

Some histories of mine closure, the idea

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Abstract

Mine closure, the idea. Where did it begin and how did we develop our current understanding of the associated technical, environmental and social challenges? This paper will present three histories of mine closure, developed using different methods and leading to somewhat different conclusions.

The first history examines societal factors that contributed to the early ideas about mine closure. It uses the normal methods of historical research, specifically review of primary and secondary written sources, and focuses on how both competing resource uses and the development of environmental movements led to early mine closure legislation.

The second history addresses scientific and technical developments related to mine closure. It uses a method known as bibliometric mapping. Over 4,000 technical references related to mine closure were collected and analysed by a series of text-mining, statistical and graphical techniques. The results show the growth in the field as a whole from the 1960s to the present day, and also the shifts in emphasis from reclamation to more holistic closure, from the major element composition of affected waters to various minor and trace elements, and from bio-physical and chemical effects to socio-economic concerns.

The third history reviews the development of mine closure practices over the last twenty years. It draws on concept mapping exercises completed by mine closure experts in 1998 and again in 2006. It shows the transition from isolated specialties to a mature discipline, complete with higher level management processes, continuing growth in technical fields, and new interests in stakeholder and sustainability issues.

Even these three approaches together do not constitute a complete history. But perhaps they will enrich our understanding of how the idea of mine closure has changed and continues to change over time and in different parts of the mining industry.

1 Introduction

The website for this conference lists approximately 110 accepted papers. Judging by titles only, over half of them will provide at least a partial history of a mine closure project. But most of us do not think of our work as history. Even the case studies typically include only a summary of facts and dates, just a bridge to get us quickly to what we see as worthy of discussion with our peers. The main focus of each paper is typically a technology, or more broadly a methodology, that we hope will be relevant to other mine closures.

As we will show later, the presentations over the next few days will add to a body of mine closure literature that now includes over 4,000 papers. There are also over 500 delegates at this conference. If each of us can name ten colleagues or associates who work in this field but are not here, the population of mine closure practitioners numbers in the thousands. And as some of your papers will make clear, mine closure is a subject of keen interest to many other stakeholders, including environmentalists, regulators, investors, mine employees and of course affected communities.

Should we continue to believe that our work in mine closure is purely the story of ever improving methodologies? Certainly many individuals with a purely technical or socio-economic focus continue to make very significant contributions to mine closures. The remainder of this paper will seek to advance the question of whether there really is anything more than that.

2 Historical approach (1870 to 1980)

If we accept that mine closure is a historical phenomenon, it is appropriate to apply the normal methods of historical research, specifically review of primary and secondary written sources. But it is important to recognise that our topic is an idea, the idea of mine closure, rather than a particular event or series of events. It is in the nature of ideas that they are conceived, possibly independently by several individuals, and then communicated, understood, misunderstood, debated and further developed by many other people. A significant additional complication is that the idea of mine closure has developed differently by region and by industry sector. We will not succeed in writing the comprehensive history of all that. Instead we will attempt to present *a* history, and hope that future efforts will fill in any critical themes that we miss.

The history that we present focuses on the United States between roughly 1870 and 1980. That period is bounded by the earliest recorded legal dispute about mining impacts on the surrounding environment, and the rapid development of federal and state mine closure legislation.

2.1 Early concepts of mine reclamation (1870s to 1930s)

Even the earliest documents about mining indicate an appreciation for what we would now call “environmental impacts.” Agricola’s *De Re Metallica*, first published in 1556, included statements such as the following:

When the woods and groves are felled, then are exterminated the beasts and bird, very many of which furnish a pleasant and agreeable food for man. Further, when the ores are washed, the water which has been used poisons the brooks and streams, and either destroys the fish or drives them away. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers, find great difficulty in procuring the necessaries of life.

But efforts to do something about these impacts appear to be a relatively recent phenomenon. In the United States the late nineteenth and early twentieth centuries saw an increase in the use of larger-scale mining methods like hydraulic mining, dredging, and strip-mining. At the same time the growth of communities and other uses of the land meant that mines had direct impacts on landscapes and water uses valued by others. The most important and vocal of these others in the early years were farmers whose lands were directly disrupted by mining.

