



ELSEVIER

Contents lists available at ScienceDirect

## Resources Policy

journal homepage: [www.elsevier.com/locate/resourpol](http://www.elsevier.com/locate/resourpol)

# A jurisdictional maturity model for risk management, accountability and continual improvement of abandoned mine remediation programs

C.J. Unger<sup>a,\*</sup>, A.M. Lechner<sup>a,b</sup>, J. Kenway<sup>c</sup>, V. Glenn<sup>a</sup>, A. Walton<sup>a</sup><sup>a</sup> Sustainable Minerals Institute, Centre for Mined Land Rehabilitation, The University of Queensland, St Lucia, Queensland 4072, Australia<sup>b</sup> Centre for Environment, University of Tasmania, Private Bag 141, Hobart, Tasmania 7001, Australia<sup>c</sup> Bluebird Consultants, Australia

## ARTICLE INFO

## Article history:

Received 27 June 2014

Received in revised form

15 October 2014

Accepted 15 October 2014

Available online 26 November 2014

## Keywords:

Abandoned mines

Derelict mines

Remediation

Maturity model

Risk management

Performance evaluation

## ABSTRACT

Abandoned mines can pose risks to the natural environment, humans and economies and prevent multiple or sequential uses of affected land. They range in size from individual shafts to large polluting open cut mines. Across Australia, there are over 50,000 abandoned mines on public and private land. A coordinated, effective management response is required to remediate these sites and reduce liabilities. We propose a novel maturity model for the evaluation of abandoned mine remediation programs and by applying it to Australian jurisdictions, demonstrate the potential for the model to be applied globally. The model incorporates 14 hierarchical evaluative criteria (including social, environmental and economic factors) which are each assessed against five performance indicators. These were derived from prior research and an Australian national policy for abandoned mines. We used the model to compare Australian jurisdictions to a leading practice benchmark jurisdiction, British Columbia, Canada, using web-accessible information and – in two cases – self-evaluation. The amount of publicly-available information varied widely between jurisdictions. Most Australian jurisdictions were ranked as less mature than the British Columbia program for most criteria. We then explain how the maturity model can be used to implement an existing regulatory framework specifically, the Australian Strategic Framework for Managing Abandoned Mines in the Minerals Industry, and discuss how the model can be applied to evaluate progress and prioritise improvements to abandoned mine management programs globally. A systematic approach to monitoring and evaluating abandoned mines programs is essential for improved accountability and to demonstrate change in liability over time. A systematic approach will also support shared learning and continual improvement within, and across, jurisdictions.

© 2014 Elsevier Ltd. All rights reserved.

## Introduction

Abandoned mines are alternatively termed ‘derelict’, ‘orphan’, ‘former’ or ‘legacy’ mines. These terms mean slightly different things in different jurisdictions. For example, orphan mines are those where the owner of the mine is unknown and untraceable, in contrast to abandoned mines which are “...mines where mining leases or titles no longer exist, and responsibility for rehabilitation cannot be allocated to any individual, company or organization responsible for the original mining activities” (Ministerial Council on Mineral and Petroleum Resources and Minerals Council of Australia (MCMR/MCA), 2010). As there is no individual, company or organization responsible for managing abandoned mines, this task falls to the government and private landholders. Regardless of terminology, an

attribute that all sites have in common is incomplete remediation. This can occur for a range of reasons including, but not limited to, premature cessation of operations, inadequate regulatory requirements, insufficient funds set aside for remediation, or inadequate community engagement to agree upon and meet closure expectations. While recognizing that different definitions are used for these sites, the term ‘abandoned’ will be used in this paper to represent all forms of mining legacies which by default have become the responsibility of governments and the community.

Abandoned mines (AMs) have accumulated in many countries globally over decades or centuries. Most originated in times when mining environmental standards and community expectations were much lower than at present. In Australia responsibility for abandoned mines can be unclear, however with a few exceptions in the Northern Territory (Department of Mines and Energy, Northern Territory (DME NT), 2013; Fawcett, 2012; Waggitt and Fawcett, 2008) state and territory governments have become responsible for abandoned mines on government owned land. Despite current freehold landholders not having mineral rights or

\* Corresponding author. Tel.: +61 417550021.

E-mail addresses: [c.unger1@uq.edu.au](mailto:c.unger1@uq.edu.au) (C.J. Unger), [Alex.Lechner@utas.edu.au](mailto:Alex.Lechner@utas.edu.au) (A.M. Lechner), [jessica.kenway@gmail.com](mailto:jessica.kenway@gmail.com) (J. Kenway), [v.glenn@uq.edu.au](mailto:v.glenn@uq.edu.au) (V. Glenn), [coolbluekoala@hotmail.com](mailto:coolbluekoala@hotmail.com) (A. Walton).

**Table 1**Risks and opportunities commonly associated with abandoned mines (adapted from [Eden Project Post-Mining Alliance, 2008](#); [Unger et al., 2012](#)).

Key risk or opportunity	Common examples
Human health/Safety risk	Exposure of local communities to contaminants Open pits and shafts
Environmental risk	Failure of tailings containment facility or other impoundments Contaminated land and water Biodiversity loss
Socio-economic risk	Communities left without livelihoods
Economic risk	Liabilities to state and landholders Litigation risk to the State Rehabilitation cost
Reputational risk	Loss of mining company social license to operate Loss of confidence in governments' ability to regulate mining
Beneficial opportunities	Domestic waste disposal in voids Mining heritage and geo-tourism Secondary mining opportunities Alternative land uses

the ability to prevent access to those minerals by third parties approved by the State government, it was the opinion of departmental staff that freehold landholders are deemed responsible for abandoned mines on freehold land in Queensland ([Queensland Flood Commission of Inquiry, 2012](#)).

Abandoned mines pose a challenge to governments and societies striving towards the sustainable development concept of inter-generational equity. There is global recognition that “some impacts [from abandoned mine sites] can be long-term and that society is still paying the price for natural capital stocks that have been drawn down by past generations” according to the report by the International Institute for Environment and Development and World Business Council for Sustainable Development ([IIED/WBCSD, 2002](#)).

The scale of the issue is significant, both in terms of the number of sites and estimated remediation costs, and compounded by the complexity and potential range of impacts ([Table 1](#)). A recent report found over 161,000 abandoned hard rock mine sites in the US (Government Accountability Office ([GAO](#)), 2011). The United States Environmental Protection Agency Office of Inspector General determined that cleanup of 63 hardrock mining sites on the National Priorities List would cost up to \$7.8 billion ([Lovingood et al., 2004](#)). In Canada, a major review of contaminated lands, including abandoned mines, estimated liabilities for abandoned mine sites at over C\$555 million for sites under federal jurisdiction alone ([Office of the Auditor General of Canada, 2002](#)). Even in Australia with its shorter mining history, it is estimated that there are in excess of 50,000 abandoned mines ranging in size from individual shafts to large polluting mines ([Unger et al., 2012](#)). However, abandoned mines may also leave positive values such as voids suitable for domestic waste disposal, heritage features for tourism and secondary mining opportunities as well as new, alternative land uses ([Eden Project Post-Mining Alliance, 2008](#); [Unger et al., 2012](#)) ([Table 1](#)).

