Act is available from the Clean Energy Regulator.⁸

Greenhouse Gas Protocol

The Greenhouse Gas Protocol, created by the World Business Council for Sustainable Development and the World Resources Institute, is the most widely used international accounting tool for government and business leaders to understand, quantify and manage greenhouse gas emissions. It provides the accounting framework for nearly every greenhouse gas standard and program in the world.

The Greenhouse Gas Protocol Corporate Standard provides standards and guidance for companies and other organisations preparing a greenhouse gas emissions inventory. It covers the accounting and reporting of the six greenhouse gases covered by the Kyoto Protocol—carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆)—and was amended in May 2013 to include nitrogen trifluoride (NF₃).

The objectives of the corporate standard are:

- to help companies prepare a greenhouse gas inventory that represents a true and fair account of their emissions, through the use of standardised approaches and principles
- to simplify and reduce the costs of compiling a greenhouse gas inventory
- to provide business with information that can be used to build an effective strategy to manage and reduce greenhouse gas emissions
- to increase consistency and transparency in greenhouse gas accounting and reporting among various companies and greenhouse gas programs.

If leading practice organisations are not required to report under the NGER Act in Australia (or under similar mandatory reporting frameworks in another countries), they nonetheless prepare a greenhouse gas inventory; the Greenhouse Gas Protocol Corporate Standard makes it easier to do so.

In 2014, the Australian Stock Exchange (ASX) Corporate Governance Principles were updated to include mandatory disclosure of material environmental risks, including climate change risks, and any associated information about energy and emissions management and performance.

⁸ Clean Energy Regulator, <http://www.cleanenergyregulator.gov.au/NGER/Pages/default.aspx>.

The current version of the ASX Corporate Governance Council's Corporate Governance Principles and Recommendations (3rd edition) was released on 27 March 2014 and took effect for listed entities' first full financial year commencing on or after 1 July 2014. The new principles and recommendations require companies to disclose material environmental and social sustainability risks and how they are being managed. Clear understanding of climate change risks (physical and regulatory) and an effective strategy for managing energy and emissions is central to this disclosure.

The *ESG reporting guide for Australian companies* (ACSI-FSC 2011) was developed to complement the reporting requirements spelt out in the ASX Corporate Governance Principles and Recommendations and other best practice guides. In addition to other environmental, social and governance considerations, the guide outlines why energy and emissions reporting is important to investors and what information they want to see disclosed in public reports.

Acknowledging that climate change regulation imposes costs on companies that produce and consume carbon-intensive goods and services, investors consider that companies that fail to understand their carbon emissions, reduce their emissions, cost-effectively manage their carbon liability, and understand their physical exposure to climate change, risk:

- higher costs as the cost of complying with carbon regulation increases
- loss of market share as customers move to low-emissions suppliers
- damage to assets as the physical impacts of climate change increase.

Commonly reported indicators that investors look for include:

- direct (scope 1) emissions, by facility or process, including those occurring in equity stakes
- indirect (scope 2) emissions associated with purchased electricity
- supply-chain carbon emissions (scope 3)
- opportunities to pass carbon costs on to customers
- opportunities to reduce carbon emissions and energy use
- targets for reducing carbon emissions and improving energy efficiency
- effective carbon liability management, including ways to reduce emissions or meet carbon liabilities at low cost
- an assessment of the physical risks from climate change
- business opportunities that climate change regulation presents.

International operations

Certain international projects (such as those financed either by the IFC or by financial institutions that are signatories to the Equator Principles) may be required to meet the IFC's Performance Standards on Environmental and Social Sustainability (IFC 2006). IFC Performance Standard 3 (IFC PS 3) on resource efficiency and pollution prevention has three key objectives:

- to avoid or minimise adverse impacts on human health and the environment by avoiding or minimising pollution from project activities
- to promote more sustainable use of resources, including energy and water
- to reduce project-related greenhouse gas emissions.

The IFC PS 3 sets particular requirements for energy and emissions performance for the corporation at project level:

In addition to the resource efficiency measures described above, the client will consider alternatives and implement technically and financially feasible and cost-effective options to reduce project-related GHG emissions during the design and operation of the project. These options may include, but are not limited to, alternative project locations, adoption of renewable or low carbon energy sources, sustainable agricultural, forestry and livestock management practices, the reduction of fugitive emissions and the reduction of gas flaring.

A recent revision of IFC PS 2 introduced additional requirements for greenhouse gas accounting:

For projects that are expected to or currently produce more than 25,000 tonnes of CO₂ annually, the client will quantify direct emissions from the facilities owned or controlled within the physical project boundary as well as indirect emissions associated with the off-site production of energy used by the project. Quantification of GHG emissions will be conducted by the client annually in accordance with internationally recognised methodologies and good practice.

4.17 Voluntary reporting

4.17.1 Carbon Disclosure Project

The largest globally acknowledged voluntary emissions reporting initiative is the Carbon Disclosure Project (CDP). The CDP is backed by major investors and requests companies to annually disclose information on their management of climate change risks and opportunities as well as greenhouse gas emissions performance.

The CDP generates company scores for both disclosure and performance, awarding points for strategic and operational information, including a clear link between business strategy and emissions reductions, a demonstrated understanding of the risks and opportunities associated with climate change, absolute emissions reduction targets and initiatives, measurement and management of scope 1, 2 and 3 emissions, and progressive emissions reductions year on year.

The CDP encourages participating companies to assess their responses in accordance with the principles of the Greenhouse Gas Protocol and is recognised leading practice globally for disclosure on emissions reporting and management.

For more information, refer to www.cdp.net.

4.17.2 Carbon offsets

While the best and most cost-effective method of reducing the total emissions profile of a company is to introduce abatement measures, there are also several offset options available for companies that wish to voluntarily reduce their carbon footprint or that need to meet certain regulatory requirements.

Carbon offsets are units that represent greenhouse gas emission reductions. They can be purchased and used to cancel out or offset the emissions generated by the company's operations.

The National Carbon Offset Standard, established by the Australian Government to encourage action to reduce carbon pollution beyond Australia's national targets, provides guidance on what is a genuine voluntary carbon emissions offset and sets minimum requirements for calculating, auditing and offsetting

the carbon footprint of a company's operations.

Eligible offset units include:

- Australian carbon credit units issued under the Carbon Farming Initiative
- credits issued under the Australian Government's former Greenhouse Friendly Program
- international units issued under the Kyoto Protocol (Joint Implementation / Clean Development Mechanisms)
- credits issued under the Gold Standard and Verified Carbon Standard (VCS)

More information on the National Carbon Offset Standard is available on the Department of the Environment's website: <http://www.environment.gov.au/climate-change/publications/national-carbon-offset-standard-version3>.

4.17.3 Value-chain emissions monitoring and reporting

There is increasing pressure on corporations to demonstrate the action that they are taking to influence their suppliers, their customers and other relevant stakeholders to reduce greenhouse gas emissions across their entire value chain.

The Greenhouse Gas Protocol's Corporate Value Chain (Scope 3) Standard allows companies to assess their entire value chain emissions impact and identify the most effective ways to reduce emissions.

Users of the new standard can account for emissions occurring both upstream and downstream of their operations and identify strategies to partner with suppliers and customers to address climate impacts throughout the value chain.

The standard is accompanied by user-friendly calculation guidance and tools developed by the Greenhouse Gas Protocol, including supplier engagement guidance and guidance for calculating scope 3 emissions.

4.18 Governance

In relation to public reporting, governance is intimately tied to the concepts of transparency and accountability. Good governance practice in businesses means a willingness to be open and communicative to stakeholders about good and poor performance, management practices, policies, decisions and other matters.

Governance disclosures in reporting typically address aspects such as executive remuneration, accountabilities, performance, and the qualifications and competencies of the organisation's board in relation to sustainability risks and opportunities. For many reporters, disclosing such information poses a challenge, in relation to both confidentiality and their ability to gather and collate the relevant data.

Enhancing governance disclosures in reporting benefits organisations and their stakeholders in the longer term by:

- helping to place sustainability considerations, and how they relate to governance, on the board's agenda
- providing sustainability managers with more internal traction
- making critical information accessible to relevant stakeholders, such as investors.

Between them, both the GRI G4 guidelines and the integrated reporting framework significantly strengthen the links between governance, performance and accountability.

The governance-related issues of corporate corruption and bribery have also been prominent in recent times and remain one of the key barriers to sustainable development. G4, in particular, makes it more difficult for reporters to completely avoid disclosing information on corruption and how it is managed within the organisation. G4's approach demonstrates a recognition that managing the issue of corruption is a cross-functional exercise that strongly relates to the values and culture of the organisation and, importantly, its people.

4.18.1 Transparency

Transparency remains one of the biggest hurdles to effective corporate accountability and public reporting. Transparency is a cultural factor that often takes time, effort and determination to realise in companies.

There is much more work to be done to improve transparency and the degree of disclosure of corporate performance at the management, executive and board levels. However, in the current era of unprecedented and largely uncontrolled social networking, whistleblower protection and proliferating camera-equipped mobile devices, there is simply no prospect of keeping unfavourable news out of the public eye.

Organisations can no longer appear to be unresponsive, unaccountable and uncaring about issues or outcomes that stakeholders decide are important or perceive as important.

In this respect, both integrated reporting and the GRI G4 place pressure on reporters in relation to transparency and, with that, accountability. Two aspects of transparency are emphasised in public reporting—completeness and balance:

- completeness, in that all material aspects of performance are covered in a report according to the boundaries set for that report
- balance, in that both good and bad performance are disclosed.

Integrated reporting emphasises the importance of balance and completeness of information as one of its fundamental principles of reporting. Similarly, in G4, completeness remains one of the guiding principles for determining report content, while balance is one of the guiding principles for determining report quality.

Transparency, if recognised and seriously tackled in reporting, enhances the company's trust and engagement with stakeholders on a deeper level than before. By embracing transparency, the company is likely to earn greater respect and credibility from its constituencies.

4.18.2 Extractive Industries Transparency Initiative

The Extractive Industries Transparency Initiative (EITI) is an international organisation that has developed a standard that assesses the levels of transparency in countries' oil, gas and mineral resources sectors.⁹

Some countries that are rich in natural resources have underperformed economically against expectations (given the richness of their resources), have a higher incidence of conflict and suffer from poor governance. Those effects are not inevitable and it is hoped that, by encouraging greater transparency in countries rich in resources, some of the potential negative impacts can be mitigated.

⁹ See EITI, <https://eiti.org/>.

Implementing countries improve their investment climate by providing a clear signal to investors and international financial institutions that the government is committed to greater transparency. EITI also assists in strengthening accountability and good governance, as well as promoting greater economic and political stability. This can contribute to the prevention of conflict based on oil, mining and gas resources.

Companies benefit from a level playing field in which all companies are required to disclose the same information. They also benefit from an improved and more stable investment climate in which they can more effectively engage with citizens and civil society.

Twenty-seven countries have become EITI-compliant, and Australia has recently completed its domestic pilot of the EITI, guided by a multi-stakeholder group.

Case study: Democratic Republic of the Congo: shedding light on tax collecting agencies' practices—greater scrutiny uncovers US\$26 million that was unaccounted for

In the Democratic Republic of the Congo (DRC), EITI reports have generated a debate about the accountability of tax collecting agencies.

One of the agencies, DGRAD, was found in the EITI report to be unable to account for US\$26 million of royalty payments. The case is under close public scrutiny, and observers expect it to lead to judicial action.

The DRC has found that a key benefit of the EITI is that it can now ensure that the taxes collected by government entities reach the accounts at the Central Bank. Other oversight institutions are also strengthened, such as the Auditor-General's Office, which is now investigating discrepancies identified in EITI reports and referring cases to the court as necessary.

4.19 Assurance

Assurance is a tripartite arrangement between the reporter, the assurer and the user of the report. The assurer's primary role is to help bridge the divide between the reporter and the report user by lending credibility to the report content and, by extension, creating trust in the reporter.

Since 2003, non-financial assurance has been largely performed against AccountAbility's *AA1000 Assurance Standard*¹⁰, the International Federation of Accountants'¹¹ *ISAE3000 International Standard on Assurance Engagements other than Audits or Reviews of Historical Financial Information* or, in some cases, both. ISAE3000, derived from the accounting discipline, has been the usual choice of the 'Big 4' accountancy firms in providing non-financial assurance (in 2012, those firms provided two-thirds of the non-financial assurance delivered to the market). AA1000, a less pedantic, more principles-based framework, is often the preferred choice of smaller specialist assurance providers.

¹⁰ See AccountAbility, <http://www.accountability.org>.

¹¹ See IFAC, <http://www.ifac.org/>.

Assurance has the potential to significantly enhance business practices, not just in organisational accountability, but more broadly in improving performance, reputation and processes. The information gleaned from assurance can be used to build the reader's confidence in the report, build stakeholder confidence in the organisation, identify improvement opportunities in reporting processes (resulting in better and more efficient future reporting), and encourage change within the business's systems and management.

While assurance statements are often seen as the key deliverable from the engagement, assurance has the potential to deliver much more than just an assurance statement. The assurance provider should be able to deliver meaningful recommendations to the company's leadership that identify opportunities to enhance the organisation's accountability, management or performance.

In addition to building external trust and transparency, assurance thus helps to underpin internal confidence and capability through its ability to identify barriers and shortcomings in processes, systems and outputs, which then becomes the basis for improvement.

4.20 Review of monitoring programs

As noted above, monitoring is the means by which mining companies and stakeholders can assess the effectiveness of management measures, verify or adjust predictions made early in a project, and develop improved management practices. With this in mind, leading practice monitoring should be regularly reviewed in the light of changes to ensure that objectives are being met. The changes may be internal (adjustments within the organisation or operation) or external (broader regional or community adjustments).

Examples of changes that should trigger a review of monitoring programs in the mining industry are:

- changes to the mine plan (for example, expansion or contraction of the operation)
- changes in the type of mining (such as from open-cut to underground) or in the ore mined and processed on the site (such as from oxide to sulphide)
- extreme events that cause the company to adjust the assumptions on which planning has been based and risk assessed
- a significant incident at another mine site of a similar type or in the same region (for example, deaths of flora or fauna or community health impacts)
- changes within the local community as the mine matures through its life cycle (for example, demographic stabilisation following periods of substantial population expansion).

Importantly, the findings of monitoring programs should be used to inform and, if necessary, modify management decisions and practices.

Case study: Upgrading monitoring systems to inform water management

The Ranger uranium mine, operated by Energy Resources of Australia (ERA) Ltd, is situated next to Magela Creek, east of Darwin in the Northern Territory. It is separate from but surrounded by the World Heritage listed Kakadu National Park.

The climate of the area is tropical monsoonal, with an average rainfall of about 1,600 mm per year, falling mainly in the wet season between October and April. The concentration of heavy rains over a relatively short period presents a significant challenge to the mining operation: it must manage its water inventory to ensure that releases of water from the site do not compromise natural and cultural values and that the downstream environments of Kakadu National Park remain protected.

In the past, the release of site catchment run-off water (not process water or seepage water from mineralised material) was permitted, depending on results from routine weekly grab samples, biological testing in specific cases, and a conservative predictive model designed to assess the suitability of release conditions in line with meeting formal water-quality objectives. While successfully protecting the environment, this approach to water management resulted in substantial volumes of water being unnecessarily stored on site and subsequently requiring further treatment. The efficiencies that could be realised by using a real-time monitoring system to identify optimal opportunities for water releases and to monitor responses in receiving water quality were clear.

Continuous monitoring of surface water quality for pH, electrical conductivity (EC) and turbidity in the receiving waters of Magela and Gulungul creeks upstream and downstream of the Ranger mine has been conducted independently by the Australian Government's Supervising Scientist Division (SSD) since 2005. Since 2007, ERA has progressively installed continuous monitoring stations at key onsite locations to enable real-time monitoring of data at key release points from the mine site. ERA has also installed an array of monitoring stations in the creeks adjacent to the mine site to assist with water management decision-making in real time. This monitoring is done in addition to statutory grab sampling for monitoring water quality in the main mine site catchments. The Northern Territory Government conducts a grab sampling monitoring program for specific analytes to check field parameters and laboratory results against those reported by the operator.

EC is a demonstrated proxy for magnesium (Mg), for which local water-quality objectives have been derived from the ecotoxicological response testing of six sensitive local aquatic species. Given the dynamic nature of water flows during the wet season, the behaviour of EC is best described by a pulse (event-based) exposure regime. It was thus recognised that traditional ecotoxicological end points based on long-term (chronic) exposure might not provide the most appropriate management framework. Accordingly, water-quality objectives spanning pulse exposure durations ranging from short term to chronic have been developed for continuously monitored EC (Figure 6). Figure 7 shows a practical example of the application of the EC pulse exposure magnitude and duration curve shown in Figure 6. A maximum peak in EC was detected at the monitoring site in Magela Creek downstream of the Ranger mine during 2009–10. In this example, the EC pulse exposure limit as inferred from the exposure limit curve is 174 $\mu\text{S}/\text{cm}$ for a pulse duration of 8 hours.

The pulse duration is defined by the period of time for which EC is above the chronic 72-hour limit of $42 \mu\text{S}/\text{cm}$. The maximum EC recorded during this event was $89 \mu\text{S}/\text{cm}$, which is only 51% of the EC pulse exposure limit (derived from Figure 6) for this event duration.