The legal dispute that arose from hydraulic mining of gold in California’s Sacramento Valley offers a well-documented example. In the 1870s and 1880s, the damage caused to farmland became so great that it prompted farmers to take legal action against the miners. It was the first legal case of its nature in the US, and quickly escalated into acts of bribery, sabotage, and violence. Legislation intended to create a compromise set up a tax funded program to reclaim the affected rivers and help in the construction of dams and levees. However, it failed to resolve the conflict and, after several further court processes, the issue had to be settled by a federal judge in 1884. The farmers, who would settle for nothing less than a ban on hydraulic mining, won a clear victory when the federal court ruled that discharge of tailings into the river was a “destructive public and private nuisance” and, ultimately, unlawful (Kelley, 1959).

The situation in Sacramento Valley is indicative of most early opposition to mining impacts. It was not motivated by the environmentalism that we know today, but by competition over resources. There were debates about the moral obligation of a miner to avoid damaging the property of others and whether or not the prosperity of a few miners should outweigh the livelihood of several hundred others. But fundamentally the farmers went to court to protect their property rights and their livelihood (Kelley, 1959).

Early efforts to reclaim closed mines were underway by the early twentieth century. By the 1920s articles were being published on the scientific reclamation of the strip-mined lands (Croxtton, 1928; McDougall, 1925). But by the late 1930s, reclamation was still largely experimental and limited to the planting of trees

(Plass, 2000; Holmes, 1944). And where reclamation of closed mines was substantial, it was entirely focused on making the land economically useful (Morrissey, 2010).

2.2 Appalachian strip-mining regulation and reclamation (1930s to 1960s)

The Appalachian coal sector in the eastern United States provides a good example of how mine closure transitioned from being the concern of a few directly affected individuals to an issue of national importance. Surface coal mining in Appalachia began in the late 1800s, but had limited impacts. The introduction of steam shovels, then electric shovels and draglines, led to a fivefold expansion in “strip mining” over the period 1900 to 1930 (Montrie, 2003).

As with prior disputes, the conflict over strip mining began with directly impacted farming communities. In this case however, they were quickly joined by others whose livelihood was threatened, specifically businessmen and deep-coal miners who together argued that strip mining undermined the regional tax base and put deep miners out of work. The efforts of these groups did culminate in State legislation requiring reclamation of mine-impacted lands. West Virginia was first in 1939, followed by Indiana in 1941, Pennsylvania in 1945, Ohio in 1948, and Kentucky in 1954. Each state implemented its own set of regulations, but common requirements were that the land be left smooth enough for agricultural tillage, that miners post financial security to cover the cost of reclamation, and that there be penalties for violations. Unfortunately enforcement of the State regulations was variable, to put it mildly, and actively compromised in some states (Montrie, 2003; Plass, 2000; Brooks, 1966).

There were also those who defended strip mining and rejected calls for regulation. A 1940 article explained how resourceful land owners had successfully transformed strip-mined land into productive uses. In one example the land owner created a successful hunting ground, while in another a recreational park was built, both without any substantial reclamation by the coal company (Hall, 1940). Concerns over the economic impacts of excessive regulation were also a common theme (Brooks, 1966).

2.3 Civil protest and federal legislation (1960s and 1970s)

In the 1960s, grassroots opposition to Appalachian strip-mining strengthened. Farmers, local businessmen and deep miners were joined by conservationists and sportsmen, or environmentalists and recreational hunters and fishers in today’s terminology. Well organised cells of opposition emerged, many of them calling for an outright ban on strip mining. Environmentalists wrote articles, both academic and popular, on the need for further regulation (Mink, 1976; Udall, 1979). Hunting and fishing groups, often including influential public figures, were supported by national entities like the Sierra Club. As the movement gained steam, calls for outright abolition of strip mining became common (Montrie, 2003).

There had been occasional calls for federal regulation of the Appalachian coal sector since the 1940s, but the pressure for federal action reached a peak in the early 1970s. State laws were no longer seen as adequate. They were insufficiently enforced, caused unfair competition across states, and failed to distinguish between private, state, and federally owned land (Schechter, 1980). The first significant discussion of federal legislation took place before the House Interior Committee in 1971. A surface mining control bill was introduced in 1973, but vetoed by President Ford. A similar bill was approved by Congress in 1975, but again vetoed by President Ford. Ford justified his vetoes with arguments that the act would cause a loss of jobs, raise consumer prices, make the US more reliant on foreign oil, and unnecessarily reduce coal production (Mink, 1976).