Recent rapid growth in the resources sector globally, and particularly in countries such as Mongolia and Australia ([Lechner et al., 2014](#); [Petkova et al., 2009](#)), has placed significant demands on regulatory personnel responsible for the approval of new mines and upstream petroleum industries, resulting in far less attention being applied to environmental management of abandoned mines. Factors contributing to this include competing priorities for human resources and funding within government and industry, the costs of managing legacy issues associated with abandoned mines, jurisdictional ambiguity over responsibilities and an absence of legislation to set the standard for their management ([Queensland Flood Commission of Inquiry, 2012](#)). Abandoned mine remediation planning at a jurisdiction level is challenging

because it requires a thorough understanding of abandoned mine causes, impacts and legal contexts to develop policies. Multi-disciplinary teams are then required to formulate technical solutions embedded in a sound framework for prioritization.

The aim of this paper is to propose a model of leading practice abandoned mine management that is integrated into an existing regulatory process. The model draws upon leading practices globally to aid in the implementation and improvement of abandoned mine programs. This model is based on a graded maturity model, whereby performance is assessed for a range of evaluative criteria such as the quality of an abandoned mine inventory and risk assessment tools. This method is consistent with the trend in many other sectors, which use scales or rubrics for evaluation purposes ([Davidson, 2005](#)). We then apply the maturity model to Australian jurisdictions, as a case study, assessing the progress of abandoned in management for seven states and territories. This assessment is based on a web search, using publicly available information and self-assessments conducted by two of the jurisdictions. We compare these results to the contaminated sites program in British Columbia, Canada ([BCCSCP, 2012](#)), which is considered a benchmark for leading practice globally ([Unger, 2009](#)). Using this case study, we demonstrate how a maturity model can assist jurisdictions by indicating how advanced their programs are along the maturity path. This information can allow jurisdictions to identify where they are positioned now and where they want to be in the future. Finally, we show how the maturity model could also be used as a basis for supporting existing regulatory processes through the development of an implementation plan for Australian jurisdictions and industry.

## Method

### *Background to the maturity model*

Monitoring is the regular collection and analysis of information to provide an indication of progress towards a desired end-point or objective. Evaluation is a process that seeks to determine the merit or worth of an object, program or policy as systematically and objectively as possible ([Owen, 2006](#)). Monitoring and evaluation are used within government and the private sector to: ensure accountability for resource expenditure; inform strategic decisions; and to improve future performance through learning from past experiences (e.g. [Department of Agriculture, 2009](#), [Caring for our Country, 2014](#)). Monitoring is also a vital component of risk management to ensure early detection of problems and to guide preventative actions ([Kusek and Rist, 2004](#)).

In this paper, we propose a systematic approach for monitoring and evaluating government abandoned mine programs based on the concept of a maturity model. Maturity models, or graded rubric scales are used in a number of other sectors (e.g.: safety prioritization (NSW government, 2011; Westrum, 1993); organizational development (Esteves et al., 2010); and student assessment (Davidson, 2005). This is the first time this approach has been proposed for the evaluation of abandoned mine rehabilitation programs.

A maturity model maps a program's 'journey' from poorly structured toward an integrated, systems-based approach to management. Westrum's (1993) maturity model identified three types of culture: Pathological, Bureaucratic and Generative. Adaptations of this model commonly include additional performance categories. For example, Hudson and van der Graaf (2002) adapted Westrum's (1993) maturity model for safety culture by replacing the 'Bureaucratic' category with Reactive, Calculative and Proactive.

The maturity model approach highlights that effective risk management systems involve several step changes and include two broad elements common to evaluation rubrics (Davidson, 2005): i) evaluative criteria and ii) merit determination. Evaluative criteria describe the aspects of performance that are the focus of evaluation. Merit determination reflect categories used to assess performance for each of the evaluative criteria.

*Evaluative criteria and performance assessment*

We identified 14 evaluative criteria to define the maturity of jurisdictional abandoned mine programs from leading practice programs internationally (Unger, 2009), the five chapters of the Australian Strategic Framework for Managing Abandoned Mines in the Minerals Industry (hereafter, the "Strategic Framework"; MCMPR/MCA, 2010) and previous research on maturity models for abandoned mines (Unger et al., 2014). The Strategic Framework formed the basis of the evaluative criteria as it was developed by the Abandoned Mines Working Group comprising abandoned mine managers from within most state governments (not all jurisdictions have formal abandoned mine programs) and representation from the Minerals Council of Australia (MCA). The Strategic Framework

describes five components (presented as separate chapters) required for successful management of an abandoned mine program with the aim to encourage convergence of state and territory jurisdictions on the following aspects: i) site inventories and data management; ii) improved understanding of liability and risk relating to abandoned mines; iii) improved performance reporting; iv) standardization of processes and methodologies; and v) knowledge and skill sharing across jurisdictions. The order of our evaluative criteria based on the Strategic Framework is in line with the maturity approach where the earlier criteria describe foundational elements for new abandoned mine programs (Fig. 1).

Our maturity model consists of five categories of performance assessment for each of the 14 evaluative criteria identified in the previous step. These categories are an adaptation of an approach used in the mining context by Anglo American and Joy in 2007 (in Foster and Hout, 2013). The categories used in our maturity model are: vulnerable, reactive, compliant, proactive, and resilient. Indicators are balanced around the central maturity indicator 'compliant' which means there are systems in place (Hudson, 2001 in Commonwealth of Australia, 2008), but the organization may not yet be focussed on continual improvement or anticipating problems before they arise. Vulnerable and reactive programs lack the information needed to make good decisions and prioritise abandoned mine sites. They also lack systematic methods for addressing abandoned mines. 'Resilient' is the highest stage of program maturity and goes beyond proactive, indicating that information is shared across jurisdictional boundaries and global leading practices solutions/method are sought out to improve on local benchmarks. For the purpose of this review we used simplified indicators to aide clarity (Table 2). Thus, in our maturity model both evaluative criteria and performance assessment can be used as indicators of a well-developed and mature abandoned mines program.

*Reviewing and ranking jurisdictions: maturity model trial application in Australia and international best practice representation*

We reviewed all states and mainland territories of Australia excluding the Australian Capital Territory (which comprises a

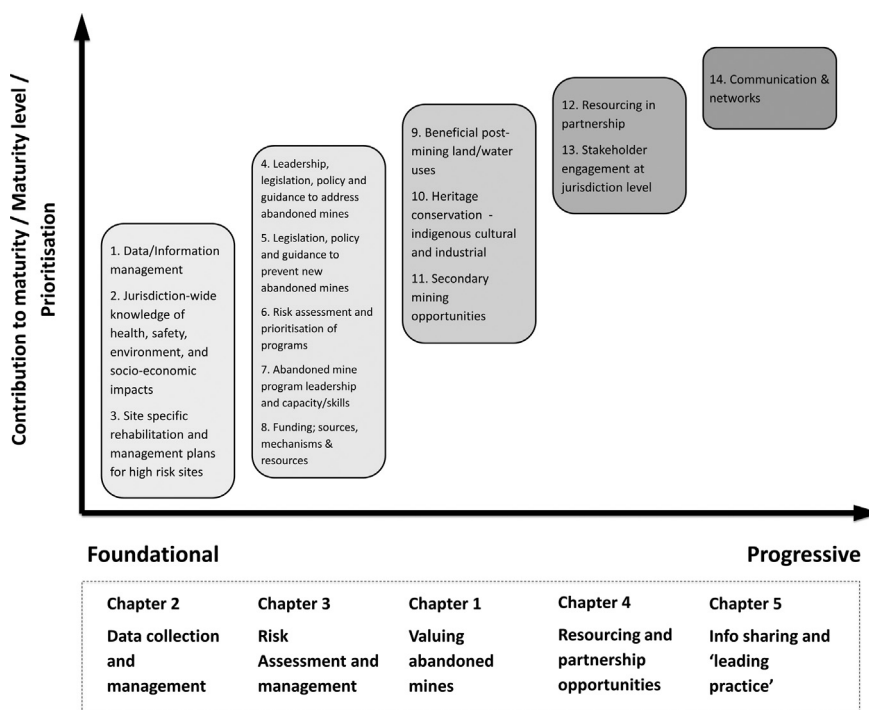


Fig. 1. Evaluative criteria of a mature abandoned mine program and relationship with Strategic Framework.