Figure 6: Water quality objectives for continuously monitored EC

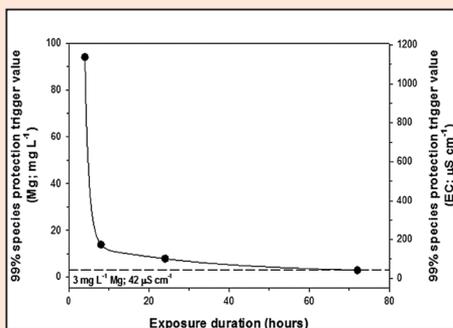
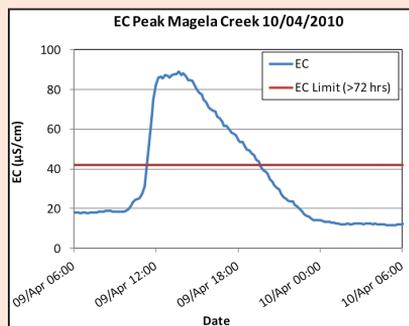


Figure 7: Practical application of EC pulse exposure magnitude and duration curve shown in Figure 6



The interpretative framework for assessing the possible effects of short-duration pulses of elevated EC (Mg) waters was formally incorporated into the statutory monitoring regime for the Ranger mine in December 2013. This was an Australian first for the implementation of an event-based water-quality assessment framework, and is one of the few examples internationally of this type of approach. Water-quality objectives are currently being developed for continuously monitored turbidity.

Online telemetry enables the immediate notification of events (via mobile phone SMS) to key staff, allowing the operator and regulators to commence timely investigations into the cause of an EC pulse, whether it be from a natural or mine-derived source. An important attribute of the continuous monitoring system is that it provides the ability to quickly distinguish differences between the upstream and downstream sites, and intermediate monitoring sites are used to identify the location of specific input sources from the mine. Adaptive management by the mine operator, using the feedback from the continuous monitoring system, of the rate and time of discharge of site run-off water ensures that the water quality in receiving surface waters downstream of the mine site remains within acceptable levels, protecting the receiving environment. The outputs from the SSD surface water quality and biological monitoring programs are posted on the SSD's website to provide ongoing assurance reporting to stakeholders and the general public.¹

All monitoring by the SSD is completely independent of that done by the mining company and the Northern Territory Government regulator. However, the data is regularly shared between the three entities in order to aid interpretation, promote transparency and achieve the implementation of leading practice monitoring methodologies for this sensitive environment.

¹ Supervising Scientist, Department of the Environment, <http://www.environment.gov.au/science/supervising-scientist/monitoring>.

The long record of macro-invertebrate and fish community data from the biological monitoring program conducted by the SSD shows that, despite some changes in water quality having occurred, the biodiversity in water bodies on the mine site has not been adversely affected. Because of this lack of demonstrated effect, the current water-quality record, including that provided by the continuous monitoring system, will be able to be used to derive water-quality closure criteria to protect the environment following rehabilitation of the Ranger site.

Case study: Environmental evaluation of QAL's red mud dam and receiving waters

The Queensland Alumina Limited (QAL) refinery, one of the largest alumina refineries in the world, is on the coast at Gladstone, central Queensland. It produces 3.95 Mt/y of smelter-grade alumina using the Bayer process. The QAL site (Figure 8) comprises the refinery (which is situated within 90 hectares of land and is bounded by buffer land, communities to the south and west, and coastal waters to the east and north), wharf facilities, boiler ash residue areas and a red mud dam (RMD). QAL operates within and adjacent to the Great Barrier Reef World Heritage Area.

Figure 8: QAL refinery and red mud dam



Note: The Great Barrier Reef World Heritage Area covers the QAL red mud dam area and South Trees Inlet.

Alkaline bauxite mud residue (red mud) slurry is transported via pipeline from the refinery to the RMD for neutralisation with seawater. The neutralised red mud and associated precipitates are separated in a clarifier, and the thickened solids fraction is pumped to one of two residue disposal areas (RMD1 and RMD2). The clarifier overflow is directed to a decant pond within RMD2. Discharge from RMD2 is via a gabion spillway structure, for aeration, into an open maze, which assists in the removal of suspended solids. From there, the discharge flows initially through an underground pipe to an open channel and then directly to South Trees Inlet via two diffusers at a continuous flow of 130,000–150,000 m³/day (Figure 9).

Figure 9: QAL's red mud dam



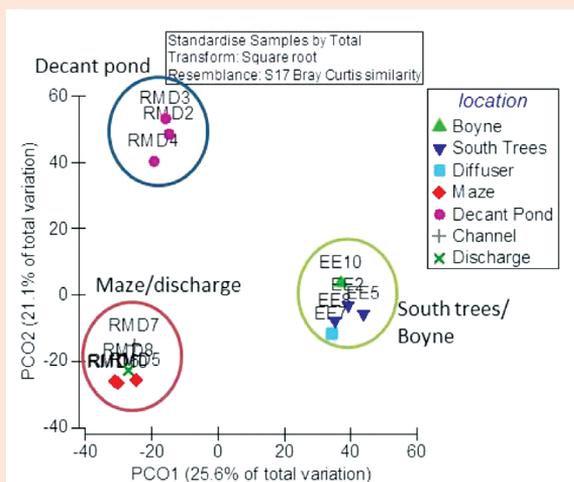
In 2010, following a series of incidents involving low dissolved oxygen in discharge waters, QAL installed aerating paddles in the open discharge channel to remedy the situation. In addition, in consultation with the Australian Institute of Marine Science, QAL developed a comprehensive environmental evaluation of impacts on the receiving aquatic environment of discharges from RMD2. The evaluation of RMD2 and South Trees Inlet used a leading practice integrated approach to gather multiple lines of evidence. The approach included:

- physicochemical assessment (water and sediment quality)
- biological characterisation using next generation genomic (DNA pyro-sequencing) techniques
- direct toxicity assessment of the RMD2 discharge
- hydrodynamic and water-quality modelling of RMD2 discharge dispersion and dilution in South Trees Inlet
- biological impact assessment (bioaccumulation, biochemical and histopathological investigation of oysters and mud crabs)
- the development of environmental values and water-quality objectives for South Trees Inlet.

Physicochemical assessment identified a number of elements (aluminium, gallium, molybdenum and vanadium) as fingerprints of the RMD2 discharge in water and sediment.

The results from the genomics characterisation showed that bacterial populations were significantly different in the RMD2 decant pond, the maze and the receiving environment and between summer and winter (Figure 10). These results showed that bacterial populations in South Trees Inlet were not being affected by the RMD2 discharge. The study also identified that the low dissolved oxygen levels measured in the decant pond were due to a high level of activity of sulphate-reducing bacteria, together with a range of heterotrophic bacteria.

Figure 10: Spatial separation of bacterial populations, revealed by principal coordinates (PCO) analysis of the genomics data



The direct toxicity assessment showed no toxicity to six marine species from five trophic levels at 100% concentration of RMD2 discharge water. While this result showed that there was no need for operational dilution of the discharge, the dilution that does occur at the diffuser within the South Trees Inlet provides an additional level of protection for the marine ecosystem of the inlet.

The biological impact assessment included an investigation of bioaccumulation of fingerprint elements, together with biochemical and histopathological investigations of oysters and mud crabs collected within 500 metres of the RMD2 diffusers in South Trees Inlet and at a reference estuary 13 km south (Colosseum Inlet). The results showed no significant differences between the two sites; a minor observed alteration in histopathology was attributed to freshwater flows resulting from floods before the evaluation.

The results from the multiple lines of evidence evaluation described here have allowed QAL to demonstrate minimal impact on the receiving environment of South Trees Inlet, and no measurable environmental harm.

Overall, the findings have resulted in significant improvements to the monitoring program, including:

- the installation of continuous water-quality monitoring buoys at the RMD outfall, upstream and downstream
- the implementation of a more robust near-field monitoring program
- the reconciliation of far-field and near-field monitoring programs, resulting in a more comprehensive and cost-effective program.

Ongoing work is being done to develop new marine water toxicity testing methods for tropical Australian marine species, including the derivation of regionally relevant water-quality guideline trigger values for several key contaminants (such as aluminium).

5.0 AUDITING

Key messages

- Auditing is a risk management tool that can be used to review environmental and social performance against agreed audit criteria.
- It is used to monitor compliance with regulatory requirements and corporate or external policies, standards and procedures.
- Auditing is a critical stage in the continuous improvement loop for sustainable management.
- There are a number of different types of environmental and social audits, the selection of which depends on the audit objectives.
- Auditing of monitoring programs enables the tracking of progress towards the achievement of environmental and social objectives.

5.1 Evaluating performance using audits

The internationally accepted definition of an 'audit' is based on the international standard ISO 19011:2011 *Guidelines for auditing management systems*:

An audit is a systematic, independent and documented process for obtaining audit evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled.

This definition can be used for a range of audits, including environmental audits, social or community relations audits, environmental security audits and health and safety audits.

The term *environmental audit* covers a wide range of activities based on the formal evaluation of a project's performance in relation to environmental objectives. The critical elements are that the audit should be objective, systematic and based on defined criteria. Those elements are discussed more broadly in the *Environmental audit guidebook* (Brown (1993–2014)).

A study or survey that does not compare the current situation with agreed audit criteria cannot be called an audit.

Internal audits, which are also called *first-party audits*, are conducted by or on behalf of the organisation for management review and other internal purposes. In many cases, particularly in smaller organisations, independence can be demonstrated by the auditor's freedom from responsibility for the activity being audited.

External audits include those generally termed *second-party audits* and *third-party audits*. Second-party audits are conducted by parties with an interest in the organisation, such as customers (for example, a power utility that purchases coal from a coalmine), or by consultants. Third-party audits are conducted by external and independent auditing organisations, such as organisations that provide certification of conformity to the requirements of a standard (such as AS/NZS ISO 14001:2004, AS/NZS ISO 9001:2008 or

AS/NZS 4801:2001); by consultants on behalf of financial institutions that are considering the provision of loan funds to a mining operation; or by independent consultants conducting a voluntary audit on behalf of an organisation (for example, an audit of a mine commissioned by its parent company).

5.2 Reasons for conducting an audit

Compliance audits assess the level of compliance or performance in relation to a set standard. Information collated through compliance audits can assist in the protection of matters of environmental and social significance and reduce the risk that serious issues will arise or compound without being detected. By demonstrating that there are systems in place to measure and improve compliance, audits also increase public confidence in the regulatory system.

Since the late 1980s, *environmental auditing* has become a common management tool in developed countries, and is increasingly being applied in developing countries both by foreign and local industries and by governments. It is being applied across the whole range of industrial and commercial activities, from the smallest enterprises to the largest resource projects (including mines, refineries, smelters and chemical plants), as well as government service organisations (such as transport systems and defence establishments). Social auditing is more recent and has been evolving since the early 2000s.

Environmental auditing is gradually changing in its nature and scope and it will continue to do so as environmental issues emerge and gain significance for the community, industry, commerce and governments. This leads to important changes in the environmental auditing process and to a proliferation of different types of environmental audit to satisfy different needs, as well as the publication of numerous standards, guidelines and codes of practice for environmental auditing.

The reason for conducting an environmental audit is to assess environmental risk and establish mitigation measures to minimise that risk. An environmental audit may be conducted or required by a mining, mineral processing or refining operation; by a parent company of one of its subsidiary mines; by a lending institution financing the development or expansion of a mine; or by a government agency exercising its regulatory powers.

5.3 Voluntary, mandatory and statutory audits

Environmental and social audits may be undertaken voluntarily or to meet the requirements of regulations or legislation.

Voluntary audits are audits that a mine conducts without compulsion from a regulatory authority and/or audits that are not required to be carried out by law. Examples of voluntary audits are environmental performance audits, compliance audits, EMS audits, energy audits and social audits voluntarily commissioned by the organisation. Most audits conducted by or on behalf of mining companies are voluntary environmental or social audits. In some parts of Australia (and some parts of the United States), legal privilege attaches to a voluntary environmental audit report, or can attach under specified circumstances. This means that the information cannot be required to be provided to an authorised officer in the administration of the relevant Act, or by a court of law.

Mandatory audits are audits that are required by a regulatory consent document such as a licence, permit, consent, authority, approval, order or notice under legal powers held by the regulatory agency requiring the audit. An example of a mandatory environmental audit is a compliance audit required under a pollution control licence, to be commissioned annually by the licence holder and conducted by an independent

auditor. It assesses compliance with environmental regulatory and licence conditions and the results are reported to the regulator. Many mining environmental licences, leases, development approvals and agreements contain a similar condition requiring audits from every six months to every three years or longer. Self-incriminatory evidence is not exempt when included in a mandatory audit report. As there are no specific social regulatory requirements, mandatory social audits have generally not been required in consent documents; however, this condition does appear in some enabling agreements signed between a government and a mining company.

In Australia, mandatory environmental audits are becoming much more common as part of the 'co-regulation' policies being established by the Australian Government and state and territory governments. It is not only the mining or petroleum regulatory agencies that require these audits, but also the Department of the Environment at the federal level under the EPBC Act and state and territory governments under planning or other legislation. For example, project approvals issued by the Department of Planning and Infrastructure in New South Wales and by the Coordinator-General's Department in Queensland usually have requirements for independent mandatory environmental compliance audits. The mandatory audit is conducted under the terms of the relevant clauses in the consent document. It is commissioned and paid for by the mine or petroleum operator that chooses the audit organisation, which must be able to demonstrate a sufficient level of independence from the operation. The terms of the audit normally include a requirement for a number of independent experts to be represented on the audit team. The auditors and experts must be approved by the regulator.

Statutory audits are audits that are compulsory under legislation. Examples of statutory environmental audits are compliance audits under the EPBC Act, industrial facility audits or site contamination audits under the Victorian *Environmental Protection Act 1970*, and 'environmental evaluations' under the *Queensland Environmental Protection Act 1994*. Statutory environmental audits may also be required under the South Australian *Environment Protection Act 1993*. In New South Wales, statutory compliance audits are conducted under the compliance audit program of the New South Wales Environment Protection Authority (EPA) to assess an enterprise's compliance with environmental legislation administered by the EPA.

What is a ‘controlled action’ audit?

Under the EPBC Act, actions that are likely to have a significant impact on matters of national environmental significance must be referred to the Minister for the Environment for assessment and approval. As part of the approval process, the action will be designated as one of the following types:

- controlled action
- not-controlled action
- not-controlled action—particular manner.

Approvals for projects with ‘controlled action’ or ‘particular manner’ designations contain conditions with which the project proponent must comply. The Department of the Environment implements a program of compliance audits of such projects. The audit principles include the independence of the auditors, ethical conduct, fairness, and due diligence on the part of the auditors by demonstrating competence, discretion and judgement.

These audits help the Australian Government to ensure that projects affecting matters of national environmental significance are implemented as approved. They also help to build knowledge about how well approval conditions are being understood and applied, and contribute to improving the effectiveness of the department’s operations.

5.4 Environmental audits

Within the broad category of environmental audits there are several types of audit that might apply to a mining operation.

An *environmental performance* audit is directed at verifying a mine’s environmental status against specific, predetermined audit criteria. The audit program objectives should articulate senior management’s or the board’s expectations for the audit program. The audit scope should address:

- the geographical and/or business system focus of the audit
- the subjects or topics to be audited, the thoroughness or depth of the audit, and the scheduling and frequency of the audit
- general criteria against which the audit will be conducted and findings established.

An *environmental management system (EMS)* audit is a specific type of environmental performance audit in which the audit scope is defined as the EMS or selected parts of it, and the audit criteria are the internal environmental policies, procedures, standards, codes of practice and so on that underpin the EMS. The EMS audit is designed to determine whether the mining operation is doing what it says it will do in its documentation of the EMS, and whether the EMS has been effectively implemented throughout the mine or that part of the mine selected for the audit. An EMS audit may assess conformance with a standard, such as ISO 14001:2004, or the mining company’s specific EMS criteria (which might or might not be based on ISO 14001:2004).

A *compliance audit* assesses a mine's compliance against selected criteria derived from legislation; regulations; licence, permit, approval or lease conditions; or other legal requirements. It may also include voluntary requirements to which the organisation subscribes, such as *Enduring value* or the International Cyanide Management Code for the Manufacture, Transport and Use of Cyanide in the Production of Gold.

Compliance audits may be statutory, mandatory or voluntary. Most multinational mining companies require periodic compliance audits to be conducted against regulatory requirements and internal policies and procedures, by either internal auditors or external auditors (or both) who report the significant results to management at the mine site and to head office. Results from multiple sites are compiled into a report for senior management and the board.

In April 2008, the Western Australian Department of Environment and Conservation introduced a condition requiring the submission of annual audit compliance reports by the holders of certain licences under the *Environmental Protection Act 1986*. The compliance reports enhance audited self-management by occupiers of prescribed premises (including mines) and help licensees to ensure greater compliance with their licence conditions. The department makes all the compliance reports submitted by industry publicly available.