In 1977, the new President Carter passed an updated version of what is now known as the Surface Mining Control and Regulation Act or SMCRA. But the successful passage of SMCRA in 1977 was not simply a result of presidential change. An additional factor was the willingness of its supporters to lessen their demands. Leaders of the pro-regulation movement dropped calls for banning strip mining and settled for a more realistic compromise. Therefore the bill passed by Carter was significantly less restrictive than those vetoed by Ford (Montrie, 2003). Nonetheless it included many of the components of modern mine closure

legislation, including requirements to restore land to pre-mining conditions, protect water courses and water quality, and post financial security.

Ending this historical review with SMCRA is not intended to imply that it represents the last stage of legislative interaction with the idea of mine closure. On the contrary, the 1970s, 80s and 90s saw the development of mine closure legislation in many other jurisdictions. By the early 2000s review articles could list nine western US states, nine Canadian provinces and territories, and 45 other countries that had some form of mine closure legislation or regulations (Berger, 2002; Clark and Clark, 2005). Requirements and enforcement varied significantly, but there was enough common ground that it was possible to talk in terms of clear trends and generally agreed principles (MMSD, 2002).

Perhaps more importantly, this brief history illustrates how the interplay between increasing mining impacts, competition from other land and water users, and broader environmental concerns has shaped modern ideas about mine closure. We believe this process has parallels in many other regions and mining sectors.

3 Bibliometric analysis (1960 to 2010)

Histories such as the above allow insights about the early development of mine closure as a concept, but how do we track development of an idea that has since come to involve hundreds or thousands of practitioners? One option is to resort to meta-analysis using methods that are being developed in the fields of bibliometrics and text mining. In general these methods seek efficient ways to identify patterns or major themes in large bodies of written material.

To apply this approach to the idea of mine closure, the authors gathered over 4,000 articles published over the period from 1900 to 2010. Roughly half of the articles were published in refereed journals and half in conference proceedings. Numbers were not statistically significant in many of the early years, so analysis was focused on the period after 1960. However, to link back to the previous section, it is worth noting that over 170 articles on mine reclamation and over 200 on acid mine drainage were published before 1960.

The first step in the text mining was to assemble the “corpus” or body of documents. The library databases GEOBASE and GeoRef proved to be good sources for journal articles, but many conference proceedings needed manual searching and input. The reference management programs RefWorks and Zotero were used to organise the assembled results into author, title, publication information, abstract, and key word fields, and remove any duplicates arising from the different searches. The software WordStat (Provalis Research) was used to transform the text fields into data that could be analysed by statistical methods. The statistics were then further analysed using MS-Excel and a clustering and visualisation tool known as VOSviewer (Van Eck and Waltman, 2007; Waaijer et al., 2010).

Figure 1 shows the most basic statistic, namely the number of mine closure articles published per year. The raw data is quite variable, so the smoothed curve gives a better perspective. The number of papers in the scientific literature as a whole is estimated to double every 15 years. The number of articles related to mine closure grew significantly faster than that, reflecting the very rapid growth of the field, especially through the 1990s.

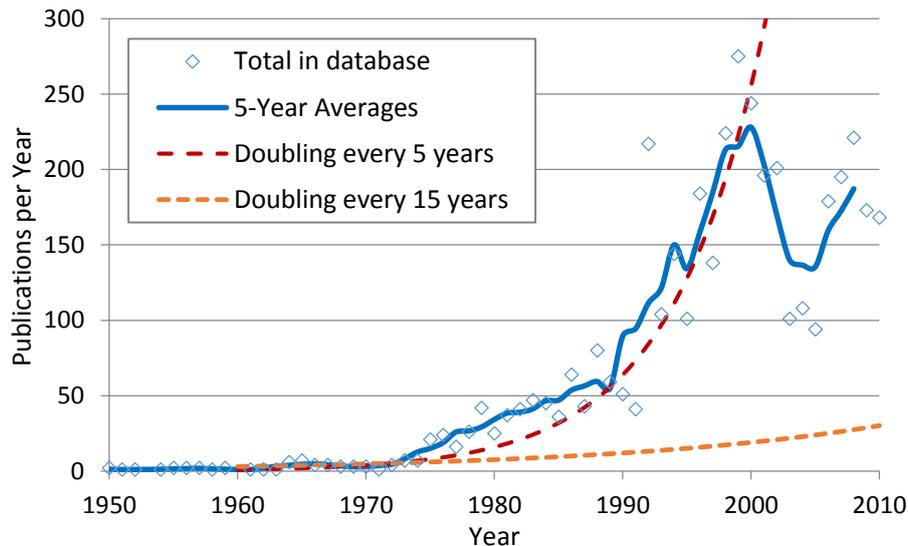


Figure 1 Rates of growth in mine closure literature (1950 to 2010)