**Table 2**

Jurisdictional maturity model for abandoned mine management (Adaptation of Unger et al. 2014).

<b>Performance indicators</b>	Vulnerable (1)	Reactive (2)	Compliant (3)	Proactive (4)	Resilient (5)	<b>Strategic framework chapter*</b>
<b>Evaluative criteria</b>				in addition to complaint...	in addition to proactive...	
<b>1 Data/information management</b>	No data and no inventory evident;	Some data on some sites, outdated inventory insufficient to make decisions on which sites require management;	An inventory exists of jurisdiction-wide abandoned mines with sufficient information to prioritise sites;	Actively addressing data and information gaps; Regular improvements to integrate data management system;	Inventory data can be compared across jurisdictions; Clear evidence of collaboration;	<b>Chapter 2: Data collection and management</b>
<b>2 Jurisdiction-wide knowledge base of impacts and opportunities (health safety, environmental and socio-economic)</b>	No details available on safety, health or environment or socio-economic impacts;	Some knowledge has been gathered for some sites, but not whole jurisdiction;	Knowledge base exists for whole jurisdiction, gaps exist but a program is in place to address gaps	Most of the key knowledge gaps have been addressed with high quality documentation; National high risk sites and priorities have been identified;	Knowledge shared widely via detailed plans, published papers, peer reviewed reports;	
<b>3 Site specific data for high risk /priority sites</b>	No site specific data for individual sites;	Site specific data for 1 to 2 sites but little if any review or interpretation;	Priority sites have data collection programs with evidence of third party review/ interpretation	Interpreted reports on priority sites available; Evidence that new knowledge informs planning;	Sharing of information within government and across jurisdictions; Actively engaging stakeholders in knowledge gathering and management;	
<b>4 Leadership, legislation, policy and guidance to address AMs</b>	No policy or legislation to address abandoned mines; Responsibility unclear;	Legislation and policy for a few sites but not the whole jurisdiction;  Responsibility involves multiple agencies;	Policy and legislation addressing AMs exist, one agency leads coordination of program;  Regular performance reporting;	Policy and legislation implementation supported by toolkits, training and case studies which encourage innovation;  External technical expertise engaged on discipline-specific review and prioritization; Collaboration with other jurisdictions where impacts go beyond borders;	Wide stakeholder engagement ensures active involvement in AM management/remediation and/or post-mining land use; Evidence of beneficial post-mining land use; Peer reviewed published articles on AM program, its elements and case studies highlighting progress;	<b>Chapter 3: Risk Assessment and management</b>
<b>5 Leadership, legislation, policy and guidance to prevent new AMs</b>	Existing regulation of mines is weak or absent on rehab and closure;	Some regulations exist to prevent future abandoned mines, with little or no enforcement;	Range of legislative mechanisms applied to prevent AMs, such as incentives, bonds, rehabilitation/closure planning guidance and review processes;	Team of regulatory rehabilitation/ closure experts systematically auditing, and taking action at, high risk sites;	Continual improvement has eliminated future legacies defaulting to the state/ tax payers/community;	
<b>6 Risk assessment and prioritization of programs</b>	No evidence of a state/NT-wide risk assessment process;	Ad hoc risk assessment for some sites undertaken but not applied across whole jurisdiction to identify high risk features and sites;	Jurisdiction-wide risk assessment applied (features and whole mine risks able to be quantified), Control measures for significant risks included in implementation plan(s); Internal reporting on program;	Evidence that significant site/feature implementation plan is successfully being deployed; Performance evaluation methods defined; Public performance report on expenditure and risk/liability reduction;	Risks well understood and prevented, routinely the 'way we do business'; Little or no chance of unpredicted significant risks;	
<b>7 Abandoned mine program leadership and capacity</b>	No permanent personnel working on AMs;	Some permanent personnel and/or temporary personnel working on AMs, but role (s) shared with regulatory or other functions;	AM team 100% focussed on abandoned mine management, leading the program strategic planning and implementation; Skills and expertise aligned with roles;	Training program, succession plan and mentoring sustains AM team;	Other jurisdictions seek advice from this team because of the caliber of leadership;	
<b>8 Funding – sources, mechanisms and resources</b>	No funding for an AM program;	Base funding focused on specific sites over short time frames (up to 3 years);	Base funding and project funding for jurisdiction-wide program, able to plan ahead 3 to 10 years ahead;	Systematically reducing liability and reporting on performance; Regular reviewing of additional/ alternative funding mechanisms	Multiple funding sources, significantly reduced liability for state/community;	

9	<b>Beneficial post-mining land use</b>	No evidence of successfully managed or closed AM with beneficial post-mining land use;	Evidence of shaft capping programs which have successfully facilitated access to land by making safe;	Evidence of beneficial post-mining land use on 1 to 3 sites following implementation of remediation/closure plans, evidence of stakeholder acceptance;	through effective stakeholder engagement; Evidence of multiple AMs (> 3) which have been remediated /closed and have enabled beneficial land uses,  Innovation evident through active research program;	Leading practice AM management; Most closed sites returned to productive/beneficial land uses; Sharing of knowledge with related sectors (quarrying, waste management, etc); Iconic heritage sites listed on national heritage register;	<b>Chapter 1: Valuing abandoned mines</b>
10	<b>Heritage conservation – indigenous and industrial</b>	No evidence of heritage conservation integrated with AM program;	Indigenous and industrial heritage surveys and planning studies carried out on a few sites;	Heritage conservation management plans being implemented on all heritage listed sites; Evidence of indigenous engagement in closure planning;	Conservation/indigenous engagement integrated with rehabilitation, with specialists guiding works and training in-house personnel, research published;	Tourism entity functioning with multiple collaborators and funding streams;  Restoration of cultural heritage (indigenous) landscape features;	
11	<b>Secondary or complementary mining opportunities (industrial ecology)</b>	Heritage values harmed during shaft capping earthworks; No evidence of secondary mining projects at an AM in the jurisdiction;	1 to 2 examples of potential secondary mining or other activities which reduce liabilities at an AM (exploration and/or mining tenure);	Several (> 2) examples of secondary mining or other management arrangements which devolve site responsibility to a third party and reduce liabilities to the state by use of robust agreements; Secondary mining plans based on accepted standards;	Innovative projects reduce waste volumes at AMs via alternative uses of materials and improved re-processing techniques derived through research; Greatly reduced liabilities for the state;	Significant proportion of AM's have third party managers/users of site wastes/water with little or no ongoing responsibility or liability for the state;	
12	<b>Resourcing in partnership</b>	No evidence of partnering with other organizations on AM management;	Evidence of partnering on <2 projects on site specific activities;	Partnering on AM program at jurisdictional level, e.g. with another government department, industry, research organization or non- government organization such as heritage/historical, tourist entity;	Clear measures of success of the partnership with communication; Review by independent parties; Collaborative publication of program /case study updates;	Partnerships constitute a global leading practice example and other nation-delegations visit to learn from it;	<b>Chapter 4: Resourcing and partnership opportunities</b>
13	<b>Stakeholder engagement</b>	No evidence of jurisdiction-wide stakeholder engagement;	Stakeholder engagement occurs on a few sites of concern/interest;	Stakeholder engagement occurs through a regular cross-functional advisory group within government; Site specific stakeholder groups including industry professionals to inform planning and implementation;	Stakeholder advisory group including regional catchment bodies, provide input to AM program providing guidance on environmental values and priorities; External technical expertise engaged to review priorities;	Stakeholders involved at all stages, including review of performance and input to public performance reporting; Participatory monitoring methods employed widely;	
14	<b>Communication and networks</b>	No evidence of networks or communications across departments;	Web-page exists, provides overview of abandoned mine works, little evidence of networking	Cross-departmental communication and networks with other organizations; Cross-jurisdictional communication on challenges in common; Regularly updated webpage(s).	Regular newsletters and public communication on AM challenges and solutions engage stakeholder groups more widely with collaboration making efficient use of limited resources;	Communications linked to global networks with information sharing between jurisdictions and nations (developed and developing) via a range of mechanisms;	<b>Chapter 5: Info sharing and 'leading practice'</b>