Many audits labelled as *energy audits* are nothing more than a generalised assessment of a mine's energy use based on tariffs or an investigation of a particular subsystem within a mine. An effective energy audit needs to examine not only the major energy end-use equipment but also the operations, maintenance and management processes of the facility and the energy sources. The energy audit is a detailed examination of how the facility uses energy, what it pays for that energy and where the energy comes from (including the security of energy supply and renewable energy sources). It should result in a set of recommendations to reduce energy costs through both equipment and operational changes. A series of energy audit tools is available from the Department of the Environment.¹²

A *waste audit* is essentially a study of all wastes generated by a mine; however, it may be restricted to a particular operation on the mine site, such as a coal handling and preparation plant or the mineral processing plant on a metalliferous mine. The audit must go beyond measuring the quantity of waste and identifying its composition to identifying the underlying reasons and operational factors for waste generation, including purchasing policies and procedures; how the wastes are stored, handled and transported; and the methods of waste reuse, recycling and disposal. A mine operator may also conduct a waste audit of the mine's waste disposal contractors to ensure that only licensed waste disposal contractors are used, that the destination of the waste is a licensed waste disposal or recycling facility, that all waste transport and disposal is correctly documented, that record keeping complies with regulatory requirements, and that the mine is in compliance with all waste regulatory requirements.

Environmental site audits (also called *environmental site assessments*) are generally undertaken for the purposes of commercial real estate transactions, for due diligence purposes or to meet regulatory requirements, including gaining certification that a site is 'fit for use'. In many jurisdictions around the world, it is compulsory to identify contaminated sites, report their presence to regulatory authorities, register them as contaminated (or potentially contaminated), remediate them if that is necessary to protect community health and safety or environmental amenity, and certify that they are suitable for their existing, planned or potential uses. This can be a lengthy and generally expensive process, and there are many standards and guidelines relating to site assessments (see 'Further reading'). AS/NZS ISO 14015:2003 *Environmental management—environmental assessment of sites and organizations* (EASO) is

¹² See *Energy audit tools*, <http://pandora.nla.gov.au/pan/65500/20061117-0000/www.greenhouse.gov.au/challenge/members/energyaudittools.html>.

the accepted international standard, and guidance information on contaminated site investigations is available from the National Environment Protection Council and most state and territory governments. The National Environment Protection (Assessment of Site Contamination) Measure published by the council was amended in 2013 and is the basis for site contamination assessment throughout Australia.¹³

Environmental security has become a major issue worldwide. A facility that stores, uses or transports dangerous goods in significant quantities must be aware of security risks and take measures to protect the goods from malicious or accidental events that may harm the environment or human health and safety. An *environmental security audit* is an essential part of this risk assessment, especially for mines that transport and use bulk quantities of substances such as cyanide, ammonium nitrate, acids, sodium hydroxide and certain toxic chemicals used in the processing of minerals. As well as raw materials, any materials that could cause significant harm if discharged into the environment, such as radioactive products (for example, yellowcake), mineral concentrates and wastes (such as used oil) need to be assessed. The environmental security audit may include vulnerability assessments of critical infrastructure facilities, combined with a gap analysis of environmental, health and safety information and security management systems. The transport of dangerous substances through sensitive environments, such as wetlands, river crossings, national parks, conservation areas, towns and villages, is an essential component of the environmental security audit.

The International Cyanide Management Code for the Manufacture, Transport and Use of Cyanide in the Production of Gold was developed as a voluntary industry code under the direction of a multi-stakeholder steering committee, the members of which were chosen by the United Nations Environment Programme and the International Council on Metals and the Environment. The code encourages improvement on an industry-wide basis by aggressively promoting participation in the code and by requiring signatories to the code to take appropriate action to manage cyanide responsibly. The International Cyanide Management Institute was established to administer the code.

The code focuses exclusively on the safe management of cyanide and cyanidation mill tailings and leach solutions. It addresses the production, transport, storage and use of cyanide and the decommissioning of cyanide facilities. It includes requirements related to financial assurance, accident prevention, emergency response, training, public reporting, stakeholder involvement and verification procedures. The code is composed of two major elements: the principles, which broadly state commitments that signatories make to manage cyanide in a responsible manner; and the standards of practice, which identify the performance goals and objectives that must be met to comply with each principle. Relevant documents can be viewed and downloaded from the code's website.¹⁴

5.5 Maturity models

While not audits in themselves, maturity models provide a method of evaluating performance where organisations have established organisational maturity targets.

Maturity models map the characteristics that organisations and programs exhibit as they improve from vulnerable and reactive towards compliance and then to proactive and resilient (see, for example, the Hudson Ladder 2001 in the *Risk management* leading practice handbook (DIIS 2016a, Hancock 2010). This

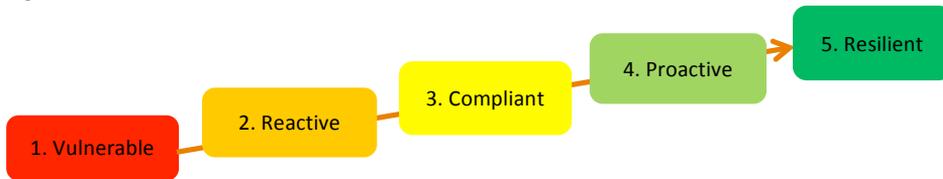
¹³ Energy audit tools, <http://pandora.nla.gov.au/pan/65500/20061117-0000/www.greenhouse.gov.au/challenge/members/energyaudittools.html>.

¹⁴ International Cyanide Management Code, <http://www.cyanidecode.org/>.

'journey model' approach enables key characteristics of various risk elements to be defined, ranked then reviewed. Maturity of key elements and overall programs can be evaluated over time.

Five phases of maturity can be applied, progressing from the least mature 'vulnerable' category through to 'reactive', 'compliant', 'proactive' and 'resilient'.

Figure 11: The Hudson Ladder



Source: DIIS (2016a); The Minerals Industry Risk Management (MIRM) maturity chart, based on the Hudson Ladder, <http://www.innovation.gov.au/resource/Documents/LPSDP/LPSDP-RiskHandbook.pdf>.

The more mature an organisation or program, the more robust the systems are to proactively address impacts with evaluation and auditing combined with open communication to continually improve those systems. Industry and government can apply this approach.

For example, the risk assessment and evaluation of corporate and government policies and government programs can be undertaken using maturity models. The maturity model approach provides a measure of how well developed a program is as both systems and organisational culture mature. A maturity model was developed Unger et al. (2012) to support the implementation of the Strategic Framework for Managing Abandoned Mines in the Minerals Industry (MCMPR-MCA 2010). A review of leading practices provided 14 elements of maturity, which were aligned to the five chapters of the framework. This model also provides an evaluative tool as programs develop over time.

Table 3: Elements of a mature abandoned mine program integrated with the Strategic Framework for Managing Abandoned Mines in the Minerals Industry

ITEM	MATURE PROGRAM CONCEPTUAL MODEL	STRATEGIC FRAMEWORK
1	Data/information management	CHAPTER 2: DATA COLLECTION AND MANAGEMENT
2	Jurisdiction-wide knowledge of health, safety, environment and socioeconomic impacts	
3	Site-specific rehabilitation and management plans for high-risk sites	
4	Leadership, legislation, policy and guidance to address abandoned mines	CHAPTER 3: RISK ASSESSMENT AND MANAGEMENT
5	Legislation, policy and guidance to prevent new abandoned mines	
6	Risk assessment and prioritisation of programs	
7	Abandoned mine program leadership and capacity/skills	
8	Funding: sources, mechanisms and resources	
9	Focus on beneficial post-mining land/water uses	CHAPTER 1: VALUING ABANDONED MINES
10	Heritage conservation—indigenous, cultural and industrial	
11	Secondary mining opportunities	
12	Resourcing in partnership	CHAPTER 4: RESOURCING AND PARTNERSHIP OPPORTUNITIES
13	Stakeholder engagement at jurisdiction level	
14	Communication and networks	CHAPTER 5: INFORMATION SHARING AND 'LEADING PRACTICE'

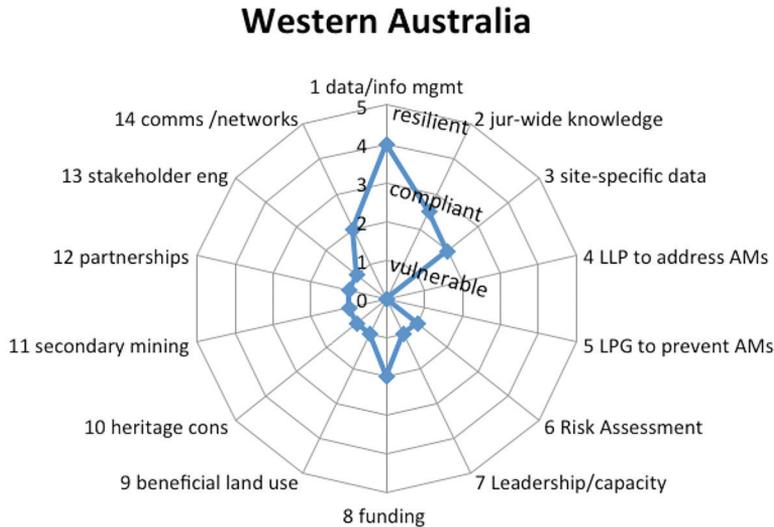
Table 4: Maturity chart content for Item 1: Data information and management, Strategic Framework for Managing Abandoned Mines in the Minerals Industry

	1. VULNERABLE	2. REACTIVE	3. COMPLIANT	4. PROACTIVE	5. RESILIENT
Spatial database/ information management	Spatial database/ information management	Inventories and data exist only for sites of concern raised by communities, landowners or other stakeholders	Jurisdiction-wide database exists An estimate for liability can be determined Data cannot be compared across jurisdictional boundaries Definitions and size classifications vary between jurisdictions No specific data manager	Jurisdictional database exists for all abandoned/ legacy mine features Can delineate risks by feature as well as by site Full liability estimate undertaken Spatial database is publicly accessible Regular review and update of data Personnel dedicated to data/ information management Data for priority sites current, of sufficiently high quality and supported by metadata	In addition to proactive descriptors: Databases include appropriate metadata to meet ISO standards Full liability calculated and updated regularly Dataset compatible across jurisdictional boundaries—risk and opportunity assessment can be undertaken on national values such as heritage, water, biodiversity and regional development Regular collaboration at national level on datasets and information management

Source: Unger et al. (2012); ISO 19115-1:2014 *Geographic information—Metadata—Part 1: Fundamentals*,
http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=53798.

In Figure 12, using Western Australia as an example, the maturity model approach highlights maturity, based on web-accessible information in early 2013. The maturity of the government's state-wide inventory is evident in Figure 12, with scores based on the Hudson Ladder (1= vulnerable, 2 = reactive, 3 = compliant, 4 = proactive, 5 = resilient) (Unger et al. 2014).

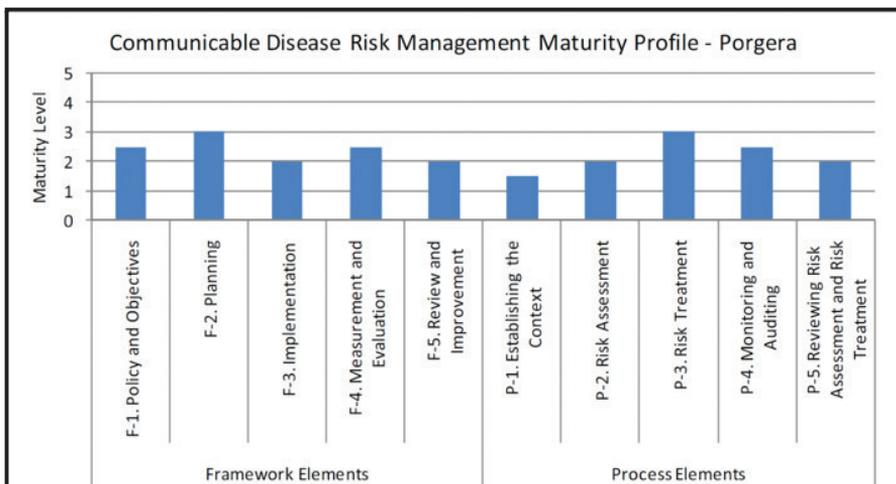
Figure 12: Maturity model approach for Western Australian example



Note: numbers and abbreviated descriptions refer to items in Table 3, p. 115.

Hancock (2010) applied the maturity model approach for evaluation of risk management systems (under ISO 31000:2009) for communicable diseases in the Papua New Guinea mining industry. This model evaluated the maturity of each element of risk of the work health and safety and medical management systems in the Ok Tedi, Porgera and Lihir mining operations. Figure 13 shows an example of this maturity ranking from Porgera.

Figure 13: Risk management maturity profile for communicable diseases at Porgera



5.6 Social audits

Social or community relations audits are required by governments and lending institutions for major resource and infrastructure projects (for example, mining, forestry, dams, power transmission lines, roads and railways or ports), especially in developing countries and to a lesser extent in developed countries.

Social audits are often combined with environmental audits, as factors that affect the environment often also affect surrounding communities. In some cases, whole villages and even tribal groups must be moved because of the extent of flooding of valleys by a major dam, or by the land requirements for a major open-cut mine and its facilities. In other cases, the lifestyles of indigenous communities are disrupted, traditional agricultural practices are restricted, heritage sites are destroyed and internal migration within the country introduces new people and cultures to an area. The transport of hazardous substances such as cyanide and ammonium nitrate to a mine, or radioactive products from a mine, may pose significant risks to both communities and sensitive environments along the transport routes.

Specific social audit protocols must be developed based on criteria sourced from a variety of documents, especially the Equator Principles (EPFI 2006), *Enduring value* (MCA 2004), and the World Bank International Finance Corporation's guidelines and performance standards (IFC 2006, 2007a, 2007b), that may apply to a particular mining project.

The IFC performance standards (PSs) of April 2006 (modified in 2012) cover social and environmental sustainability. They include:

- PS1: Assessment and management of environmental and social risks and impacts
- PS2: Labour and working conditions
- PS3: Resource efficiency and pollution prevention
- PS4: Community health, safety and security
- PS5: Land acquisition and involuntary resettlement
- PS6: Biodiversity conservation and sustainable management of living natural resources
- PS7: Indigenous peoples
- PS8: Cultural heritage.

5.7 Specific-subject audits

An organisation may decide to undertake an environmental or social audit on a specific operation or part of a mine, or an affected community, for a variety of reasons, such as ensuring compliance, improving efficiency, effecting cost savings or reducing risk. These audits may be of any aspect of the company's own mining operations, the onsite or offsite operations of contractors for whose environmental, safety and community relations performance the company is legally responsible, or the operations of waste contractors and external waste disposal and recycling facilities. This is often important during the exploration phase of a project, when earthmoving and drilling contractors may be operating over a wide area with little corporate supervision.

Many mining and petroleum operations develop integrated management systems, which can include environment, health, safety, security, community relations and other aspects, such as planning and construction or financial accounting. Some examples are:

- Anglo American's Safety, Health, Environment and Community Management System
- BP's Getting HSE Right
- Atlantic Richfield Oil Company's Operating Excellence System
- BHP Billiton's Health, Safety, Environment and Community Management System.

These systems may be audited regularly by internal auditors, or by external auditors commissioned by the company. In some cases, they are audited by the lending institutions funding mining operations.

5.8 Greenhouse and energy audits

Many mining and petroleum companies use a trigger or threshold, which may be a greenhouse gas emissions threshold, an energy production threshold or an energy consumption threshold, to trigger greenhouse gas and energy audits.

The National Greenhouse and Energy Reporting Regulations 2008 and the National Greenhouse and Energy Reporting (Audit) Determination 2009 set out detailed requirements for the conduct of greenhouse and energy audits, including requirements of audit team members, documentation, the audit process and audit conclusions.

Most greenhouse and energy audits are expected to be carried out on behalf of the Clean Energy Regulator to assess compliance with the legislation. Voluntary audits are commonly carried out for reporting entities to assist them in complying with the legislation. The Act also provides a number of circumstances in which the Clean Energy Regulator might initiate a greenhouse and energy audit.

A registered greenhouse and energy auditor (registered by the Clean Energy Regulator) must be appointed as the audit team leader. The audit team leader must be a Category 2 or Category 3 registered greenhouse and energy auditor and is responsible for ensuring that the requirements of the National Greenhouse and Energy Reporting (Audit) Determination 2009 are satisfied. The way that objective is achieved is at the discretion of the audit team leader.

There are three different types of greenhouse and energy audits as defined under the NGER Act: assurance engagements providing either reasonable or limited assurance, and verification engagements providing no assurance.

Assurance and verification engagements may examine any or all aspects of the audited body's compliance with the NGER Act and other subordinate legislation, including:

- emissions, energy production and energy consumption reported in accordance with section 19 of the NGER Act
- definitions of corporate group and facilities through the application of overall and operational control
- requirements for identification and measurement of emissions sources, energy consumption and production points
- requirements for accuracy, completeness and validity of reported greenhouse and energy information, including record-keeping requirements.

5.9 Audit personnel

Environmental and social audits can be conducted by internal or external auditors. The definition of an auditor in ISO 19011:2011 is 'a person who conducts the audit'. The level of competence required for an audit is a decision for management of the organisation commissioning the audit, and is set out in detail in Section 7 of ISO 19011:2011.