Figure 2 shows another interesting trend, the shift over time from use of the term “reclamation” to “closure” and more recently “remediation.” There are at least two underlying reasons. First the field has clearly shifted away from a focus on land reclamation to a more balanced consideration of physical, chemical and socio-economic factors that are incorporated in the term “closure.” Second, increasing emphasis on chemical contamination has led to mine sites being thought of as problems needing “remediation.” External factors also contribute to these trends, such as the development of more holistic mine closure guidelines in some areas and contaminated sites legislation in others.

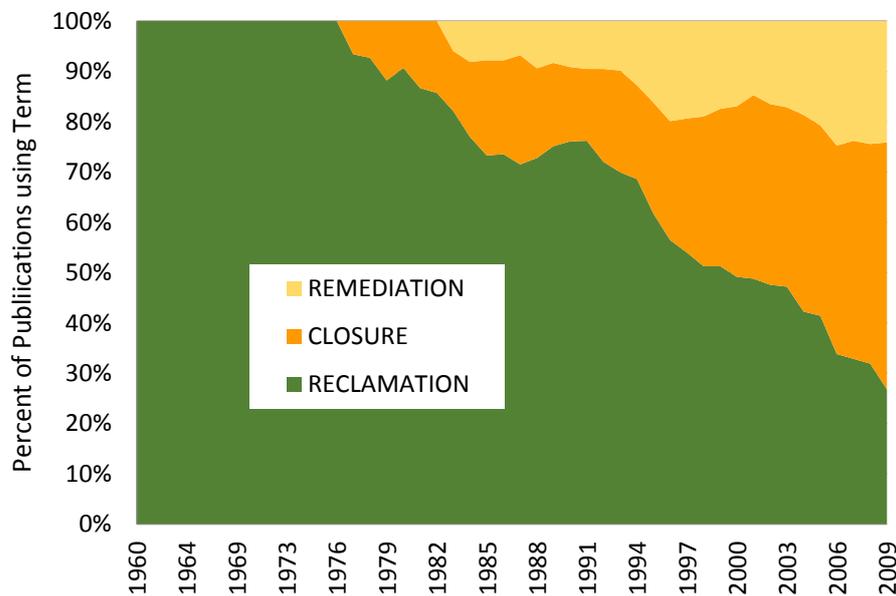


Figure 2 Trend in uses of the terms “reclamation”, “closure” and “remediation”

Figure 3 shows the frequency of contaminant names in the mine closure literature. For clarity, only a few contaminants are shown. But the full data show a growing interest in major element chemistry and acidity in the 1980s, followed by metal contaminants in the mid-1990s, and continuing through progressively more “exotic” minor metals and oxyanions in recent years.