AMs – abandoned mines.

relatively small land area) and compared their abandoned mine management framework and practice to British Columbia, Canada. Australia was chosen as a case study to evaluate our model because like many developed and developing nations, it has experienced recent growth in its mining and petroleum extraction sector yet does not have a national authority for managing abandoned mines. Furthermore, it is relatively straightforward to collect web-based information. The jurisdictional rankings were derived only from a range of web information sources as a way of evaluating the abandoned mine program information that is accessible to the general public.

The British Columbia Crown Contaminated Sites Program (BCCSP) was also assessed in our analysis as previous research has identified it as a benchmark for leading practice globally (Unger, 2009; Unger et al., 2012). This program has addressed the recommendations of various reviews including an audit by the Auditor-General (Office of the Auditor General of British Columbia, 2003). The BCCSP has evolved to a sophisticated program addressing a range of regulatory, personnel, information management, accountability and transparency challenges (Unger, 2009; BCCSP, 2012; 2014).

This web-based review was undertaken by a researcher with very little experience in abandoned mines to ensure that the rankings were not biased by inside knowledge of the industry. The scores for each jurisdiction and British Columbia were then plotted in a spider chart to provide a graphical representation of this multivariate data in two dimensions.

In addition to our independent evaluation, we requested self-evaluations from each jurisdiction. Only two self-evaluations were obtained in response to our request (South Australia and Tasmania). The self-evaluations provide a subjective method for evaluating the accuracy of the web-based review method.

Finally, a hierarchical cluster analysis was performed to provide an exploratory assessment of which jurisdiction had similar patterns in evaluative criteria and performance indicator scores. It provided a single descriptive method for summarising the rankings of 8 jurisdictions, 15 evaluative criteria and 5 performance indicator scores. The cluster analysis was conducted in R using the pvclust package version 1.2-2 (Suzuki, 2013).

## Results

### Information sources

The web-based information sources used in our review varied from dedicated web sites for jurisdiction-wide abandoned mine programs to information on abandoned mines specific to just one or two sites (Table 3). As the term 'abandoned mines' was not used by every jurisdiction, searches under other associated terms were

needed to locate relevant programs or site information (Table 3). This was the case for Victoria, for example, which yielded no information using 'abandoned mine', however the search term, 'contaminated sites', proved more effective revealing a reference to an audit by the Victorian Auditor General's Office (VAGO, 2011) with recommendations for two government departments as well as councils who are 'not effectively managing contaminated sites...'. Similarly, in British Columbia, the term 'contaminated sites' provided jurisdiction-wide information via the Crown Contaminated Site Program web site and associated biennial performance reports (BCCSP, 2012; 2014).

### Ranking

Our web-analysis found large variability in the maturity of abandoned mine programs for a range of evaluative criteria across Australia. Western Australia ranked highest (proactive – four) for criterion one (data and information management), due to their comprehensive WABMINES database (Strickland and Forbes; 2004), while having a score of zero for two other criteria (Fig. 2). A score of three was achieved by the Northern Territory for criterion five (Legislation, policy and guidance to prevent new AMs) due to the evidence of methods for prevention of mining legacies and detailed data on two particular sites, Mt Todd and Rum Jungle (DME NT, 2013). New South Wales and Tasmania had the highest average score of 1.7, however, this was not much higher than the overall average for jurisdictions in Australia at 1.5 and is thus well within the bounds of uncertainty associated with the web search method.

On average, Australian jurisdictions ranked lower than British Columbia for most categories with an average score of 1.5 versus 3.1, respectively. Our cluster analysis, which identified similarity in rankings for evaluative criteria, also showed that British Columbia is very distinct in comparison to Australian jurisdictions (Fig. 3). The clustering reflects not only the scores for the performance indicators but also the evaluative criteria in which each jurisdiction shows maturity. For example, the Northern Territory and Victoria are clustered as they had the lowest average scores of 1.1 and low values in similar criteria, while Queensland and Western Australia were also clustered as they both score highly in the foundational evaluative criteria.

All programs rated very low for criteria 10 (Heritage conservation – indigenous, cultural and industrial) and 11 (Secondary mining opportunities), including British Columbia, Canada. This does not mean these values were not being addressed at any sites. Rather – as with each of these scores – these results reflect the web-accessible information based on what a member of the public could find if they were searching for this information. The unexpectedly low score (3) for British Columbia's beneficial use of post-mining landscapes (criterion 9) in the context of the British Columbia Brownfield Renewal program (British Columbia Brownfield Renewal, 2014) is

**Table 3**  
Summary of web-based information sources.

Jurisdiction	Website information scale	Key search term	Summary of available information
<i>Australia</i>			
New South Wales	Jurisdiction-wide	Derelict mines	Program website; Current program of works
Northern Territory	Site-specific	Legacy sites	Site-specific programs (Mt Todd, Rum Jungle); Mine levy for AM management
Queensland	Jurisdiction-wide	Abandoned mines	Program website; Five site-specific programs; Two shaft-capping programs
South Australia	Site-specific	Abandoned mines	Program identified; Site-specific program (Brukunga)
Tasmania	Jurisdiction-wide	Abandoned mines	Program website; Policy, criteria for site prioritization, cross-functional engagement – trust fund committee.
Victoria	Site-specific	Contaminated sites	List of priority sites includes four former mines; no site-specific remediation details, jurisdictional audit reports
Western Australia	Jurisdiction-wide	Abandoned mines	Jurisdiction-wide inventory, mine rehabilitation fund
<i>Canada</i>			
British Columbia	Jurisdiction-wide	Contaminated sites	Program website; Performance reports