All members of an audit team, or the lead auditor only, may be required to be certified as an environmental auditor by an accredited personnel certification body such as Exemplar Global (formerly RABQSA International).¹⁵ Most organisations require their external auditors to be certified by a recognised body, not necessarily in Australia. For example, certification is available through the Institute of Environmental Management and Assessment in the United Kingdom and the Board of Environmental Health and Safety Auditor Certifications in the United States among others. There is currently no certification available specifically for a social auditor.

Members of the audit team may also be required to have undertaken an internal auditor training course approved by management and in accordance with the organisation's own procedures.

Greenhouse and energy audits under the National Greenhouse and Energy Reporting Regulations 2008 can only be conducted by a greenhouse and energy auditor registered by the Clean Energy Regulator.

5.10 Audit plan

An environmental or social audit should be carried out by competent auditors following an audit plan that incorporates an agreed environmental audit protocol.

The audit plan should include, if applicable, the:

- name and position of the auditee's representative
- audit objectives and scope audit criteria
- organisational and functional units to be audited
- functions and/or individuals within the auditee's organisation that have significant direct responsibilities regarding the audit
- elements of the auditee's environmental and/or social management programs that are of high audit priority (based on risk)
- procedures for auditing the auditee's management program elements, as appropriate for the auditee's organisation
- working and reporting languages of the audit details of reference documents
- expected time and duration for major audit activities
- dates and places where the audit is to be conducted
- names of audit team members
- schedule of meetings to be held with the auditee's management
- report confidentiality requirements
- report content, format and structure

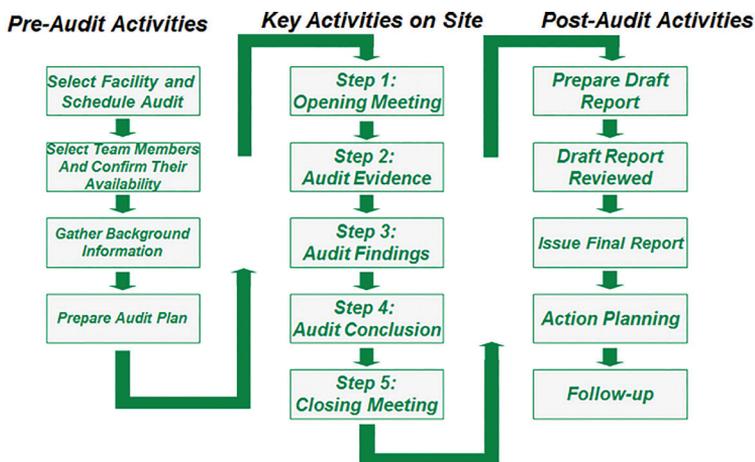
¹⁵ Exemplar Global, www.exemplarglobal.org/.

- expected date of issue and distribution of the report document
- retention requirements.

A detailed audit plan provides a format for assigning specific tasks to individual members of the audit team, for comparing what was accomplished during the audit with the original audit plan, and for summarising and recording the work in progress and work completed.

An environmental or social audit is generally carried out in three phases: pre-audit activities, site activities and post-audit activities (Figure 14).

Figure 14: Audit phases



5.11 Audit protocol

The environmental or social audit protocol presents a process for the auditor to follow to accomplish the objectives of the audit. The process may be a standard procedure or a guideline specific to the organisation or facility being audited.

Using a comprehensive audit protocol ensures consistency in the audit process and reporting procedures. This is particularly important where audit teams are used and where members of those teams may be selected on a rotating basis. An audit protocol can also be used to help train inexperienced auditors and to reduce the amount of supervision required by the leader of the environmental audit team.

Audit protocols can be general or they can be specific to a particular audit type or to the mine site being audited. The criteria agreed for the audit should be reflected in the audit protocol. This enables the auditor to assess the level of conformance by the mine site with the criteria by using the audit protocol. Generally, mandatory audit protocols are derived from the conditions of the documents that are mandated to be reviewed in the relevant clause of the document requiring the audit, and may include planning approvals, mining leases, water licences, other permits and environmental management plans required by the consent documents. The protocol can include several hundred conditions to be audited.

Audit protocols may incorporate a rating system or other numerical process for evaluating the results of the audit. This can be valuable in comparing the environmental or social performance of one mine with the performance of others, and for tracking improvement (or decline) over time. The maturity model is a

risk-based approach to evaluate the level of organisation within a company to address a particular issue. Originating in mine safety, this approach is increasingly being applied to other disciplines (DIIS 2016a).

5.12 Audit evidence

Only evidence that is verifiable is accepted as audit evidence. Audit evidence is verified by a combination of:

- review of documentation—the highest standard of verification
- observation of activities or situations—a lower standard of verification
- interview of appropriate personnel—the lowest standard of verification.

In general, audit evidence is persuasive rather than conclusive. It is necessary for the auditor to use professional judgement to evaluate the audit evidence and determine whether sufficient inquiry has been made. If firm conclusions cannot be drawn from the evidence available, it may be necessary to qualify the audit report accordingly.

5.13 Audit report

The contents of the environmental or social audit report depend on the type of audit being carried out and what is agreed between the auditor and the management commissioning the audit. Some audit reports of mine sites are very detailed; others report only exceptions (that is, only instances where the audit findings do not meet the agreed audit criteria).

Audit reports may include recommendations (which is common for external audit reports) or, in the case of internal and management systems audits, they may only report nonconformances with internal policies, procedures and standards, or noncompliances with regulatory requirements. Recommendations may be graded (for example, emergency, urgent, improvement or normal) and nonconformances may be ranked (for example, major, minor, improvement or observation). The auditor may be required to verify at a later date that recommendations have been addressed, or that nonconformances have been subjected to corrective and/or preventive action.

Mandatory audit reports may be restricted by the regulator in the terminology that can be used. For example, some regulators requiring mandatory audits may permit only compliance and noncompliance to be used; others may allow compliance, part-compliance, noncompliance, observation and improvement to be used. It is important that the auditor undertaking a mandatory environmental compliance audit of a mine obtains direction from the regulator on the terminology to be used.

Greenhouse and energy audit reports must follow the mandatory requirements in the Audit Determination Handbook published by the Clean Energy Regulator in October 2015 (CER 2015).

Contents of a typical environmental audit report under the EPBC Act

- 1 Audit objective
- 2 EPBC Act controlling provisions
- 3 Audit findings
 - 3.1 Compliance
 - 3.2 Noncompliance
 - 3.3 Undetermined
 - 3.4 Observations
- 4 Recommendations
- 5 Audit process
- 6 Terminology
- 7 Attachment A—approval notification—EPBC 2001/x
- 8 Final report distribution

5.14 Assurance

The level of inquiry or assurance applicable to an environmental or social audit depends on the type of audit being conducted, the authority for the audit (internal, external, voluntary, mandatory and/or statutory) and an organisation's internal auditing standards or mandatory or statutory requirements.

ISO 19011:2011 provides guidance on this subject; however, a number of other guidance documents or required standards can be useful for audits in or of the mining industry. They include ASAE 3000 *Assurance engagements other than audits or reviews of historical financial information* (2007) and ASAE 3100 *Compliance engagements* (2008), issued by the Australian Government's Auditing and Assurance Standards Board; guidance information on contaminated site investigations from the National Environment Protection Council and most state and territory governments; and the 'all appropriate inquiry' regulation issued by the United States Environmental Protection Agency in Subtitle B of Title II of the *Small Business Liability Relief and Brownfields Revitalization Act* of 2002.

For environmental and social audits, 'materiality' relates to the extent to which the auditor believes that the report could be misstated and still not affect the decisions of reasonable users.

Consideration of materiality assists in planning an efficient and effective audit, as trivial items can be ignored and the audit procedures can be conducted in areas considered to be of higher importance or risk, providing a greater level of assurance.

6. CONCLUSIONS

This handbook provides guidance on how companies can use monitoring, auditing and reporting to achieve their sustainable development goals, with case studies illustrating leading practice approaches to monitoring.

Evaluating performance is an essential component of leading practice sustainable development in mining. Monitoring and auditing, together with accurate and transparent reporting, are the tools companies use for evaluating and improving performance in relation to meeting their objectives for the protection and re-establishment of environmental, social and economic values. Companies recognised for their leading performance not only fulfil regulatory requirements consistently and on time, but also frequently go beyond the minimum requirements for monitoring, auditing and reporting.

Leading practice monitoring design is based on accepted risk management procedures and sound scientific principles, with mine closure and the agreed end-use of the land in mind. It focuses on all aspects of sustainable development: environmental, social, socioeconomic, cultural and spiritual. Monitoring programs are designed in consultation with all interested stakeholders, with the involvement of community groups, NGOs and others, helping to ensure that all key elements and issues are covered. Techniques used include the best available methods, and staff safety is a primary consideration.

Monitoring links to research by identifying areas for further investigation and assessing the effectiveness of new procedures.

Monitoring programs should be transparent and provide data to stakeholders through appropriate reporting procedures, which in some cases might include online access to real-time air or water quality monitoring data. Independent external assurance is increasingly used to verify the quality and accuracy of reporting. Monitoring programs are regularly reviewed to ensure their current relevance by taking into account changes in mine plans, legislation, community circumstances, monitoring technology or any other relevant aspects.

Auditing provides a check on performance by comparing the current situation with agreed audit criteria. Internal audits are conducted by companies for management review and related purposes. External audits are conducted by parties external to the organisation (for example, where independent verification of performance is required). There is a variety of different types of audits, which may be mandatory or voluntary. All audits are based on agreed protocols and audit criteria. They may be designed to assess compliance with regulatory requirements, or performance in relation to implementing environmental and social procedures and management systems or meeting defined standards. Commonly, the reason for conducting an environmental or social audit is to assess risk and establish mitigation measures to minimise that risk.

The type of reporting varies, depending on the type of audit and its purpose; however, voluntary independent audits are increasingly being used to communicate performance to external stakeholders. Auditing can occur at the site level, or at a cumulative scale across multiple sites within a company, and it can also be used to evaluate the performance of programs. Maturity models are increasingly being applied as a risk assessment process and evaluative tool as programs become more developed.

Together, monitoring and auditing can be used to develop completion criteria and confirm that associated targets and milestones have been met.

Reporting systems for monitoring and auditing must be accurate and timely and address the information needs of all stakeholders. Feedback from monitoring programs should inform operational planning and decision-making.

Public reporting, when undertaken strategically, can help to manage sustainability resources within the organisation, identify gaps in sustainability information or data collection processes, and generate momentum for improvement to environmentally and socially responsible practices in company operations and processes.

Overall, the leading practice approach to monitoring can be summarised as follows:

- Regardless of the size of the mining operation, a risk-based approach is used to ensure that site-specific monitoring programs incorporate appropriate monitoring elements, parameters, frequencies and applicable performance criteria on which to assess the monitoring data.
- The relevance and quality of data produced, and the effectiveness of monitoring programs, are audited regularly.

APPENDIX 1: TEN PRINCIPLES OF SAMPLING

The 10 principles of sampling were originally defined by RG Green in 1979 (*Sampling design and statistical methods for environmental biologists*, John Wiley & Sons, New York). Although this is an old reference, the principles of sound experimental design have not changed, and it is worth restating them because companies and their advisers still occasionally design and run monitoring programs that are not suited to rigorous analysis and unequivocal interpretation of the findings. Leading practice requires that the 10 principles be taken into account when designing quantitative monitoring programs (some additional notes are provided below in italics). More detail on experimental design is in Section 3.2.

1. Be able to state concisely to someone else what question you are asking.
2. Take replicate samples within each combination of time, location and any other controlled variables. Differences among sites can only be demonstrated by comparison with differences within sites. (*Take care to avoid pseudoreplication.*)
3. Take an equal number of randomly allocated replicate samples for each combination of controlled variables. Sampling in 'representative' or 'typical' places is **not** random sampling.
4. To test whether a condition has an effect, collect samples both where the condition is present and where the condition is absent but all else is the same. An effect can only be demonstrated by comparison with a control. (*Note: The definition of control and reference sites varies but in this instance the use of 'control' refers to comparing potentially affected sites with unaffected sites using conventional statistical procedures.*)
5. Carry out some preliminary sampling to provide a basis for evaluation of sampling design and statistical analysis options.
6. Verify that your sampling device is sampling the population that you think you are sampling, and with equal and adequate efficiency over the entire range of sampling conditions to be encountered (e.g. aquatic invertebrates).
7. If the area to be sampled has a large scale pattern, break the area up into relatively homogeneous subareas and allocate samples to each in proportion to the size of the subarea ('stratification').
8. Verify that your sample unit size is appropriate to the size, densities and spatial distributions of the organisms you are sampling. Then estimate the number of replicate samples required to obtain the precision you want.
9. Test your data to determine whether the error variation is homogeneous, normally distributed and independent of the mean. If it is not, as will be the case for most field data, then (a) appropriately transform the data, (b) use a distribution-free (nonparametric) procedure, (c) use an appropriate sequential sampling design, or (d) test against simulated null hypothesis (H_0) data.
10. Having chosen the best statistical method to test your hypothesis, stick with the result. An unexpected or undesired result is **not** a valid reason for rejecting the method and hunting for a 'better' one.

APPENDIX 2: TYPICAL ELEMENTS OF A MONITORING AND PERFORMANCE EVALUATION PROGRAM

Table A2.1: Typical environmental elements of a mining project's monitoring and performance evaluation program

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
GENERAL					
Site inspections / facility audits	Water, soils/erosion, land clearance, flora/fauna, noise, air quality, hazardous materials and general waste management	Weekly	Weekly	Quarterly/ yearly	Commitments specified in site Environmental Management Plan.
Meteorology	Rainfall, evaporation ^c , temperature, solar radiation, wind speed, wind direction, relative humidity etc.	Daily/ continuous	Daily/ continuous	Daily / continuous (remote) / as required	n.a.
Hydrology—upstream and downstream of site	Flow rate (discharge) ^d , water level	Daily/ continuous	Daily/ continuous	Daily (remote) / as required	Minimal alteration of downstream hydrology.
Sediment transport / geomorphology—upstream and downstream of site	Erosion and sediment transport rates (fluvial ^e and/or aeolian processes), composition, geomorphology (visual; surveyed cross-sections/ profiles; remote sensing; digital terrain modelling)	Baseline	Quarterly / half-yearly (seasonal) / yearly / event-based	Quarterly/ yearly	n.a.
Surface water quality—upstream and downstream of site	General water quality parameters (field) ^f	Quarterly	Daily / weekly / event-based	Quarterly/ yearly	State/national water quality guidelines for ambient surface water / drinking water (e.g. ANZECC-ARMCANZ 2000b; NHMRC 2004). Baseline and upstream. Collaboration with other stakeholders recommended for reference data collection if required.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Surface water quality—upstream and downstream of site	General and detailed water quality parameters (laboratory) ^g	Quarterly	Weekly / monthly / event-based	Quarterly/ yearly	State/national water quality guidelines for ambient surface water drinking water (e.g. ANZECC-ARMCANZ 2000; NHMRC 2004). Baseline and upstream. Collaboration with other stakeholders recommended for reference data collection if required.
Hydrogeology—upgradient and downgradient of site (including public/private water supply bores)	Groundwater levels	Monthly/ quarterly	Weekly/ monthly	Quarterly/ yearly	Minimal alteration of groundwater levels beyond the project boundary.
	General water quality parameters (field) ^f	Monthly/ quarterly	Weekly/ monthly	Quarterly/ yearly	State/national water quality guidelines for groundwater / drinking water. Baseline and upgradient data.
	General and detailed water quality parameters (laboratory) ^g	Quarterly/ yearly	Monthly/ quarterly	Quarterly/ yearly	
Site water balance	Flow rates / pump rates	Baseline	Daily	n.a.	Sufficient but not excessive volume of water on site.
	Water levels and volumes in storage facilities	n.a.	Daily	Daily (remote)/ as required	
Site acidity/ salinity/ contaminant load balance	Site water balance (see above)	See above	See above	See above	No evidence of significant increase in acidity, salinity or contaminant loads over time associated with the project.
	Acidity/salinity/ contaminant concentrations	Baseline	Weekly/ monthly/ quarterly	Daily (remote) / as required	
Discharge water	Flow rates, water levels	n.a.	Continuous/ daily/ event-based	n.a.	State/national/international water quality guidelines for discharge water (e.g. IFC 2007a). Mixing zones important.
	General water quality parameters (field) ^f	n.a.	Continuous / daily / event-based	n.a.	
	General and detailed water quality parameters (laboratory) ^g	n.a.	Monthly / quarterly / event-based	n.a.	
Drinking water supply (project site and potentially affected communities)	General water quality parameters (field) ^f	Baseline; Weekly	Weekly	Quarterly/ yearly	State/national/international water quality guidelines for drinking water (e.g. NHMRC 2004; WHO 2004).
	General and detailed water quality parameters (laboratory) ^g	Baseline; Monthly/ quarterly	Monthly/ quarterly	Quarterly/ yearly	