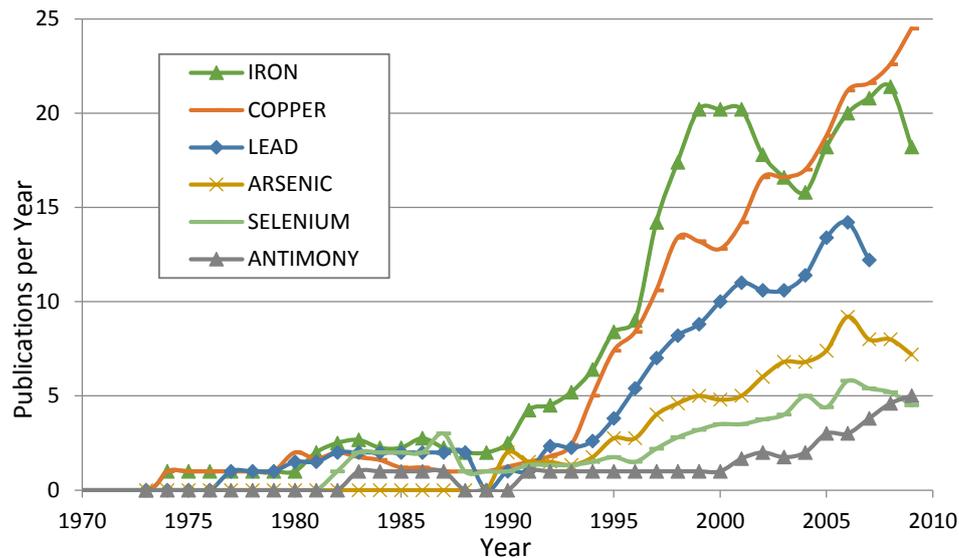


Figure 3 Trend in contaminants discussed in mine closure papers

All of the above examples arise from analysis of individual factors. The true power of text mining is clearer when two-factor and multi-factor interactions are examined. For example, the two-factor analyses of location and commodity type show the growing regionalisation of mine closure issues. Papers about the closure of precious metal mines are widely distributed geographically, but papers on the closure of coal mines are primarily from the US east and midwest, papers on iron and aluminium mine closures are primarily from Australia, and papers on uranium mine closures are primarily from Canada and Europe. In most cases these patterns reflect the historical development of mining in these regions, but large projects that generate many papers also skew the numbers.

Figure 4 presents the results of a multi-factor cluster analysis. It displays individual papers as numbered dots positioned so that more similar papers are closer together, and with a coloration to indicate the main groupings. This result and many others like it indicate dominant themes associated with the idea of mine closure, and how they change over time.

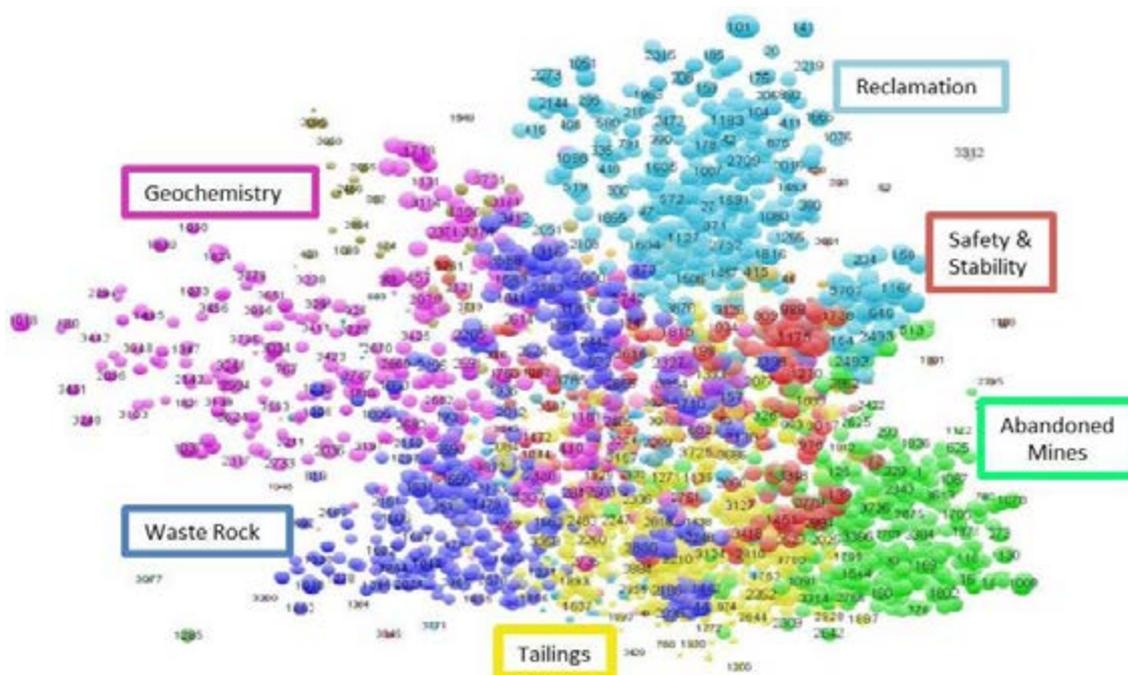


Figure 4 Cluster analysis of 4000 mine closure articles: labels indicate theme of each cluster

4 Mapping expert knowledge (1998 to 2015)

One weakness of bibliometric methods is that they look at quantity of publications and do not easily account for differences in quality. For mine closure, there has been exponential growth in the number of papers being published, but has there been exponential growth in knowledge? Here we use the term knowledge to imply something that is greater than data or information, and capable of being put to practical use.

A measure of mine closure knowledge can be gained by polling experts in the field. In 1998, SRK gathered twenty senior professionals from around the globe to create a “mine closure knowledge map” that sought to represent all of the areas of expertise related to the practice of mine closure. That exercise was repeated in 2006 and the two resulting knowledge maps provide another set of insights into development of the idea of mine closure.