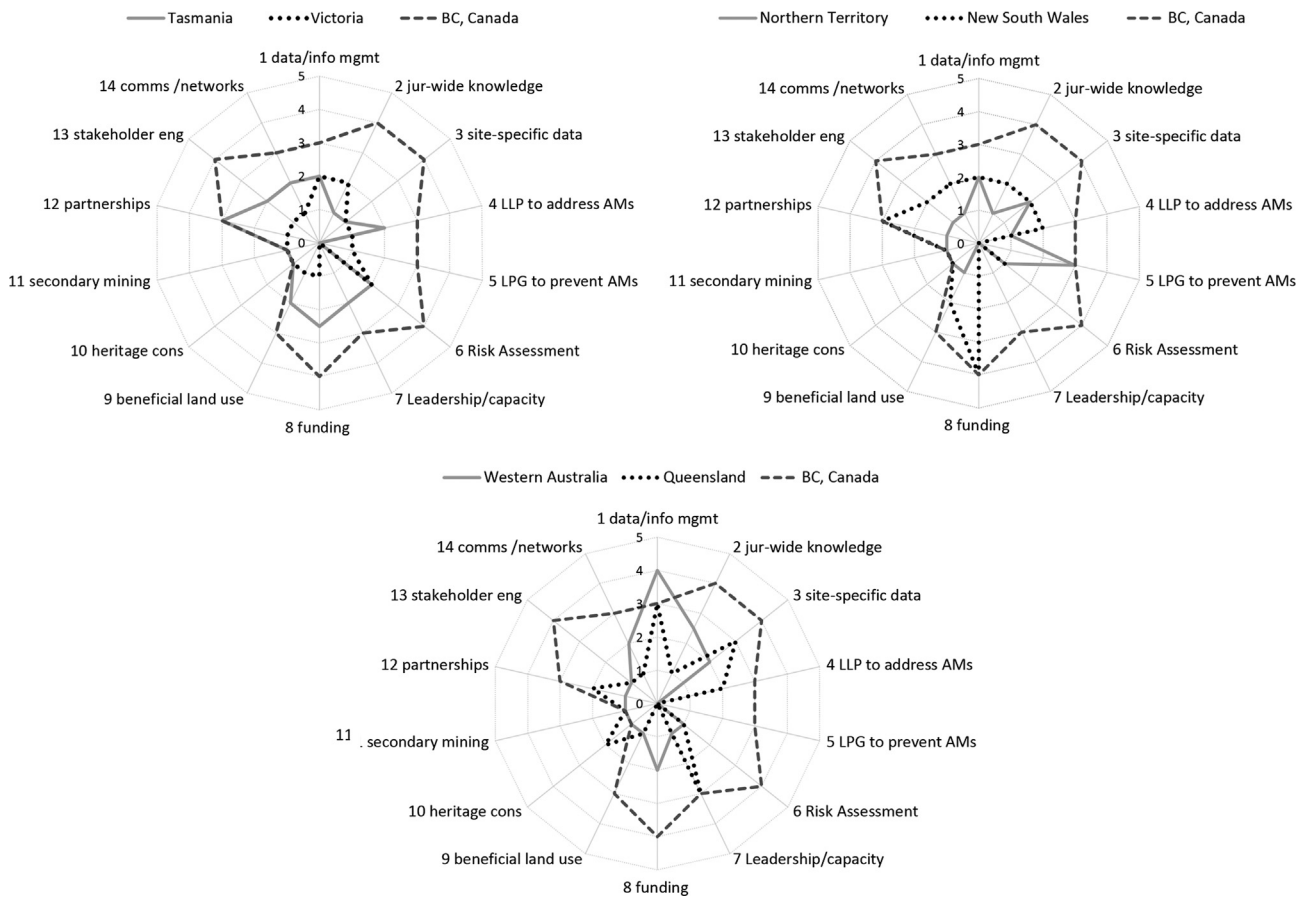


Fig. 2. Spider diagrams of jurisdictional maturity for abandoned mines for Australian jurisdictions and British Columbia (BC), Canada.

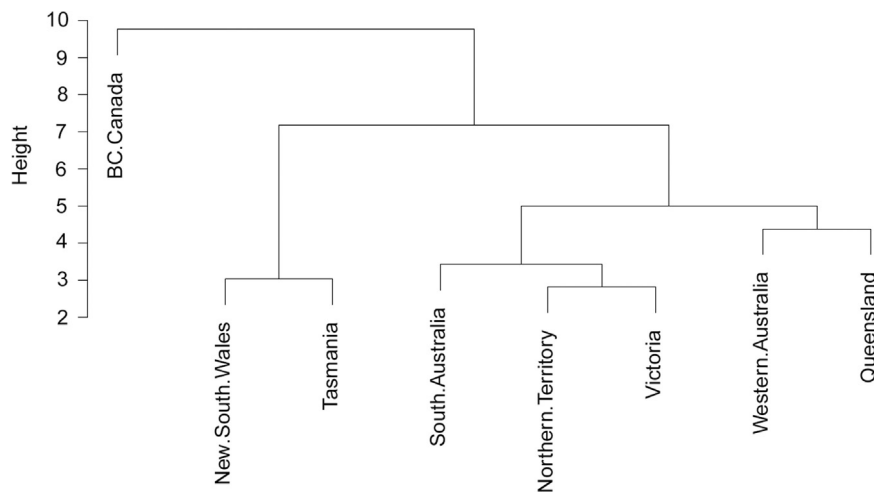


Fig. 3. Hierarchical cluster analysis of jurisdictional maturity for abandoned mines for Australian jurisdictions and British Columbia, Canada. Height indicates the degree of similarity between jurisdictions.

because this program was not found during the web-analysis, nor its connection to the Crown Contaminated Sites Program recognized. While some abandoned mines are included in the Brownfield Renewal program, many sites are other types of industrial sites located in urban areas where land values are higher than remote BC.

*Self-ranking*

While the web-analysis reflected information available to a member of the public, the self-assessments conducted by Tasmania

and South Australia showed that the independent assessment was only accurate for some of the evaluative criteria (Fig. 4). Both self-assessments resulted in higher overall scores as would be expected given that less information is available publicly. The difference between the self-evaluation and the web-based average scores was 1.1 and 0.6 for Tasmania and South Australia respectively. However, the difference between five out of the 14 evaluative criteria and seven out of the 14 criteria were less than 0.5 for Tasmania and South Australia respectively, demonstrating that many of the criteria were assessed reasonably with the web-based approach.

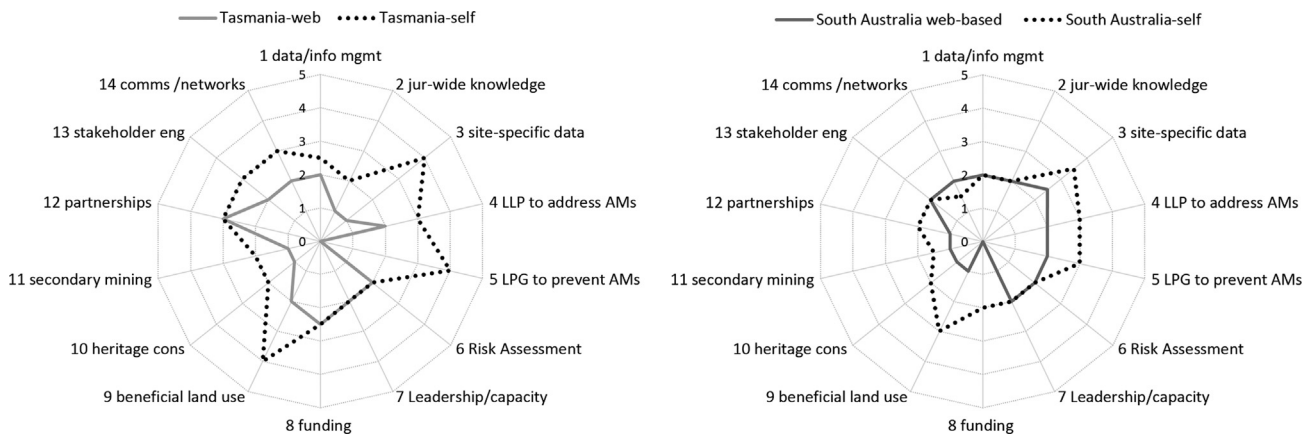


Fig. 4. Spider diagrams of jurisdictional maturity for Tasmania and South Australia comparing independent web-based assessment with self-assessment.