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Terrestrial ecosystems (e.g. revegetated waste rock pile covers, other rehabilitated areas, reference sites); groundwater ecosystems	Indicators of ecosystem health, diversity and sustainability, extent of vegetation cover / cleared land, dieback / tree decline or bare patches (if any), diversity of flora, indicator fauna species (e.g. mammals, avifauna, invertebrates, stygofauna), feral animals, mosquito / health risk vectors, soil/ plant pathogens, abundance of weeds, bushfire risk / control measures; human food chain indicators (e.g. bush tucker, fish, crustaceans, mammals). See <i>Biodiversity management</i> and <i>Mine rehabilitation</i> handbooks.	Baseline	Half-yearly/ yearly	Half-yearly/ yearly	Baseline and reference site data on natural ecosystems and rehabilitated areas.
Riparian ecosystems—reference and impact sites (ambient)	Indicator species of riparian flora/fauna—determine whether groundwater / baseflow dependent ecosystem (GDE) (groundwater and surface water monitoring as well as water use by plants to determine whether dependent upon baseflow or other water sources)	Baseline/ seasonal (late dry season to determine water source(s) used by potential GDEs)	Seasonal	Seasonal	Baseline and reference site data. Target set by groundwater extraction rates for drawdown or other potential impact and monitored signs of tree stress/decline.
Aquatic ecosystems—reference and impact sites (ambient)	Indicator species (e.g. algae, micro-/ macro-invertebrates, fish, other vertebrates); refer to <i>Biodiversity management</i> handbook	Baseline; monthly / yearly (taxa and ecosystem specific)	Monthly / yearly (taxa and ecosystem specific) / event-based	Half-yearly (seasonal) / yearly	Reference site aquatic fauna/ flora.
Aquatic ecosystems—direct toxicity assessment	Indicator species (e.g. algae, macro-invertebrates, fish, larger vertebrates); refer to <i>Biodiversity management</i> handbook	As appropriate for pilot plant / bench test effluents	As required	As required	Trigger value as determined by ANZECC–ARMCANZ (2000) procedures.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Aquatic ecosystems—environmental flows	Flow regime alteration (see above – Hydrology)	Baseline over several seasons/ years (hydrology; flow dependency of aquatic and riparian biota)	See above (hydrology, aquatic and riparian ecosystems). Will need specific indicators included in monitoring.	See above (hydrology, aquatic and riparian ecosystems)	Minimal alteration of flow regime, particularly base flows and timing and frequency of peak flow events. Flow dependent ecosystem status. Minimal alteration of organism distributions.
Aquatic ecosystems—environmental flows	Flow regime alteration (see above—‘Hydrology’)	Baseline (hydrology; flow dependency of aquatic and riparian biota)	See above (hydrology, aquatic and riparian ecosystems)	See above (hydrology, aquatic and riparian ecosystems)	Minimal alteration of flow regime, particularly base flows and timing and frequency of peak flow events. Flow-dependent ecosystem status. Minimal alteration of organism distributions.
Aquatic ecosystems—organism passage	Passage design and operation; organism passage and persistence; upstream and downstream	Baseline (passage requirements of aquatic and riparian biota)	Yearly/ event-based	Yearly/ event-based	Minimal alteration of organism distributions. Organism passage rates unchanged.
Soils (including soil cover materials)	General chemical parameters (e.g. pH, electrical conductivity), composition, geochemical classification ^h , moisture content, porosity, permeability, structure, texture, organic matter content, soil erosion, soil biota, stockpile quantities, quality and longevity, extent/nature of contamination	Baseline	As required for rehabilitation planning / water quality control	Quarterly/ yearly	n.a.
Grazing animals—baseline and reference sites	Carrying capacity of paddocks, grazing trials, pasture production, weeds and pests	Baseline	Yearly (seasonal)	Yearly (seasonal)	Targets set as part of post-mining land use for grazing (community requirement / condition of mining lease).
Intensive agriculture/ horticulture—baseline and reference sites	Crop production / biomass, soil quality, erosion (e.g. alluvial areas); soil chemistry and physical properties (see above—‘Soils’)	Baseline	Seasonal (crop cycles)	Seasonal (crop cycles)	Production targets for post-mining land use (agreed pre-mining).

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Ambient noise— control sites, sensitive receptors and on site	Noise (e.g. A-weighted decibels)	Baseline	As required / during selected blasts	n.a.	State/national/international guidelines (e.g. IFC 2007b)
Ambient air quality— control sites, sensitive receptors and on site	Depositional dust (e.g. rate of deposition, composition), suspended dust (e.g. PM10)	Baseline	As required / during selected blasts	n.a.	Baseline and upwind data.
	Airborne contaminants (e.g. sulphur dioxide, nitrogen oxide, PM10, carbon monoxide)	Baseline	Monthly/ quarterly	n.a.	State/national/international guidelines (e.g. IFC 2007b).
Energy consumption	Direct energy consumption (fuels); indirect energy consumption (electricity)	Baseline	Yearly	n.a.	Baseline data. Production efficiency / energy use ratio is maintained or improved.
Greenhouse gas emissions	Direct emissions from power stations / smelters (see below) and vehicles/machinery/ plant used on site (carbon dioxide equivalent)	Baseline	Yearly	n.a.	Baseline data. Production efficiency / emissions ratio is maintained or improved.
	Indirect emissions associated with electricity use (carbon dioxide equivalent)	Baseline	Yearly	n.a.	
Hazardous material consumption	Rate of hazardous material consumption (process chemicals, explosives etc.); refer to <i>Hazardous materials management</i> handbook	Monthly/ quarterly	Monthly/ quarterly	n.a.	n.a.
Hydrocarbon consumption	Rate of hydrocarbon consumption (fuels, oils, lubricants etc.)	Monthly/ quarterly	Monthly/ quarterly	n.a.	n.a.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Radiation	Radon emanation and gamma radiation from ore stockpiles, tailings mass and rehabilitated tailings impoundment; radiologically contaminated waste disposal sites for scrap metal etc.; radionuclide mobility in drainage (to surface water and groundwater); radionuclides in airborne dust (applies to all industries working with naturally occurring radioactive material (NORM), not just uranium, thorium and mineral sands); OHS measures	Environmental baseline from pre-mining survey data. Operational baseline from pilot plant, trial plots, lab-based samples and modelling	Frequent early measurement (to verify model data), then adjust according to variations in ore grade / composition and changes in operations / technology used (e.g. include ventilation outlets if underground operations commence)	Frequency depends on parameter (e.g. immediately after operations / residue containment, frequency may be continuous for radon) and authorisation, often half-yearly or seasonal	Radiological standards. Radiation safety and OHS and environmental monitoring all to be integrated.
Emergency response (e.g. spill)— location of emergency; receiving environment (e.g. surface water, groundwater, soil)	General water quality parameters (field) ^f	Event-based	Event-based	Event-based	Minimal risk to receiving environment.
	General and detailed water quality parameters (laboratory) ^g				
	Extent/nature of soil contamination				
	Ecosystem impacts (e.g. terrestrial/groundwater/ riparian/aquatic ecosystems)				
Environmental / social safety ^j	Geotechnical hazards (e.g. landslip, collapse); natural hazards (e.g. bushfire, storm, flood, earthquake, extreme heat/cold); chemical, biological (e.g. fungus) or radiological hazards; personal exposure / ambient (e.g. oxygen, carbon dioxide, methane, hydrogen sulphide, temperature, smoke, dust, illumination)	As required	As required	n.a.	Environmental/social safety risks minimised.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
WASTE ROCK AND ORE STOCKPILES					
Waste rock and ore material	Waste rock and ore production rates, mass/ volume of waste rock piles (including location/ amounts of different waste rock materials) and ore stockpiles	Modelled predictions	Daily	n.a.	Modelled data.
	Geochemical characterisation of lithologies ^h	Baseline / as required	As required	As required	Geochemical condition not threatening rehabilitated landscape or downstream ecosystems.
Hydrology (surface run-off and seepage)	Flow rates (surface run-off, surface seepage), water levels	n.a.	Weekly	Quarterly/ yearly	n.a.
Water quality (surface run-off and seepage)	General water quality parameters (field) ^f	n.a.	Weekly	Quarterly/ yearly	Baseline and upstream data. Predicted water quality.
	General and detailed water quality parameters (laboratory) ^g	n.a.	Monthly	Quarterly/ yearly	
Hydrogeology (water in waste rock piles; groundwater upgradient, beneath and downgradient of piles)	Infiltration rates and moisture content in waste rock piles (pore pressure / hydraulic / lysimeter data)	n.a.	Quarterly	As required	Target/design infiltration rates.
	Water levels; volume of pore water in waste rock piles; mass/ volume of waste rock exposed to oxygen	n.a.	Monthly	Quarterly/ yearly	n.a.
	Geophysical survey (e.g. time domain electromagnetic; resistivity) to map subsurface conductivity and seepage flow pathways	As required	As required	As required	n.a.
	General water quality parameters (field) ^f	n.a.	Monthly	Quarterly/ yearly	State/national guidelines for groundwater quality. Baseline and upgradient.
	General and detailed water quality parameters (laboratory) ^g	n.a.	Quarterly	Quarterly/ yearly	

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Geotechnical stability	Erosion, subsidence, landslips, water levels (see above)	n.a.	Daily/weekly	Yearly/as required	Engineering design specifications; rehabilitation objectives.
TAILINGS STORAGE FACILITIES, TAILINGS DAMS					
Tailings material	Milling and tailing production rates, mass/volume transferred to tailings storage facilities	Modelled predictions	Weekly	n.a.	Modelled data.
	Geochemical characterisation ^h	Baseline / as required	As required	n.a.	Geochemical condition not threatening rehabilitated landscape or downstream ecosystems.
Hydrology (supernatant water)	Volume, water level, flow rate of tailings into facility, flow rate of decant pumps, spillway flow rates	n.a.	Daily	Daily (remote) / as required	n.a.
Hydrology (surface seepage)	Flow rate, water level	n.a.	Weekly/monthly	Daily (remote)/as required	n.a.
Water quality (supernatant water and surface seepage)	General water quality parameters (field) ^f	n.a. or modelled	Weekly/event based	Quarterly/yearly	Site-specific water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	n.a.	Monthly	Quarterly/yearly	
Hydrogeology (pore water in tailings; groundwater upgradient, beneath and downgradient of tailings storage facilities)	Water levels; mass/volume tailings exposed to oxygen	Baseline	Monthly	Quarterly/yearly	n.a.
	Geophysical survey (e.g. time domain electromagnetic; resistivity) to map subsurface conductivity and seepage flow pathways	As required	As required	As required	n.a.
	General water quality parameters (field) ^f	Baseline	Monthly	Quarterly/yearly	State/national guidelines for groundwater quality. Baseline and upgradient data.
	General and detailed water quality parameters (laboratory) ^g	Baseline	Quarterly	Quarterly/yearly	
Fauna	Avifauna, mammals, livestock	Baseline	Weekly; event-based	Yearly	No evidence of project-related fauna deaths.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Geotechnical stability	Erosion, subsidence, landslips, supernatant and groundwater levels (see above); tailings density, strength (penetrometer) and water content (water liberated by consolidation and ability to support a cover if required); refer to <i>Tailings management handbook</i>	Modelled predictions	Daily/weekly/event-based	Yearly/as required	Engineering design specifications; rehabilitation objectives.
PITS / OPEN CUTS					
Pit wall material (groundwater cone of depression)	Mass/volume of material exposed to oxygen	Modelled predictions	As required	As required	Modelled data.
	Geochemical characterisation of lithologies ^h	Baseline/as required	As required	As required	Geochemical condition not threatening rehabilitated landscape or downstream ecosystems.
Pit hydrology / stormwater	Dewatering pump flow rates	Modelled predictions	Daily	As required	n.a.
Pit water quality	General water quality parameters (field) ^f	Modelled predictions	Weekly	Quarterly/yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	Modelled predictions	Monthly	Quarterly/yearly	
Pit hydrogeology (groundwater cone of depression)	Groundwater levels, flow rates (e.g. dewatering bores)	Modelled predictions	Weekly	Quarterly/yearly	Modelled data.
	General water quality parameters (field) ^f	Baseline	Weekly	Quarterly/yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a).
	General and detailed water quality parameters (laboratory) ^g	Baseline	Monthly	Quarterly/yearly	
Blasting	Ground vibration and airblast overpressure	n.a.	All blasts monitored	n.a.	State/national/international guidelines (e.g. Standards Australia 1998).
	Noise, flyrock (distance travelled)	n.a.	Selected blasts	n.a.	State/national/international guidelines (e.g. IFC 2007b). No flyrock beyond safety exclusion zone.
Geotechnical stability (pit wall material)	Erosion, subsidence, landslips, groundwater levels (see above)	n.a.	Daily/weekly/event-based	Yearly/as required	Engineering design specifications; rehabilitation objectives.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
UNDERGROUND MINES					
Dewatered material (cone of depression)	Mass/volume of material exposed to oxygen	Modelled predictions	Monthly	As required	Modelled data.
	Geochemical characterisation of lithologies ^h	Baseline; As required	As required	n.a.	Geochemical condition not threatening rehabilitated landscape or downstream ecosystems.
Hydrogeology (groundwater cone of depression)	Groundwater levels and flow rates (dewatering bores); adit flows	Baseline; Monthly	Weekly	Quarterly/ Yearly	n.a.
	General water quality parameters (field) ^f	Baseline; Monthly	Weekly	Quarterly/ Yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a).
	General and detailed water quality parameters (laboratory) ^g	Baseline; Monthly	Monthly	Quarterly/ Yearly	
Blasting	Ground vibration and airblast over-pressure (above ground)	n.a.	All blasts monitored	n.a.	State/national/international guidelines (e.g. Standards Australia 1998).
	Noise (above ground)	n.a.	Selected blasts	n.a.	State/national/international guidelines (e.g. IFC 2007b).
Geotechnical stability	Wallock stability, subsidence (above ground), landslips	n.a.	Daily/weekly/ event-based	As required	Engineering design specifications; rehabilitation objectives.
Underground air quality, fungus	See below— Occupational health and safety (OHS)	(OHS) ⁱ	(OHS) ⁱ	(OHS) ⁱ	(OHS) ⁱ
HEAP AND DUMP LEACH PILES					
Ore material	Ore production rates, mass/volume of ore in leach pad	Modelled predictions	Daily	n.a.	Modelled data.
	Geochemical characterisation of lithologies ^h	Baseline/as required	As required	n.a.	Geochemical condition not threatening rehabilitated landscape or downstream ecosystems.
Hydrology (surface run-off and seepage)	Flow rates, water levels	n.a.	Daily	Quarterly/ yearly	n.a.
Water quality (surface runoff and seepage)	General water quality parameters (field) ^f	Baseline	Weekly	Quarterly/ yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	Baseline	Monthly	Quarterly/ yearly	

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Hydrogeology (groundwater upgradient, beneath and down gradient of heap leach pad /leach piles)	Groundwater levels	Baseline	Weekly	Quarterly/ yearly	n/a
	Geophysical survey (e.g. time domain electromagnetic) to map subsurface flow	As required	As required	As required	n/a
	General water quality parameters (field) ^f	Baseline	Weekly	Quarterly/ yearly	State/national guidelines for groundwater quality. Baseline and upgradient.
	General and detailed water quality parameters (laboratory) ^g	Baseline	Monthly	Quarterly/ yearly	
Geotechnical stability	Erosion, subsidence, landslips	n.a.	Daily/weekly/ event-based	As required	Engineering design specifications; rehabilitation objectives.
HAUL ROADS, ACCESS ROADS, EXPLORATION ROADS, DRILL PADS					
Road runoff/ surface seepage water quality	General water quality parameters (field) ^f	n.a.	Event-based; as required	Quarterly/ yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	n.a.			
Ambient noise	Noise (e.g. A-weighted decibels)	Baseline	As required	n.a.	State/national/international guidelines (e.g. IFC 2007b).
Geotechnical stability	Erosion, subsidence, landslips	Daily/ weekly/ event-based	Daily/weekly/ event-based	As required	Engineering design specifications; rehabilitation objectives.
Aquatic ecosystems—organism passage	Passage design and operation; organism passage and persistence upstream and downstream	Baseline (passage requirements of aquatic and riparian biota)	Yearly/ event-based	Yearly/ event-based	Minimal alteration of organism distributions. Organism passage rates unchanged.
QUARRIES					
Pit water quality	General water quality parameters (field) ^f	n.a.	Weekly	Quarterly/ yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	n.a.	Monthly	Quarterly/ yearly	
Blasting	Ground vibration, airblast overpressure, flyrock (distance travelled)	n.a.	All blasts monitored	n.a.	State/national/international guidelines (e.g. Standards Australia 1998).
	Noise (e.g. A-weighted decibels)	n.a.	Selected blasts	n.a.	State/national/international guidelines (e.g. IFC 2007b).
Geotechnical stability	Geotechnical stability (erosion, subsidence, landslips)	n.a.	Daily/ weekly/ event-based	As required	Engineering design specifications; rehabilitation objectives.
POWER GENERATING FACILITIES					
Stack/flue emissions	Airborne contaminants (e.g. sulphur dioxide, nitrogen oxide, PM10, carbon monoxide)	n.a.	As required	n.a.	State/national/international guidelines (e.g. IFC 2007b).