Very briefly, the knowledge maps were constructed in facilitated workshops. In the heart of each workshop, subject matter experts selected a topic related to mine closure, gave it a simple name and a one-sentence definition, and then created lists of inputs, outputs, typical subtasks, and example projects. Table 1 shows a typical topic description. The topic descriptions were then grouped and sub-grouped, and assembled into a two-dimensional map.

The initiative started without the assistance of professional knowledge managers, but the approach meets most formal knowledge management criteria. Specifically the mapping is a form of classification system or taxonomy, the descriptions represent a vocabulary, together with the logical input-output relationships they form an ontology, the project examples serve as a bibliography, and the project contact lists create an expert directory. As SRK has been one of the most active consulting groups working in mine closure during this period, the maps represent a reasonable perspective on the development of mine closure knowledge.

Table 1 Example topic description from mine closure knowledge map

Content type	Example content
Topic	Pit backfilling
Summary description	Backfilling of waste rock into a pit to reduce surface impacts, place potentially acid generating material below the water table, and/or prevent formation of a pit lake
Key input links	Geochemical characterisation of waste rock Pit volume capacity curves Site water balance and site hydrogeology
Key output links	Backfill volumes Requirements for alkalinity addition or other treatment Control program, including long term planning, short term ... Water quality prediction ...
Subtasks	Assess geochemical characterisation of waste ... Design program for short term control of backfilling ...
Example projects	Flambeau Mine, Wisconsin – Project F107108 Lichtenberg Pit, Germany – Project W104108
SRK Contacts	Daryl Hockley, Vancouver John Chapman, Brisbane

Of most interest for this paper is how the mine closure knowledge map has changed over the period since 1998. The rapid development of the field required that the entire map be re-organised in 2006, but it is convenient to use the “continents” of that map and ask what “regions” were added or heavily modified between 1998 and 2006.

At the highest level of the current map, the categories are closure strategy and planning, closure management, closure methods and technologies, and closure investigations. None of these are completely new, but two of them were not initially considered high level categories. By 2006, closure strategy and planning included many sub-categories, ranging from the development of corporate closure policy to the assessment of methods to involve stakeholders in closure decisions. In broad terms these are higher level or second order functions that typically accompany the maturation of a complex field. The closure management category was also significantly expanded by 2006, and now includes a range of systems that are typical of large project management in other fields. Many of those systems were put in place as a response to problems encountered when ambitious closure plans first began to be fully implemented.

Changes at lower levels of the map are too numerous to list. A clear pattern is the increasing number and level of detail related to investigation methods. Significant advances are also apparent in areas driven by external pressures. A good example is the improvement in methods for estimating mine closure costs, driven in part by recognition that closure costs are material, but also by changes to both financial security requirements and international accounting practices. A second example is the significantly greater emphasis on communities, both as participants in closure decisions and as a key factor in post-mining sustainability. Perhaps surprisingly, the number of truly new closure technologies is quite limited, except perhaps under the category of water treatment.

Another theme that is apparent in the map development is the extent of interaction with other disciplines. Adjacent knowledge maps for fields like geochemistry and mine planning have always shared borders with mine closure, but the extent of overlap has increased. Whether this is a reflection of a more holistic approach to mine development or simply an artefact of growth in the various disciplines is one of the interesting questions worthy of further debate.

5 Conclusions

These three analyses, a selective historical review, text mining of the technical literature, and review of knowledge mapping by expert groups, paint an admittedly incomplete picture of the history of mine closure, the idea. Despite these limitations, the methods provide a number of insights into how the concept has changed, and continues to change today. A few broad patterns that emerge are:

- Requirements for mine closure became a subject of contention in the late nineteenth and early twentieth centuries, in particular where the scale of mining impacts began to threaten other uses of land and water.
- Continuing growth in the scale of mining, the weakness of initial regulatory efforts, and increasing environmental awareness led to the development of comprehensive mine closure requirements in the 1960s and 1970s.
- Mine closure legislation spread around the globe in the 1980s and 1990s, and the range of topics considered part of mine closure expanded from surface reclamation and water use to include much broader environmental protection and remediation.
- Technical literature related to mine closure experienced a boom in the 1990s and early 2000s, and the field took on many of the characteristics of a mature discipline, including the development of guidelines, procedures and higher level management processes.
- The range of considerations, implications and requirements related to mine closure continues to expand, with notable recent examples being the increased attention given to stakeholder input and the sustainability of mining-affected communities.

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