## Discussion

The abandoned mine maturity model presented in this research illustrates a novel application of the maturity model concept. It allows for the strengths and weaknesses to be identified in current approaches to abandoned mine management taken by each jurisdiction against current international practice. It also allows for performance evaluation of abandoned mine programs against the maturity pathway.

### Outcomes for Australian jurisdictions

The independent review based on web-accessible information made apparent that some Australian jurisdictions were more mature in some criteria than in others. In most cases, the British Columbia Crown Contaminated Sites Program was more mature than abandoned mine management under Australian jurisdictions. The variability in abandoned mine maturity over the range of evaluation criteria highlights that cross-jurisdictional dialog is likely to be beneficial. For example, the Western Australia abandoned mine mapping program resulted in a high score for criterion 1 (data and information management) and other jurisdictions are likely to benefit from their experience. While the average of all scores for Australian jurisdictions was 1.5, the average of the maximum scores for each evaluation criterion across all Australian jurisdictions was 3.2. This value is similar to the result for our leading practice benchmark of British Columbia, Canada (with an average score of 3.1). Therefore, sharing knowledge within Australia and linking jurisdictions to leading practices overseas would assist abandoned mine managers to continually improve towards leading practice.

For the criteria against which jurisdictions appeared weaker, the maturity model provides an indication of step-wise improvements that could be taken on the path to maturity. Furthermore, the evaluative criteria are ordered in a manner logically consistent with leading practice internationally and thus, effort should be prioritized towards strengthening program performance in the foundational evaluative criteria (i.e., starting with data/information management and establishing a jurisdiction-wide knowledge base). Deviations from this, indicated by high scores in upper-level criteria, may serve as a warning that the necessary preliminary information or program development has not been undertaken.

A key piece of information missing from most websites was the total liability from abandoned mines and methods of prioritization and risk assessment. It was not clear whether this liability was known or if the information was not released publicly. Where abandoned mine programs existed in Australia, the program expenditure *per annum* was also missing from their websites. As

a result, researchers and the public cannot easily assess how much of the total abandoned mine liability is being addressed each year and the scale of the problem. This is in contrast to some of the US and Canadian programs that have publicly available estimates (e.g. BCCSCP, 2012; Lovingood et al., 2004; Office of the Auditor General of Canada, 2002;). Risk and prioritization information commonly utilize estimates of site liability – together with environmental, safety and health risk data – to identify which mines to apply investigative focus. Investigations then identify the risk consequences and probability so that high risks are identified and given priority for remediation action. Site liabilities can then be estimated. The lack of liability reporting in Australia could represent the fact that investigations and risk rankings have not been undertaken. The absence of accurate estimates of abandoned mine liabilities indicates a significant shortcoming in abandoned mine management in Australia when compared with Canada.

While care was taken to review all publicly available web-based information, it is likely that this review underestimated maturity across jurisdictions and those jurisdictions that have emphasized transparency would have received higher scores. For the two cases in which jurisdictions self-evaluated, their evaluation scores were much higher. The web-based evaluation of South Australia appeared to more closely resemble the self-evaluation than Tasmania. Perhaps this was due to their advanced planning and investment for one site in particular, Brukunga, in South Australia which has involved remediation planning over many years, concurrent with water treatment (Department of Manufacturing, Innovation, Trade, Resources and Energy, 2013). In Tasmania, where Mineral Resources Tasmania are the lead agency for rehabilitation of abandoned mine lands, there appears to be greater jurisdictional planning with a cross-functional Trust Fund Committee to provide advice to the Minister on allocation of funds to abandoned mine remediation.

The web-based review makes assumptions based on the information provided on web sites. Wherever quantitative data was not available, subjectivity could have been a factor in the ranking. For example, during the ranking process, it was apparent that the researcher needed to know all of the possible terminology for abandoned mines in order to find relevant information. The search phrase 'abandoned mines' was not used by all jurisdictions, with jurisdictions using terms such as contaminated sites, legacy sites and derelict mines (Table 3). In some cases, there was no online inventory for abandoned mine sites. For example, few, if any, Northern Territory legacy sites were truly abandoned as they were often incorporated into mining tenure for current projects. Under the operator's Mine Management Plan and associated rehabilitation bond, the company would not become responsible for the pre-existing site liability until they undertook new mining



activities in former mining areas. However, this is not easy to determine from a web search. Thus, those programs that have a unified and dedicated program are likely to have higher rankings. Furthermore, the management of abandoned mines is constantly evolving and our trial of the maturity model represents the state of abandoned mine management in Australia as of July 2013 when the review was completed. Some jurisdictions have since made significant changes that may raise their scores against the evaluative criteria such as Western Australia ([Western Australia Department of Mines and Petroleum, 2014](#)) and Northern Territory ([Clayton Utz, 2013; Woollard, 2014](#)).

#### *Maturity model for monitoring and evaluation*

Through further testing and refinement, and with input from jurisdictional abandoned mine managers, the maturity model could be applied to jurisdictions globally to address gaps or weaknesses in policies, legislation and programs. Maturity models have successfully been applied in other areas globally. For example, maturity models have been applied to safety in the mining and other industries ([Commonwealth of Australia, 2008; Hancock, 2010; Hudson and van der Graaf, 2002; Westrum, 1993](#)). [Hancock \(2010\)](#) applied the maturity model to risk management of communicable diseases in the Papua New Guinean mining industry to provide a path for development. He stated that, “the maturity model can be used to heighten awareness of the strengths and weaknesses of an organization, to prioritise effort in organizational improvement activities and to provide a vision of mature application of the risk management process and the journey by which maturity may be attained”. Hancock’s applications of the model are similar to those outlined by [MacGillivray et al. \(2006 and 2007\)](#) which include use of the model: i) by the organization as a self-assessment tool; ii) by management and technical staff as a reference model; and iii) to evaluate contractors or partners.

The maturity model is just one of many monitoring and evaluation tools that may be applied to abandoned mines. An evaluation of the range of circumstances that have led to the occurrence of abandoned mines can provide useful context and knowledge to help inform current mining practices, regulation and policy to reduce the likelihood of them developing in the future. The monitoring and evaluation literature advocates that quantitative approaches be applied to program evaluation. Future research based on the principles of Utilization Focused Evaluation ([Patton, 2008; 2013](#)) could be used to further refine this maturity model. This approach focuses on the principle that an evaluation is most useful when assessed by its intended users and thus, jurisdictions should adapt our maturity model to their specific requirements.

#### *Integrating the maturity model with existing frameworks*

The maturity model could form the basis for achieving implementation of existing regulatory frameworks or policies that have been developed by jurisdictions at any level globally. Strategic-level documents lack the level of detail required for implementation and jurisdictions – particularly, but not exclusively, those in developing nations – may lack suitably qualified personnel to translate policy into workable plans with clear task prioritization. The maturity model presented here provides a hierarchical, step-wise guide to developing a robust abandoned mine management program. The model could also support the development of appropriate tools to assist knowledge sharing and progression of abandoned mine programs along the path to maturity based on the well-established monitoring and evaluation principles referred to earlier.

This paper demonstrates in the Australian context how a strategic framework could be developed into a maturity model through adapting the chapters of the strategic framework and leading

global leading practice into evaluative criteria. An implementation plan for the Strategic Framework is the next step in addressing abandoned mines in Australia and would provide minimum jurisdictional expectations to encourage convergence across jurisdiction boundaries and give rise to a consistent national approach, as has occurred for the National Mine Safety Framework ([MCMPR, 2009](#)). Targets would need to be set and performance measures agreed. It is anticipated that this maturity model could provide a foundation for this plan by enabling jurisdictions to map a path toward the leading practice programs. Gaps in knowledge, policy and legislation can then be systematically addressed for holistic programs to persist over time, including across changes of government. Inter-generational equity demands long-term persistence in abandoned mine programs.