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^b	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
ORE CRUSHING AND PROCESSING FACILITIES					
Process water; site run-off/bund water	General water quality parameters (field) ^f	n.a.	Daily/weekly/event-based	n.a.	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	n.a.	Weekly/event-based	n.a.	
PRIMARY SMELTING FACILITIES					
Stack/flue emissions	Airborne contaminants (e.g. sulphur dioxide, nitrogen oxide, PM10, carbon monoxide)	n.a.	As required	n.a.	State/national/international guidelines (e.g. IFC 2007b).
WATER STORAGE, SEDIMENT BASINS, ETC.					
Hydrology	Flow rates, water levels	n.a.	Event-based / as required	Quarterly/yearly	n.a.
Water quality	General water quality parameters (field) ^f	n.a.	Event-based/as required	Quarterly/yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	n.a.	Event-based / as required	Quarterly/yearly	
Sedimentation	Bathymetry (visual; surveyed cross-sections/profiles; remote sensing; digital terrain modelling); water storage capacity/residence time; sediment composition	n.a.	Event-based/as required	Quarterly/yearly	Engineering design specifications.
Geotechnical stability	Erosion, subsidence, landslips	n.a.	Daily/weekly/event-based	Quarterly/yearly	Engineering design specifications; rehabilitation objectives.
Aquatic ecosystems—organism passage	Passage design and operation; organism passage and persistence upstream and downstream	Baseline (passage requirements of aquatic and riparian biota)	Yearly/event-based	Yearly/event-based	Minimal alteration of organism distributions. Organism passage rates unchanged.
CONSTRUCTED WETLANDS					
Hydrology	Flow rates, water levels	n.a.	Event-based/as required	Quarterly/yearly	n.a.
Water quality/odour (influent, effluent)	General water quality parameters (field) ^f , odour	n.a.	Continuous/weekly	Quarterly/yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	n.a.	Continuous/monthly/seasonal	Quarterly/yearly	

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION / FEASIBILITY PHASE ^a	CONSTRUCTION / OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE (E.G. 3+ YEARS)	
Sedimentation	Bathymetry (visual; surveyed cross-sections/profiles; remote sensing; digital terrain modelling); water storage capacity/residence time; sediment composition	n.a.	Event-based / as required	Quarterly/yearly	Engineering design specifications.
Geotechnical stability	Geotechnical stability (erosion, subsidence, landslips)	n.a.	Daily/weekly/event-based	Yearly/as required	Engineering design specifications; rehabilitation objectives.
Wetland vegetation	Vegetation health and diversity	n.a.	Monthly/seasonal	Quarterly/yearly	n.a.
OTHER WATER TREATMENT FACILITIES (E.G. DRINKING WATER, GREYWATER, SEWERAGE)					
Water consumption / wastewater generation	Flow rates, water levels	n.a.	Daily/weekly	n.a.	n.a.
Water quality/odour (influent, effluent)	General water quality parameters (field) ^f , odour	n.a.	Daily/ weekly	n.a.	Water quality criteria (onsite use) or drinking water quality guidelines (e.g. NHMRC 2004; WHO 2004).
	General and detailed water quality parameters (laboratory) ^g	n.a.	Weekly/monthly	n.a.	
SOLID WASTE DISPOSAL FACILITIES					
Waste generation	Rate of solid waste generation, reuse, recycling and disposal, according to type	Weekly/monthly	Weekly	n.a.	n.a.
Hydrology (leachate/run-off)	Flow rates	Weekly/monthly	Weekly/monthly	Quarterly/yearly	n.a.
Water quality/odour (leachate/run-off)	General water quality parameters (field) ^f , odour	Weekly/monthly	Weekly/monthly	Quarterly/yearly	Water quality criteria (onsite use) or discharge water quality guidelines (e.g. IFC 2007a; ANZECC-ARMCANZ 2000).
	General and detailed water quality parameters (laboratory) ^g	Monthly/quarterly	Monthly/quarterly	Quarterly/yearly	
	Direct toxicity assessment (macro-invertebrates, fish, larger vertebrates); refer to <i>Biodiversity management handbook</i>	Monthly/quarterly	Monthly/quarterly	As required	Trigger value as determined by ANZECC-ARMCANZ (2000) procedures.
Geotechnical stability	Geotechnical stability (erosion, subsidence, landslips)	n.a.	Daily/weekly/event-based	Yearly/as required	Engineering design specifications; rehabilitation objectives.
Visual	Pests/scavengers/litter	Daily	Daily	Quarterly/yearly	n.a.

a Monitoring frequency for some locations may need to be higher during the wet season (and high-flow periods) and lower during the dry season (and low/no-flow periods). A higher frequency will also be required before/during offsite discharge (e.g. in the case of downstream surface water monitoring). A trend towards continuous monitoring of environmental parameters is emerging as new technologies are being developed to enable more cost-effective and remote monitoring; continuous monitoring facilitates the identification of acute impacts (e.g. pulses of contaminated water) as well as long-term trends. Certain projects may require a higher monitoring frequency

during closure than after closure; monitoring frequencies for closure/post-closure are combined here for simplification.

- b Monitoring frequency during the exploration/feasibility phase may vary with the expected time before commencement of operations.
- c Calibration of pan evaporation factors required to ensure water balance uses accurate evaporation data/assumptions.
- d Calibration/rating curve for each stream gauging station to enable conversion of water-level data to flow rates.
- e Estimation of fluvial sediment transport rates is facilitated by continuous hydrology monitoring data (see 'Hydrology').
- f General field parameters may include pH, temperature, electrical conductivity/salinity, turbidity, dissolved oxygen and redox potential.
In some cases, more detailed parameters (e.g. particular metals or other contaminants of concern) need to be monitored at a similar frequency to general field parameters. This may involve onsite laboratory analysis or the use of field test kits.
- g Relevant parameters may include total suspended solids, acidity/alkalinity, major ions and ligands, metals, nutrients, organic carbon, hydrocarbons, E. coli, total coliforms, and other potential site-specific contaminants (e.g. cyanide species, radionuclides).
- h Geochemical characterisation typically involves a combination of static tests (e.g. acid-base accounting, geochemical composition, mineralogy) and kinetic tests (column leach tests, sulphide oxidation rate tests, in-situ measurement of pore space oxygen concentration). Refer to the *Preventing acid and metalliferous drainage* handbook.
- i More general occupational health and safety (OHS) aspects are beyond the scope of this handbook; see IFC (2007b) for further guidance.

Sources: ANZECC-ARMCANZ (2000); IFC (2007a, 2007b); NHMRC (2004); Standards Australia (1998); WHO (2004).

Table A2.2: Typical social elements of a mining project’s monitoring and performance evaluation program

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION/ FEASIBILITY PHASE ^b	CONSTRUCTION/ OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE	
Archaeology and Indigenous cultural heritage/ physical cultural resources (PCR)	Cultural heritage sites, grave sites, archaeological sites/ artefacts, spiritual beliefs and practices	Baseline	As required	As negotiated, as part of closure plan	Culturally significant sites and artefacts are preserved.
Built	Physical infrastructure/ investment; buildings, transportation, traffic movement on/off site, community facilities and communications	Baseline/ yearly	Yearly; traffic movement ongoing	As negotiated, as part of closure plan	Utilisation of community amenity, housing availability, use of public transportation, impacts of traffic quantified and managed, volume of private (home) ownership.
Community grievances and attitudes	Social disturbances (e.g. noise, traffic) and complaints; community attitude towards the mining project	Baseline	Weekly/ monthly	Quarterly/ yearly	Continued community support for the project; community complaints and suggestions addressed.
Compensation	Number of people affected, nature and extent of disturbance to land/assets/livelihood; measures taken to compensate for loss/ disturbance	As required	As required	As required	Affected persons are appropriately compensated.
Governance	Formal and informal leadership structures, political systems and protocols, capacity to respond to development	Baseline/ yearly	As required	Yearly	Time taken for development approvals, voting turnout, local support for local/ municipal government.
Health and nutrition	Health/nutrition surveys (general health, diet, exposure to hazardous materials, drinking water quality, drug use, air quality, access to sanitation and health services, incidence of prevalent illnesses and sexually transmitted infections)	Baseline/ yearly	Quarterly/ yearly	As negotiated, as part of closure plan	State of health and nutrition is maintained or improved, increase in dysfunctional behaviours, increased vulnerability of subpopulations (elderly, women, youth).
Human	Skills, knowledge, education, expertise, in-out migration	Baseline/ yearly	Quarterly/ yearly	As negotiated, as part of closure plan	Portion of people remaining in community after high school, high school diplomacy rates, portion of operational workforce that have remained in the community for [timeframe], retention rates, vocational enrolment rates.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY*			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION/ FEASIBILITY PHASE ^b	CONSTRUCTION/ OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE	
Incidents	Traffic incidents; project-related injuries; downstream impacts associated with discharge events	As required	As required	As required	Rate of incidence declines.
Indigenous cultural elements in rehabilitation	Bush tucker, habitat for key wildlife, biodiversity related to traditional diet	Baseline	Frequent in early stages; half-yearly after initial rehabilitation; yearly thereafter	Yearly	Conservation and transplanting of key elements, protection of specific areas from disturbance followed by monitoring return of key species, consultant to assess community satisfaction.
Land use	Land and asset surveys; land use requirements and impacts; economic value of land, assets and natural resources; grazing animals and intensive agriculture/ horticulture (see Table A2.1)	Baseline	As required	Yearly	Natural resources are maintained or improved.
Livelihood/ socioeconomics	Livelihood/ socioeconomic surveys (employment, income, financial resources, living costs, living conditions), economic diversity opportunities (dependency), job creation activities	Baseline/ yearly	Quarterly/ yearly	As negotiated, as part of closure plan	Employment (level of workforce participation in local community, unemployment rates), income, land and assets are maintained or improved relative to living costs; wellbeing is maintained or improved.
Non-indigenous cultural heritage/ practice	Heritage significance, rates of decay, stability, safety	As required	Yearly	Yearly	Conservation requirements of National Estate listing or state/ territory heritage listings and/or heritage guidelines.
Pre-existing historic underground workings and shafts	Safety controls, bat populations, tourism use/impacts, interpretive plans, progress toward implementation, economic measures of community value	Baseline	As required	As required	Conservation plans, safety risk assessment control measures.
Social	Community networks, cooperation and relationships, social and civic participation, local and regional community leadership, social norms, pace of change of vulnerable communities	Baseline/ yearly	Quarterly/ yearly	As negotiated, as part of closure plan	New families in the region participating in community services, rise/ fall of social programs.
Visual/ aesthetics	Photography, aerial photography/remote sensing	Baseline	Yearly	Yearly	n.a.

ELEMENT	PARAMETERS	INDICATIVE FREQUENCY ^a			PERFORMANCE EVALUATION CRITERIA
		EXPLORATION/ FEASIBILITY PHASE ^b	CONSTRUCTION/ OPERATIONS PHASE	CLOSURE / POST-CLOSURE PHASE	
Water quality, hydrology, hydrogeology, air quality (including dust), noise, vibration/airblast/flyrock, flora and fauna	See Table A2.1	n.a.	n.a.	n.a.	n.a.
Water use	Downstream water use surveys (e.g. drinking, fishing/aquaculture, irrigation/farming, livestock, washing, bathing, small-scale mining, hydropower, recreation, cultural significance etc.)	Baseline/ yearly	Quarterly/ yearly	Yearly	Natural resources are maintained or improved.

a Monitoring frequency during the exploration/feasibility phase may vary with the expected time before commencement of operations.

b Monitoring frequency during the exploration/feasibility phase may vary with the expected time before commencement of operations.

APPENDIX 3: GRIEVANCE MANAGEMENT MECHANISMS

In recent years, grievance management has become an important part of monitoring and evaluation.

Kemp & Bond (2009) drew on mining industry experience of conflict in operational settings to identify what works. With some additional elements, what works are:

- an organisational culture that supports a focus on community perspectives
- a dedicated pipeline for complaints and grievances
- an effective procedure to record, track and close out resolved grievances
- a grievance mechanism established as part of broad-based engagement that aims to establish trusting relationships
- a grievance mechanism that allows and encourages grievances to be lodged in local languages or dialects
- collaborating with local people and others about how best to handle grievances before they escalate
- taking a principled approach, including, as a minimum, transparency, accessibility, timeliness, fairness and a simple and reliable recourse mechanism
- considering issues in context, not in isolation
- understanding the problem, not just solving it
- building the social competencies of community relations practitioners and senior leaders
- having a community relations function with structural power and formally recognised authority
- ensuring that community relations personnel handling grievances are from the local community.

What does not work:

- failing to plan for conflict on the assumption that it can be avoided, or that it can be handled 'on the fly'
- giving communities no way to lodge issues, so that they must resort to destructive behaviour to get a response from the company
- relying on negotiation and position bargaining, rather than also including dialogue to build mutual understanding
- ignoring or refusing to engage 'least trusted' groups
- having a disconnected and isolated community relations function
- lacking documented grievance procedures and grievance record keeping
- refusing to accept legacy issues as part of the company's management responsibilities
- doing little analysis and due diligence
- speaking words without doing actions
- introducing third parties who impose processes ill-suited to the local context
- following corporate procedures without modifying them to suit local cultures and conditions.

Additional guidance on grievance mechanisms and the role of non-judicial grievance mechanisms in contemporary business practice is in ICMM (2009) and IFC (2009).

REFERENCES

- ACSI-FSC (Australian Council of Superannuation Investors & Financial Service Council) (2011). ESG reporting guide for Australian companies: building the foundation for meaningful reporting, http://www.asx.com.au/documents/asx-compliance/esg_reporting_guide_mar14.pdf.
- ANCOLD (Australian National Committee on Large Dams) (2012). *Guidelines on tailings dams: planning, design, construction, operation and closure*, ANCOLD, Hobart, May 2012.
- ANZECC-ARMCANZ (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand) (2000a). *Australian and New Zealand guidelines for fresh and marine water quality*, National Water Quality Management Strategy, ANZECC & ARMCANZ, Canberra.
- (2000b). *Australian guidelines for water quality monitoring and reporting*, National Water Quality Management Strategy, ANZECC & ARMCANZ, Canberra.
- ANZMEC-MCA (Australian and New Zealand Minerals and Energy Council & Minerals Council of Australia) (2000). *Strategic framework for mine closure*, ANZMEC & MCA.
- ARPANSA (Australian Radiation Protection and Nuclear Safety Agency) (2005). *Code of practice and safety guide for radiation protection and radioactive waste management in mining and mineral processing*, Radiation Protection Series, no. 9, August 2005, ARPANSA, <http://www.arpansa.gov.au/Publications/Codes/rps9.cfm>
- (2008). *Safety guide for the management of naturally occurring radioactive material (NORM) (2008)*, Radiation Protection Series, no. 15, August 2008, ARPANSA, <http://www.arpansa.gov.au/Publications/Codes/rps15.cfm>
- (2014). *Fundamentals for protection against ionising radiation*, Radiation Protection Series, F-1, ARPANSA.
- Austral Archaeology Pty Ltd (2001) *Conservation and heritage scoping study for Mount Morgan mine (MM801)*, Allom Lovell Pty Ltd and 3D Exhibitions, Adelaide, DME 95.
- (2002). *Conservation Management Plan, volume 1: Incorporating conservation policies and management strategies for the Mount Morgan mine site*, Adelaide, South Australia, NRM 141a.
- Australia ICOMOS (International Council on Monuments and Sites) (2013). *The Burra Charter: the Australia ICOMOS Charter for Places of Cultural Significance*, http://australia.icomos.org/wp-content/uploads/BURRA_CHARTER.pdf.
- Australian Government (2013). *Significant impact guidelines 1.3: Coal seam gas and large coal mining developments—impacts on water resources*, <http://www.environment.gov.au/resource/significant-impact-guidelines-13-coal-seam-gas-and-large-coal-mining-developments-impacts>.
- Australian Solomons Gold Limited (2009). *Gold Ridge Gold Mine Resettlement Action Plan*, <http://www.solomonsgold.com.au/assets/File/Resettlement%20Action%20Plan%2021st%20April%202009.pdf>.