## Conclusions

In this paper, we presented a novel application of the maturity model to jurisdictions managing abandoned mines to highlight the benefits of understanding key elements against which management inputs are required. Appropriate monitoring and evaluation tools, such as the maturity model, are needed to assess performance, while also supporting learning between jurisdictions that have responsibility for abandoned mines. This approach can improve efficiency and progress toward adoption of leading practices via information sharing. Applying our model to assess the performance of Australian abandoned mine plans and programs showed that Australian jurisdictions appeared to be at the foundational steps in addressing abandoned mines issues.

The complexities of abandoned mines and their potential for long-term impacts require that robust management programs be developed. Any jurisdictional abandoned mine program can potentially fail if a systematic approach is not taken to assessing outcomes in an objective and quantitative manner. These programs are also vulnerable to political involvement in decision making, particularly when economies contract. Robust programs that are strongly evidence-based ensure that the key risks and liabilities are identified, quantified and become the focus of remediation. National leadership to achieve a connection to global leading practices can bring innovative solutions to address impacts and harness the opportunities from those values that some abandoned mines have, such as industrial heritage values. Innovation in methods and collaboration can provide beneficial post-mining opportunities and sustainable local economies.

## Acknowledgments

The authors would like to acknowledge the support of colleagues, David Mulligan, Mansour Edraki and Ros Howse, during this research. We would also like to acknowledge the Centre for Mined Land Rehabilitation, The University of Queensland, for supporting this research.

## References

- BCCSCP, 2012. Crown Contaminated Sites Program (Biennial Report. Crown Land Opportunities and Restoration Branch). Ministry of Forests, Lands and Natural Resource Operations, Victoria, British Columbia.
- BCCSCP, 2014. Crown Contaminated Sites Program (Biennial Report. Crown Land Opportunities and Restoration Branch). Ministry of Forests, Lands and Natural Resource Operations, Victoria, British Columbia.
- British Columbia Brownfield Renewal, 2014. British Columbia Brownfield renewal Strategy, Crown Land Restoration Branch, Ministry of Environment, Land Remediation, Victoria, British Columbia. (accessed June 2014) ([www.brownfieldrenewal.gov.bc.ca/index.html](http://www.brownfieldrenewal.gov.bc.ca/index.html)).