- Baker, AL, Ernst, WHO, Van Der Ent, A, Malaisse, OIS, Ginocchio, R (2010). 'Metallophytes: the unique biological resource, its ecology and conservational status in Europe, central Africa and Latin America', in Batty, LC, Hallberg KB (eds), *Ecology of industrial pollution*, Cambridge University Press.
- Barnett, B, Townley, LR, Post, V, Evans, RE, Hunt, RJ, Peeters, L, Richardson, S, Werner, AD, Knapton, A, Boronkay, A (2012). *Australian groundwater modelling guidelines*, Waterlines report series no. 82, National Water Commission, Canberra.
- Bennett, C (1975). 'Up the hierarchy', *Journal of Extension*, 13(2):7-12.
- Bennett, K, Thom, V (2013). 'Tailoring corporate reporting to promote and enhance sustainable social development outcomes', 2nd International Conference on Social Responsibility in Mining.
- Black, A, Hughes, P (2001). *The identification and analysis of indicators of community strength and outcomes*, Department of Family and Community Services, Western Australian Government.
- Brown, GA (1993–2014). *Environmental audit guidebook*, loose-leaf publication updated three times per year, Thomson Reuters, Australia.
- Bruce, SL, Noller, BN, Ng, JC, Grigg, AH, Mullen, BF, Mulligan, D (2002). *A study of metal and metalloid uptake by cattle grazing on rehabilitated tailings at Kidston Gold Mine, North Qld*, National Research Centre for Environmental Toxicology, Brisbane.
- Bruce, SL, Noller, BN, Grigg, AH, Mullen, BF, Mulligan, DR, Ritchie, PJ, Currey, N, Ng, JC (2003). 'A field study conducted at Kidston Gold Mine, to evaluate the impact of arsenic and zinc from mine tailing to grazing cattle', *Toxicology Letters*, 137(1-2):23-34.
- Bureau Veritas Group (2009). *Sustainability report assurance*, service sheet pamphlet, <http://www.bureauveritas.com/wps/wcm/DownloadServiceSheetFile?p=UINBX2ZpbGVOYWlIPVwyODY2XEFTUi5wZGY=>.
- CER (Clean Energy Regulator) (2015). *Audit determination handbook*, CER, Canberra, <http://www.cleanenergyregulator.gov.au/DocumentAssets/Documents/Audit%20determination%20handbook.pdf>.
- DEAT (Department of Environmental Affairs and Tourism) (2004). *Cumulative effects assessment, integrated environmental management*, Information series 7, DEAT, Pretoria, http://www.environment.gov.za/sites/default/files/docs/series7_cumulative_effects_assessment.pdf.
- DEHP (Department of Environment and Heritage Protection) (2013). *Guideline: mining: model mining conditions*, DEHP, Brisbane, <http://www.ehp.qld.gov.au/assets/documents/regulation/rs-gl-water-conditions-mines-fitzroy.pdf>.
- (2014). *EM1122 Rehabilitation requirements for mining resource activities*, guideline, DEHP, Brisbane.
- DERM (Department of Environment and Resource Management) (2009). *A study of the cumulative impacts on water quality of mining activities in the Fitzroy River Basin*, DERM, Brisbane.
- DEWHA (Department of the Environment, Water, Heritage and the Arts) (1992). *Intergovernmental Agreement on the Environment*, DEWHA, Canberra.
- DIIS (Department of Industry, Innovation and Science) (2006). *Stewardship*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.
- (2016a). *Risk management*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.
- (2016b). *Community engagement and development*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.

— (2016c). *Working with Indigenous communities*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.

— (2016d). *Preventing acid and metalliferous drainage*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.

— (2016e). *Mine closure*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.

— (2016f). *Biodiversity management*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.

— (2016g). *Mine rehabilitation*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.

— (2016h). *Tailings management*, Leading Practice Sustainable Development Program for the Mining Industry, DIIS, Canberra.

DMP-EPA (Western Australian Department of Minerals and Petroleum & Environmental Protection Authority) (2011). *Guidelines for the preparation of mine closure plans*, DMP & EPA, Perth.

DRET (Department of Resources, Energy and Tourism) (2008a). *Water management*, Leading Practice Sustainable Development Program for the Mining Industry, DRET, Canberra

— (2008b). *Cyanide management*, Leading Practice Sustainable Development Program for the Mining Industry, DRET, Canberra.

Dunlop et al. (2011). *Development of ecosystem protection trigger values for sodium sulfate in seasonally flowing streams of the Fitzroy River Basin*, ACARP, Australia.

Elzinga, CL, Salzer, DW, Willoughby, JW (1998). *Measuring and monitoring plant populations*, Bureau of Land Management, Denver, Colorado, <http://www.blm.gov/nstc/library/pdf/MeasAndMon.pdf>.

EPFI (Equator Principles Financial Institutions) (2006). *Equator principles*, <http://www.equator-principles.com>.

ESMAP, World Bank & ICMM (2005). *Community development toolkit*, <http://www.icmm.com/document/4080>.

Faith, DP, Dostine, PL, Humphrey, CL (1995). 'Detection of mining impacts on aquatic macroinvertebrate communities: results of a disturbance experiment and the design of a multivariate BACIP monitoring programme at Coronation Hill, Northern Territory', *Australian Journal of Ecology*, 20(1):167-180, doi:10.1111/j.1442-9993.1995.tb00530.

FFSNI (Forest Fauna Surveys and Newcastle Innovation) (2013). *Mt Owen Complex fauna monitoring 2012 annual report*, report to Mt Owen Complex prepared by Forest Fauna Surveys Pty Ltd and Newcastle Innovation.

Franks, D (2012). *Social impact assessment of resource projects*, International Mining for Development Centre, Sustainable Minerals Institute, University of Queensland, http://im4dc.org/wp-content/uploads/2012/01/UWA_1698_Paper-02_Social-impact-assessment-of-resource-projects1.pdf.

Franks, DM, Brereton, D, Moran, CJ, Sarker, T, Cohen, T (2010a). *Cumulative impacts: a good practice guide for the Australian coal mining industry*, Australian Coal Association Research Program, Centre for Social Responsibility in Mining and Centre for Water in the Minerals Industry, Sustainable Minerals Institute, University of Queensland, Brisbane, www.csr.uq.edu.au/docs/CSRM%20SMI%20Good%20Practice%20Guide%20document%20LR.PDF.

- Franks, DM, Brereton, D, Moran, CJ (2010b). 'Managing the cumulative impacts of coal mining on regional communities and environments in Australia', *Impact Assessment and Project Appraisal*, 28(4):299–312.
- (2013). 'The cumulative dimensions of impact in resource regions', *Resources Policy*, 38:640–647.
- Geoscience Australia (2010). *Australia's in situ recovery uranium mining best practice guide: groundwaters, residues and radiation protection*, Geoscience Australia, Canberra, <http://www.ga.gov.au/webtemp/1549218/70503.pdf>.
- Glencore (no date). *Restoration research*, Glencore Mt Owen Complex website, <http://www.mtowncomplex.com.au/EN/biodiversityandlandmanagement/Pages/RestorationResearch.aspx>.
- Grant, CD, Ward, SC, Morley, SC (2007). 'Return of ecosystem function to restored bauxite mines in Western Australia', *Restoration Ecology*, 15(4)(Supplement): S94–S103.
- Green, RG (1979). *Sampling design and statistical methods for environmental biologists*, John Wiley & Sons, New York.
- GRI (Global Reporting Initiative) (2006). *Sustainability reporting guidelines*, version 3.0, http://www.globalreporting.org/NR/rdonlyres/ED9E9B36-AB54-4DE1-BFF2-5F735235CA44/0/G3_GuidelinesENU.pdf.
- Hall G, Buchar A, Bonham-Carter G (2012). *Quality control assessment of portable XRF analysers: development of standard operating procedures, performance on variable media and recommended uses*, Canadian Mining and Industry Research Organization Exploration Division, Project 10E01, Phase I, <http://www.appliedgeochemists.org/index.php/publications/other-publications/2-uncategorised/106-portable-xrf-for-the-exploration-and-mining-industry>.
- Hancock, MG (2010). 'Risk management systems for communicable diseases in the Papua New Guinean mining industry: maturity models—paths for development', PhD thesis, University of Queensland.
- Hirth, G (2014). *A review of existing Australian radionuclide activity concentration data in non-human biota inhabiting uranium mining environments*, technical report no. 167, ARPANSA, Yallambie.
- Howard, EJ, Roddy, BP (2012). 'Evaluation of the Water Erosion Prediction Project (WEPP) model: validation data from sites in Western Australia', in Fourie, A, Tibbet, M (eds), *Mine closure 2012* (pp. 81–92), proceedings of the Seventh International Conference on Mine Closure, 25–27 September, Brisbane, Australian Centre for Geomechanics, Perth.
- Howse R (2004). 'Biological impacts of acid mine drainage in the Dee River, downstream of the Mt Morgan Mine, Central Queensland, Australia', MAppSc thesis, Central Queensland University, Rockhampton, Queensland.
- (2007). 'Chironomids abound in the acid mine drainage of the Dee River, Mt Morgan', *Australasian Journal of Ecotoxicology*, 12:3–8.
- Humphrey, C, Pidgeon, R (2001). *Instigating an environmental monitoring program to assess potential impacts upon streams associated with the Ranger and Jabiluka mine sites: a report to the Alligator Rivers Region Technical Committee*.
- Humphrey, CL, Faith, DP, Dostine, PL (1995). 'Baseline requirements for assessment of mining impact using biological monitoring', *Australian Journal of Ecology*, 20(1):150–166, doi:10.1111/j.1442-9993.1995.tb00529.
- IAEA (International Atomic Energy Agency) (2002). *Management of radioactive waste from the mining and milling of ores: safety guide*, Safety Standards series no. WS-G-1.2, IAEA, Vienna, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1134_scr.pdf.

- (2003a). *Monitoring and surveillance of residues from the mining and milling of uranium and thorium*, Safety Reports series no. 27, IAEA, Vienna, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1146_scr.pdf.
- (2003b). *Radiation protection and the management of radioactive waste in the oil and gas industry*, Safety Reports series no. 34, IAEA, Vienna, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1171_web.pdf.
- (2003c). *Extent of environmental contamination by naturally occurring radioactive material (NORM) and technological options for mitigation*, Technical Reports series no. 419, IAEA, Vienna, http://www-pub.iaea.org/MTCD/Publications/PDF/TRS419_web.pdf.
- (2011). *Radiation protection NORM residues management in the production of rare earths from thorium containing materials*, Safety Reports series no. 68, IAEA, Vienna, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1512_web.pdf.
- (2013). *Radiation protection and management of NORM residues in the phosphate industry*, Safety Reports series no. 78, IAEA, Vienna, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1582_web.pdf.
- ICMM (International Council on Mining and Metals) (2003). *Mining, Minerals and Sustainable Development Project: 10 principles*, ICMM, London, <http://www.icmm.com/our-work/sustainable-development-framework/10-principles>.
- (2006). *Sustainable development framework*, ICMM, London, <http://www.icmm.com/page/1182/good-practice-guidance-for-mining-and-biodiversity>.
- (2008). *Planning for integrated mine closure*, ICMM, London, <http://www.icmm.com/page/9568/planning-for-integrated-mine-closure-toolkit>.
- (2009). *Human rights in the mining and metals industry: handling and resolving local level concerns and grievances*, ICMM, London.
- (no date). *Community development toolkit*, ICMM, London, <http://www.icmm.com/document/4080>.
- ICRP (International Commission on Radiological Protection) (2007). *The 2007 recommendations of the International Commission on Radiological Protection*, ICRP publication 103, *Annals of the ICRP*, 37(2-4).
- IFC (International Finance Corporation) (2002). *Handbook for preparing a resettlement action plan*, IFC, Washington DC.
- (2006). *Performance standards on social and environmental sustainability*, IFC, Washington DC.
- (2007a). *Environmental health and safety guidelines for mining*, IFC, Washington DC, December 2007.
- (2007b). *Environmental, health, and safety general guidelines (general EHS guidelines)*, IFC, Washington DC.
- (2009). *Good practice note addressing grievances from project-affected communities: guidance for projects and companies on designing grievance mechanisms*, IFC, Washington DC.
- (2013). *Good practice handbook: cumulative impact assessment and management*, IFC Washington DC, April 2007.
- IIED (International Institute for Environment and Development) (2002). *Breaking new ground*, final report of the Mining, Minerals and Sustainable Development Project, IIED, London, <http://pubs.iied.org/pdfs/9084IIED.pdf>.

IUCN & ICMM (World Conservation Union and International Council on Mining and Metals) (2008). *IUCN-ICMM roundtable on restoration of legacy sites*, Toronto, Canada, 2–3 March 2008, Post-Mining Alliance, IUCN & ICMM.

Jeffrey, RA, Twining, JR, Thompson, J (2001). 'Recovery of fish communities in the Finnis River, Northern Australia, following remediation of the Rum Jungle uranium/copper mine site', *Environmental Science & Technology*, 35:2932–2941.

Kemp, D, Bond, C (2009). *Mining industry perspectives on handling community grievances*, Centre for Social Responsibility in Mining, in collaboration with Harvard Kennedy School's Corporate Social Responsibility Initiative.

Koch, JK (2007a). 'Alcoa's mining and restoration process in south western Australia', *Restoration Ecology*, 15(4)(Supplement):S11–S16.

— (2007b). 'Restoring a jarrah forest understorey vegetation after bauxite mining in Western Australia', *Restoration Ecology*, 15(4)(Supplement):S26–S39.

Kuipers, JR, Maest, AS, MacHardy, KA, Lawson, G (2006). *Comparison of predicted and actual water quality at Hardrock Mines—the reliability of predictions in environmental impact statements*, Kuipers & Associates and Buka Environmental.

Majer, JD, Brennan, KE, Moir, ML (2007). 'Invertebrates and the restoration of a forest ecosystem: 30 years of research following bauxite restoration in Western Australia', *Restoration Ecology*, 15(4)(Supplement):S104–S115.

MCA (Minerals Council of Australia) (2004). *Enduring Value: the Australian minerals industry framework for sustainable development*, MCA, http://www.minerals.org.au/data/assets/pdf_file/0006/19833/EV_SummaryBooklet_June2005.pdf.

MCMPR–MCA (Ministerial Council on Mineral and Petroleum Resources and Minerals Council of Australia) (2010). *Strategic Framework for Managing Abandoned Mines in the Minerals Industry*, Canberra, <http://www.industry.gov.au/resource/Mining/Documents/StrategicFrameworkforManagingAbandonedMines.pdf>.

Meadows, D (1998). *Indicators and information systems for sustainable development: a report to the Balaton Group*, Sustainability Institute, Hartland Four Corners, Vermont.

MME (Ministry of Mines and Energy) (2010). *Strategic environmental assessment for the central Namib uranium rush*, MME, Windhoek, Namibia.

Mudd, GM (2009). 'Sustainability reporting and mining: an assessment of the state of play for environmental indicators', *Proceedings of the SDIMI 2009 (Sustainable Development Indicators in the Minerals Industry) Conference*, 6–8 July 2009, Gold Coast, Queensland, Australasian Institute of Mining and Metallurgy.

Newmont (2008). *Beyond the mine: the journey towards sustainability*, <http://www.beyondthemine.com/2008/>.

NHMRC (National Health and Medical Research Council) (2004). *National Water Quality Management Strategy: Australian drinking water guidelines*, NHMRC, Canberra, <http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm>.

Nichols, OG (2006). 'Developing completion criteria for native ecosystem reconstruction—a challenge for the mining industry', in Fourie, A, Tibbett, M (eds) 2006, *Mine Closure 2006: Proceedings of the First International Seminar on Mine Closure, 13–15 September 2006, Perth, Australia* (pp. 61–74), Australian Centre for Geomechanics, University of Western Australia.

Nichols, OG, Grant, CD (2007). 'Vertebrate fauna restored of rehabilitated bauxite mines— key findings from almost 30 years of monitoring and research', *Restoration Ecology*, 15(4)(Supplement):S116– S126.

NSWEPA (NSW Environment Protection Agency (2015). Hunter River Salinity Trading Scheme, NSWEP, <http://www.epa.nsw.gov.au/licensing/hrsts/>.

OOW (NSW Office of Water) (2014) *Groundwater monitoring and modelling plans: information for prospective mining and petroleum exploration activities*, OOW, Sydney, <http://www.water.nsw.gov.au/Water-management/Law-and-policy/Key-policies/Aquifer-interference/Aquifer-interference>.

Paul, E, Nieland, K (2013). *Integrated reporting: going beyond the financial results*, PricewaterhouseCoopers, LLP.

Porritt, J (2005). *Capitalism: as if the world matters*, London, Earthscan.

QFCI (Queensland Floods Commission of Inquiry) (2012). Queensland Floods Commission of Inquiry: final report, QFCI, http://www.floodcommission.qld.gov.au/__data/assets/pdf_file/0007/11698/QFCI-Final-Report-March-2012.pdf.

Quinn, GP & Keough, MJ (2006). *Experimental design and data analysis for biologists*, Cambridge University Press, Port Melbourne, Australia.

Read, J, Stacey, P (2009). *Guidelines for open pit slope design*, CSIRO, <http://www.publish.csiro.au/pid/6108.htm>.

Richardson, S, Irvine, E, Froend, R, Boon, P, Barber, S, Bonneville, B (2011). *Australian groundwater-dependent ecosystems toolbox part 2: assessment tools*, Waterlines report series No. 70, National Water Commission, Canberra.

Rio Tinto (2004). *Development of rehabilitation completion criteria for native ecosystem rehabilitation on coal mines in the Bowen Basin*, Australian Coal Association Research Program project C12045.

— (2005). *Development of rehabilitation completion criteria for native ecosystem rehabilitation on coal mines in the Hunter Valley*, Australian Coal Association Research Program project C13048.

— (2008). *Rio Tinto and biodiversity: achieving results on the ground*, <http://www.riotinto.com/documents/ReportsPublications/RTBiodiversitystrategyfinal.pdf>

SCER (Standing Council on Energy and Resources) (2013). *Multiple Land Use Framework*, SCER, Canberra, <https://scer.govspace.gov.au/workstreams/land-access/mluf/>.

SCEW (Standing Council on Environment and Water) (2013). *National Environment Protection (Assessment of Site Contamination) Measure*, SCEW, Canberra, <http://www.scew.gov.au/nepms/assessment-site-contamination>.

— (no date). *National Environment Protection Measure (NEPMs)*, SCEW, Canberra, <http://www.scew.gov.au/nepms>.

Smith, R, Jeffree, R, John, J, Clayton, P (2004). *Review of methods for water quality assessment of temporary stream and lake systems*, Australian Centre for Minerals Extension and Research.

Standards Australia (1998). AS 2187.2-1998 *Explosives—storage, transport and use—part 2: use of explosives*, Standards Australia.

Stokes, C, Meers, T, Unger, C, Davis-Hall, S, Montgomery, E (2008). 'Integration of ethno-botany with mine rehabilitation at RTA Gove bauxite mine', poster presented by Matrixplus Pty Ltd at MCA SD08, Darwin,

15-19 September 2008.

Sundaram, B, Feitz, A, Caritat, P de, Plazinska, A, Brodie, R, Coram, J, Ransley, T (2009). *Groundwater sampling and analysis: a field guide*, Geoscience Australia, record 2009/27 95 pp.
http://www.ga.gov.au/image_cache/GA15501.pdf

Taylor, GJ (2004). 'Chemical impacts of acid mine drainage in the Dee River, downstream of the Mount Morgan mine, Central Queensland, Australia', MAppSc thesis, Central Queensland University, Rockhampton.

Temple, HJ, Anstee, S, Ekstrom, J, Pilgrim, JD, Rabenantoandro, J, Ramanamanjato, J-B, Randriatafika, F, Vincelette, M (2012). *Forecasting the path towards a net positive impact on biodiversity for Rio Tinto QMM*, IUCN, Gland, Switzerland.

Underwood, AJ (1991). 'Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations', *Australian Journal of Marine and Freshwater Research* (Melbourne), 42:569-587.

Unger, C, Lechner, AM, Glenn V, Edraki, M, Mulligan, DR (2012). 'Mapping and prioritising rehabilitation of abandoned mines in Australia', AusIMM/CMLR Life-of-Mine Conference 2012.

Unger C J, Lechner A M, Walton A, Glenn V, Edraki M, Mulligan DR (2014). 'Maturity of jurisdictional abandoned mine programs in Australia based on web-accessible information', AusIMM/CMLR Life-of-Mine Conference 2014.

Vink, S, Hoey, D, Robbins, S, Roux, E (2013). *Regulating mine water releases using water quality trading*, International Mine Water Association, Reliable Mine Water Technology, Golden, Colorado.

WAEPA (Western Australian Environmental Protection Agency) (2013). *Environmental assessment guideline for consideration of subterranean fauna in environmental impact assessment in WA*, Environmental Assessment Guideline no. 12,
<http://edit.epa.wa.gov.au/EPADocLib/EAG12%20Subterranean%20fauna.pdf>.

WHO (World Health Organization) (2004). *Guidelines for drinking water quality*, 3rd edition, WHO, Geneva.

Williams, DJ (2008). 'The influence of climate on seepage from mine waste storages during deposition and post-closure', in Fourie, A, Tibbett, M, Weiersbye, I, Dye, P (eds) 2008, *Mine Closure 2008: Proceedings of the Third International Seminar on Mine Closure* (pp. 461-473), 14-17 October 2008, Johannesburg, South Africa, Australian Centre for Geomechanics, University of Western Australia.

Williams, DJ, Williams, DA (2007). 'Possible impacts on mine water balance arising from lining of a tailings storage facility in Western Australia', in Fourie, A (ed.) 2007, *Proceedings of Total Tailings Management Seminar, Perth, Australia* (pp. 5-15), Australian Centre for Geomechanics, University of Western Australia.

FURTHER READING

General

Allom Lovell Architects (2002). *Conservation Management Plan, Volume 2: Incorporating condition reports and recommendations for conservation works on 14 selected buildings*, Allom Lovell Architects, Brisbane, Queensland, DME 243.

Environment Australia (2002). *Energy efficiency and greenhouse gas reduction*, Australian Government, Canberra.

Graham A Brown & Associates & Westwood, A (2001). *Waste management and minimisation guidebook*, Thomson Reuters, Sydney.

ICOMOS (1964). *International Charter for the Conservation and Restoration of Monuments and Sites*, http://www.international.icomos.org/charters/venice_e.htm.

Koch, JM, Ward, SC (1994). 'Establishment of understorey vegetation for rehabilitation of bauxite-mined areas in the jarrah forest of Western Australia', *Journal of Environmental Management*, 41:1-15.

Koch, JM, Ward, SC, Grant, CD, Ainsworth, GL (1996). 'Effects of bauxite mine restoration operations on topsoil seed reserves in the jarrah forest of Western Australia', *Restoration Ecology*, 4(4):368-376.

McKenzie, NJ, Grundy, MJ, Webster, R, Ringrose-Voase, AJ (2008). *Guidelines for surveying soil and land resources*, 2nd edition, CSIRO Publishing, Melbourne.

Meers, T, Stokes, C, Unger, C, Dunbar, C (2008). 'The discovery of a critically endangered plant; lessons learnt at Rio Tinto Alcan Gove mine', paper presented at MCA SD08, Darwin, 15-19 September 2008.

National Committee for Soil and Terrain (2009). *Australian soil and land survey field handbook*, 3rd edition, CSIRO Publishing, Melbourne.

Norman, MA, Koch, JM, Grant, CD, Morald, TK, Ward, SC (2006). 'Vegetation succession after bauxite mining in Western Australia', *Restoration Ecology*, 14:278-288.

Thomas, I, Elliott, M (2009). *Environmental impact assessment in Australia: theory and practice*, 5th edition, Federation Press, Leichhardt, New South Wales.

Thomas, I (2005). *Environmental management: processes and practices for Australia*, Federation Press, Leichhardt, New South Wales.

Ward, SC, Koch, JM, Grant, CD (1997). 'Ecological aspects of soil seed-banks in relation to bauxite mining. I. Unmined jarrah forest', *Australian Journal of Ecology*, 22:169-176.

Australian environmental legislation websites

Australian Legal Information Institute (AustLII) (access to Australian, New Zealand and international legislation), <http://www.austlii.edu.au>.

Energy and emissions reporting and management

The ICMM has released the following publication on energy and emissions reporting:

Measurement, reporting and verification and the mining and metals industry, <http://www.icmm.com/document/2660>.

Other ICMM documents relating to energy and emissions management include:

The cost of carbon pricing: competitiveness implications for the mining and metals industry, <http://www.icmm.com/document/5286>.

Adapting to a changing climate: implications for the mining and metals industry, <http://www.icmm.com/document/5173>.

The role of mining and metals in land use and adaptation, www.icmm.com/document/2662.

Fugitive methane emissions in coal mining, <http://www.icmm.com/document/2040>.

References by jurisdiction

Environment

Commonwealth

Department of the Environment, <http://www.environment.gov.au/about/legislation.html>.

NSW

Department of Environment and Heritage, <http://www.environment.nsw.gov.au/legislation/>.

Vic.

Environment Protection Authority, <http://www.epa.vic.gov.au/about-us/legislation>.

Qld

Department of Environment and Heritage Protection, <http://www.ehp.qld.gov.au/about/legislation/index.html>.

WA

Environmental Protection Authority, <http://www.epa.wa.gov.au/AbouttheEPA/legislation/Pages/default.aspx>.

SA

Department of Environment, Water and Natural Resources, <http://www.environment.sa.gov.au/about-us/Legislation>.

Tas.

Environment Protection Authority, <http://epa.tas.gov.au/policy/>.

ACT

Environment and Planning Directorate, http://www.environment.act.gov.au/environment/environment_protection_authority/legislation_and_policies.

NT

Northern Territory Environment Protection Authority, <http://www.ntepa.nt.gov.au/about-nt-epa/legislation>.

Legislation

Commonwealth

ComLaw, <http://www.comlaw.gov.au>.

NSW

NSW Parliamentary Counsel's Office,
<http://www.legislation.nsw.gov.au/maintop/scanact/inforce/NONE/0>.

Vic.

Victorian Law today, <http://www.legislation.vic.gov.au>.

Qld

Office of the Queensland Parliamentary Counsel, <https://www.legislation.qld.gov.au/OQPChome.htm>.

WA

State Law Publisher, <http://www.slp.wa.gov.au/legislation/statutes.nsf/default.html>.

SA

Attorney-General's Department, <http://www.legislation.sa.gov.au>.

Tas.

Tasmanian legislation, <http://www.thelaw.tas.gov.au>.

ACT

ACT Legislation Register, <http://www.legislation.act.gov.au>.

NT

Parliamentary Counsel,
http://www.dcm.nt.gov.au/strong_service_delivery/supporting_government/parliamentary_counsel.

References relevant to uranium monitoring and management

Department of the Environment

Supervising Scientist. *Annual report 2012-13*,
<http://www.environment.gov.au/resource/supervising-scientist-annual-report-2012-2013>.

Geoscience Australia

Australia's in situ recovery uranium mining best practice guide: groundwaters, residues and radiation protection, Canberra, 2010, <http://www.ga.gov.au/webtemp/1549218/70503.pdf>.

World Nuclear Association

Sustaining global best practices in uranium mining and processing: principles for managing radiation,

health and safety, waste and the environment, 2007, <http://www.world-nuclear.org/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=16982>.

International Atomic Energy Agency

Monitoring and surveillance of residues from the mining and milling of uranium and thorium, Safety Reports series no. 27, Vienna, 2003, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1146_scr.pdf.

Radiation protection and the management of radioactive waste in the oil and gas industry, Safety Reports series no. 34, Vienna, 2003, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1171_web.pdf.

Surveillance and monitoring of near surface disposal facilities for radioactive waste, Safety Reports series no. 35, Vienna, 2004, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1182_web.pdf.

Assessing the need for radiation protection measures in work involving minerals and raw materials, Safety Reports series no. 49, Vienna, 2007.

Radiation protection and NORM residue management in the zircon and zirconia industries, Safety Reports series no. 51, Vienna, 2007.

Radiation protection and NORM residue management in the production of rare earths from thorium containing minerals, Safety Reports series no. 68, Vienna, 2011, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1512_web.pdf.

Radiation protection and NORM residue management in the titanium dioxide and related industries, Safety Reports series no. 76, Vienna, (2012), http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1568_web.pdf.

Radiation protection and management of NORM residues in the phosphate industry, Safety Reports series no. 78, Vienna, 2013.

Management of radioactive waste from the mining and milling of ores safety guide, Safety Standards series No. WS-G-1.2, Vienna, 2002, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1134_scr.pdf.

Occupational radiation protection in the mining and processing of raw materials safety guide, Safety Standards series No. RS-G-1.6, Vienna, 2004, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1183_web.pdf.

Australian Radiation Protection and Nuclear Safety Agency

Radiation Protection series

No. 1: *Recommendations for limiting exposure to ionizing radiation (1995) and National standard for limiting occupational exposure to ionizing radiation (republished 2002)*, March 2002, <http://www.arpana.gov.au/Publications/Codes/rps1.cfm>.

No. 2: *Code of practice for the safe transport of radioactive material*, January 2008, <http://www.arpana.gov.au/Publications/Codes/rps2.cfm>.

No. 2.1: *Safety guide for the safe transport of radioactive material*, August 2008, http://www.arpana.gov.au/Publications/Codes/rps2_1.cfm.

No. 9: *Code of practice and safety guide for radiation protection and radioactive waste management in mining and mineral processing*, August 2005, <http://www.arpana.gov.au/Publications/Codes/rps9.cfm>.

No. 15: *Safety guide for the management of naturally occurring radioactive material (NORM)*, August 2008, <http://www.arpana.gov.au/Publications/Codes/rps15.cfm>.

No. 16: *Safety guide for the predisposal management of radioactive waste*, September 2008, <http://www.arpsa.gov.au/Publications/Codes/rps16.cfm>.

References relevant to cumulative impacts

Biophysical

Australian Government (2013). *Significant impact guidelines 1.3: Coal seam gas and large coal mining developments—impacts on water resources*, <http://www.environment.gov.au/resource/significant-impact-guidelines-13-coal-seam-gas-and-large-coal-mining-developments-impacts>.

Department of Environment and Resource Management (2009). *A study of the cumulative impacts on water quality of mining activities in the Fitzroy River Basin*, Queensland Government, 49 pp.

Department of Environmental Affairs and Tourism (2004). *Cumulative effects assessment, integrated environmental management*, Information Series 7, Pretoria, 20 pp., www.environment.gov.za/sites/default/files/docs/series7_cumulative_effects_assessment.pdf.

Hunter River Salinity Trading Scheme: working together to protect river quality and sustain economic development, www.epa.nsw.gov.au/resources/licensing/hrsts/hrsts.pdf.

Mason, L, Unger, C, Lederwasch, A, Razian, H, Wynne, L, Giurco, D (2013). *Adapting to climate risks and extreme weather: a guide for mining and minerals industry professionals*, National Climate Change Adaptation Research Facility, Gold Coast, 76 pp, www.nccarf.edu.au/publications/climate-risks-extreme-weather-guide-mining.

Vink, S, Hoey, D, Robbins, S, Roux, E (2013). *Regulating mine water releases using water quality trading*, International Mine Water Association, Reliable Mine Water Technology, Golden, Colorado.

Sustainable development—triple bottom line

Ministry of Mines and Energy (2010). *Strategic environmental assessment for the central Namib uranium rush*, Windhoek, Namibia.

International Finance Corporation (2013). *Good practice handbook: cumulative impact assessment and management guidance for the private sector in emerging markets*.

Global Reporting Initiative (2011). *Sustainability reporting guidelines and mining and metals sector supplement version 3.0*, www.globalreporting.org/resourcelibrary/MMSS-Complete.pdf.

Franks, DM, Brereton, D, Moran, CJ, Sarker, T, Cohen, T (2010a). *Cumulative impacts: a good practice guide for the Australian coal mining industry*, Australian Coal Association Research Program, Centre for Social Responsibility in Mining and Centre for Water in the Minerals Industry, Sustainable Minerals Institute, University of Queensland, Brisbane, www.csr.uq.edu.au/docs/CSR%20SMI%20Good%20Practice%20Guide%20document%20LR.PDF.

Franks, DM, Brereton, D, Moran, CJ (2013). 'The cumulative dimensions of impact in resource regions', *Resources Policy*, 38:640–647.

Franks DM, Brereton, D, Moran, CJ (2010). 'Managing the cumulative impacts of coal mining on regional communities and environments in Australia', *Impact Assessment and Project Appraisal*, 28(4):299–312.

Standards and guidelines relating to auditing and performance

Australian and New Zealand standards

AS/NZS ISO 14004:2004 *Environmental management systems—General guidelines on principles, systems and support*, Standards Australia.

AS/NZS ISO 14015:2003 *Environmental management—Environmental assessment of sites and organizations (EASO)*, Standards Australia.

Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand (2000). *Australian and New Zealand guidelines for fresh and marine water quality*, ARMCANZ, Canberra.

— (2000). *Australian guidelines for water quality monitoring and reporting*, National Water Quality Management Strategy, Canberra.

International Organization for Standardization standards

For standards in the ISO 1400 series, see <http://www.iso14000-iso14001-environmental-management.com/iso14000.htm>.

Other 'standards' in the series are guidelines, many of which are designed to help companies achieve certification to ISO 14001:2004. They include the following:

- ISO 14004:2004 provides guidance on the development and implementation of environmental management systems.
- ISO 14020:2000 covers labelling issues.
- ISO 14030+ provides guidance on performance.
- ISO 14040:2006 covers life-cycle issues.
- ISO 19011:2002 provides guidance on the principles of auditing quality and environmental management systems, and is applicable to all other types of management system auditing.

Other standards and guidelines

ASTM International, Standard E1528–06 *Standard practice for environmental site assessments: transaction screen process*, ASTM.

— E1527–05 *Standard practice for environmental site assessments: Phase I environmental site assessment process*, ASTM.

— E1903–97 (2002) *Standard practice for environmental site assessments: Phase II environmental site assessment process*, ASTM.

Auditing and Assurance Standards Board (2008). *ASAE 3100 Compliance engagements*, AUASB, September 2008.

— 2007, *ASAE 3000 Assurance engagements other than audits or reviews of historical financial information 2007*, AUASB, July 2007.

Department of the Environment, Water, Heritage and the Arts (2005). *Greenhouse challenge plus energy audit tool*, consisting of 11 energy audit protocols, <http://www.environment.gov.au/settlements/challenge/members/energyaudittools.html>.

NSW Department of Environment and Conservation (2006). *Compliance audit handbook*, DEC, 2006/13, <http://www.environment.nsw.gov.au/resources/licensing/cahandbook0613.pdf>.

South Australian Environment Protection Authority (2003). *Protection for voluntary environmental audits*, 013/03, September.

Victorian Environment Protection Authority (2007). *Environmental auditor guidelines for conducting environmental audits*, publication 953.2, August 2007.

World Bank (1995). 'Environmental Auditing', *Environmental Assessment Sourcebook Update 11*, Environment Department, Washington DC.

World Bank Group (1998). 'Environmental audits in industrial projects', *Pollution prevention and abatement handbook*, July.



Leading Practice Sustainable Development Program for the Mining Industry