- Caring for our Country, 2014. Monitoring, Evaluation, Reporting and Improvement (MERI), National Landcare Program, Australian Government, Canberra. (accessed June 2014). ([www.nrm.gov.au/funding/meri/](http://www.nrm.gov.au/funding/meri/)).
- Clayton Utz, 2013. Environmental levy to be imposed on Northern Territory Mines. (accessed August 2013). ([www.claytonutz.com.au/publications/news/201307/02/environmental\\_levy\\_to\\_be\\_imposed\\_on\\_northern\\_territory\\_mines.page](http://www.claytonutz.com.au/publications/news/201307/02/environmental_levy_to_be_imposed_on_northern_territory_mines.page)).
- Commonwealth of Australia, 2008. Risk Assessment and Management, Leading Practice Sustainable Development Program for the Mining Industry, Handbook. Department of Resources Energy and Tourism, Canberra ([www.ret.gov.au/resources/Documents/LPSDP/LPSDP-RiskHandbook.pdf](http://www.ret.gov.au/resources/Documents/LPSDP/LPSDP-RiskHandbook.pdf)).
- Davidson, J., 2005. *Evaluation Methodology Basics – The Nuts and Bolts of Sound Evaluation*. SAGE Publications, London.
- Department of Agriculture, 2009. Monitoring and Evaluation. Last reviewed 08 April 2009. (accessed June 2014). ([www.daff.gov.au/natural-resources/evaluation](http://www.daff.gov.au/natural-resources/evaluation)).
- Department of Manufacturing, Innovation, Trade, Resources and Energy, 2013. Brukunga Mine site, Water Monitoring Report, 2012. Mine Completion Program, Final Report, September 2013, Report book 2013/00012, EPA Licence 10577. South Australian Resources Information Geoserver, Department of Primary Industries and Resources, Adelaide. (accessed June 2014). (<https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/RB201300012.pdf>).
- DME NT, 2013. Former Rum Jungle Mine Site, Conceptual Rehabilitation Plan. Department of Mines and Energy, Northern Territory Government. (accessed February 2014). ([www.nt.gov.au/d/rumjungle/](http://www.nt.gov.au/d/rumjungle/)).
- Eden Project Post Mining Alliance, 2008. Background paper IUCN-ICMM Roundtable on the restoration of legacy sites. Eden Trust, Bodelva, Cornwall. ([www.postmining.org/documents/Roundtablebackgroundpaper.pdf](http://www.postmining.org/documents/Roundtablebackgroundpaper.pdf)).
- Esteves, A.M., Brereton, D., Samson, D. and Barclay, M., 2010. Procuring from SMEs in Local Communities: A Good Practice Guide for the Australian Mining, oil and gas sectors. Centre for Social Responsibility in Mining, University of Queensland ([www.csr.uq.edu.au/docs/4361%20CSR%20SME%20Report%20Email%20V2.pdf](http://www.csr.uq.edu.au/docs/4361%20CSR%20SME%20Report%20Email%20V2.pdf)).
- Fawcett, M., 2012. South Alligator Valley Legacy Uranium Site Remediation, International Atomic Energy Agency Training Meeting, Darwin, NT, August 2012. ([www.iaea.org/OurWork/ST/NE/NEFW/Technical\\_Areas/NFC/documents/uranium/tr-darwin-2012/Presentations/42.Fawcett\\_\(NT\\_DoR\)\\_Sth\\_Alligator\\_Valley\\_Case\\_study.pdf](http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/documents/uranium/tr-darwin-2012/Presentations/42.Fawcett_(NT_DoR)_Sth_Alligator_Valley_Case_study.pdf)).
- Foster, P., Hoult, S., 2013. The safety journey: using a safety maturity model for safety planning and assurance in the UK coal mining industry. *Minerals* 203 (3), 59–72. <http://dx.doi.org/10.3390/min3010059>.
- GAO, 2011. Information on the Number of Hardrock Mines, Cost of Cleanup, and Value of Financial Assurances (Testimony before the Subcommittee on Energy and Mineral Resources, Report no. GAO-11-834T). (Committee on Natural Resources, House of Representatives, July 14, 2011).
- Hancock, M.G., 2010. (A thesis submitted for the degree of Doctor of Philosophy at The University of Queensland in October 2010). Risk Management Systems for Communicable Diseases in the Papua New Guinean Mining Industry: Maturity Models – Paths for Development. Sustainable Minerals Institute (SMI), Brisbane.
- Hudson, P. and van der Graaf, G. C., 2002. Hearts and minds: the status after 15 years research. In: Proceedings of the International Conference on HSE in Oil and Gas Exploration and Production. Society of Petroleum Engineers (SPE 73941). Kuala Lumpur. March 2002, pp. 20–22.
- IIED/WBCSD, 2002. Chapter 10, Mining, minerals and the environment, Breaking new ground. Report of the Mining Metals and Sustainable Development (MMSD) Project, May 2002. Earthscan Publications, London. <http://62.50.73.67/DocRoot/ev8jEjvTiMYd4mJhGGHQ/finalmmsdreport.pdf>. (<http://pubs.iied.org/pdfs/G00902.pdf>).
- Kusek, J.Z., Rist, R.C., 2004. Ten Steps to a Results-based Monitoring and Evaluation System: A Handbook for Development Practitioners. World Bank, Washington, DC.
- Lechner, A.M., Baumgartl, T., Matthew, P., Glenn, V., 2014. The impact of underground longwall mining on prime agricultural land: a review and research agenda. *Land Degrad. Dev.*, <http://dx.doi.org/1.1002/ldr.2303>.
- Lovingood, T., Parker, B., Smith, T.N., Canes, H., Fennell, F., Cofer, D., Reilly, T., 2004. Nationwide Identification of Hardrock Mining Sites. United States Environmental Protection Agency (Report no. 2004-P-00005).
- MacGillivray, B.H., Hamilton, P.D., Hrudehy, S.E., Reekie, L., Pollard, S.J.T., 2006. Benchmarking risk analysis practice in the international water sector. *Water Pract. Technol.* 1 (2), 172 [https://dspace.lib.cranfield.ac.uk/bitstream/1826/2797/1/MacGillivray\\_Thesis.pdf](https://dspace.lib.cranfield.ac.uk/bitstream/1826/2797/1/MacGillivray_Thesis.pdf).
- MacGillivray, B.H., Sharp, J.V., Strutt, J.E., Hamilton, P.D., Pollard, S.J.T., 2007. Benchmarking risk management within the international water utility sector. Part I: design of a capability maturity methodology. *J. Risk Res.* 10 (1), 85–104.
- MCMR, 2009. National Mine Safety Framework, Implementation Report, Updated June 2009. Ministerial Council on Mineral and Petroleum Resources, Canberra. ([www.industry.gov.au/resource/Documents/Mining/NMSF-Implementation-Report-June2009.pdf](http://www.industry.gov.au/resource/Documents/Mining/NMSF-Implementation-Report-June2009.pdf)).
- MCMR/MCA, 2010. Strategic Framework for managing abandoned mines in the minerals industry. Ministerial Council on Mineral and Petroleum Resources, Canberra. ([www.industry.gov.au/resource/Mining/Documents/StrategicFrameworkforManagingAbandonedMines.pdf](http://www.industry.gov.au/resource/Mining/Documents/StrategicFrameworkforManagingAbandonedMines.pdf)).
- NSW government, 2011. Guideline MDG 1010: Minerals industry safety and health risk management guideline. Mine Safety Operations Branch. ([www.resources.nsw.gov.au/\\_data/assets/pdf\\_file/0010/419518/MDG-1010-Guideline-for-Minerals-Industry-Safety-and-Health-Risk-Management-Updated-Jan-2011.pdf](http://www.resources.nsw.gov.au/_data/assets/pdf_file/0010/419518/MDG-1010-Guideline-for-Minerals-Industry-Safety-and-Health-Risk-Management-Updated-Jan-2011.pdf)).
- Office of the Auditor General of British Columbia, 2003. Managing Contaminated Sites on Provincial Lands. Report 2002/2003: 5, British Columbia, Canada. ISBN 0-7726-4869-7.
- Office of the Auditor General of Canada, 2002. Report of the Commissioner of the Environment and Sustainable Development, Chapter 3 – Abandoned Mines in the North. ([www.oag-bvg.gc.ca/internet/English/par\\_cesd\\_200210\\_03\\_e\\_12409.html](http://www.oag-bvg.gc.ca/internet/English/par_cesd_200210_03_e_12409.html)).
- Owen, J.M., 2006. *Program Evaluation: Forms and Approaches*. Allen & Unwin, St Leonards, NSW.
- Patton, M.Q., 2008. *Utilization-Focused Evaluation*. Sage Publishing, Thousand Oaks.
- Patton, M.Q., 2013. Utilization-Focused Evaluation (U-FE) Checklist. ([www.wmich.edu/evalctr/wp-content/uploads/2013/03/UFE\\_checklist\\_2013.pdf](http://www.wmich.edu/evalctr/wp-content/uploads/2013/03/UFE_checklist_2013.pdf)).
- Petkova, V., Lockie, S., Rolfe, J., Ivanova, G., 2009. Mining developments and social impacts on communities: Bowen basin case studies. *Rural Soc.* 19, 211–228.
- Queensland Flood Commission of Inquiry, 2012. Chapter 13 Mining, Section 13.8 Abandoned mines. Queensland Government, Brisbane. ([www.floodcommission.qld.gov.au/\\_data/assets/pdf\\_file/0017/11717/QFCI-Final-Report-Chapter-13-Mining.pdf](http://www.floodcommission.qld.gov.au/_data/assets/pdf_file/0017/11717/QFCI-Final-Report-Chapter-13-Mining.pdf)).
- Strickland, C. and Forbes, M., 2004. Field Inventory of Abandoned Mine Sites in Western Australia, LinksPoint White Paper, Links Point, Inc. ([www.linkspoint.com/docs/GSWA\\_Mines\\_White\\_Paper.pdf](http://www.linkspoint.com/docs/GSWA_Mines_White_Paper.pdf)).
- Suzuki, R., 2013. Package 'pvclust': Hierarchical Clustering with P-Values via Multiscale Bootstrap Resampling. ([www.cran.r-project.org/web/packages/pvclust/pvclust.pdf](http://www.cran.r-project.org/web/packages/pvclust/pvclust.pdf)).
- Unger, C., 2009. The James Love Churchill Fellowship to study leading practice abandoned mine rehabilitation and post-mining land use projects in Austria, Germany, England and Canada. Winston Churchill Memorial Trust, Canberra. ([http://www.churchilltrust.com.au/media/fellows/UNGER\\_Corinne\\_2009.pdf](http://www.churchilltrust.com.au/media/fellows/UNGER_Corinne_2009.pdf)).
- Unger C. J., Lechner A. M., Glenn V., Edraki, M. and Mulligan, D. R., 2012. Mapping and prioritising rehabilitation of abandoned mines in Australia. In: Proceedings of the Life of Mine Conference 2012, CMLR/AusIMM, Brisbane.
- Unger C. J., Lechner A.M., Walton A., Glenn V., Edraki, M. and Mulligan D. R., 2014. Maturity of jurisdictional abandoned mine programs in Australia based on web-accessible information. In: Proceedings of the AusIMM/CMLR Life-of-Mine 2014 Conference, Brisbane.
- VAGO, 2011. Managing Contaminated Sites December 2011 PP No 90, Session 2010–11. Victorian Auditor-Generals Office, Melbourne. ([www.audit.vic.gov.au/publications/20111207-Contaminated-Sites/20111207-Contaminated-Sites.html](http://www.audit.vic.gov.au/publications/20111207-Contaminated-Sites/20111207-Contaminated-Sites.html)).
- Waggiit, P. W. and Fawcett M. N. R., 2008. Uranium mine rehabilitation in the Gunlom Land Trust, Northern Territory, AusIMM Bulletin No. 3 May/June 2008, pp. 52–58.
- Westrum, R., 1993. Cultures with requisite imagination. In: Wise, J.A., Hopkin, D.V., Stager, P. (Eds.), *Verification and Validation in Complex Man-Machine Systems*. Springer, New York, ISBN: 978-3-662-02933-6, pp. 401–416.
- Western Australia Department of Mines and Petroleum, 2014. Mining Rehabilitation Fund (MRF). (accessed March 2014). ([www.dmp.wa.gov.au/19344.aspx](http://www.dmp.wa.gov.au/19344.aspx)).
- Woollard, J., 2014. Overcoming the challenges of legacy mines in the Northern Territory, AusIMM Bulletin. 3 June 2014, pp. 55–56.