Potential environmental and social-economic impacts from neglected mining occurrences in Victoria, Australia

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ABSTRACT: Victoria has a proud history of mining which helped create some of the largest goldfield cities in Victoria including Ballarat and Bendigo. Although historic mines over the past 100+ years had substantial benefits to Victoria's economy, they leave behind legacies such as pollution and hazards due to the historic lack of regulation and rehabilitation. This report combines multiple mine/quarry databases and categorises the mineral occurrence sites into a mining occurrence hierarchy using GIS spatial analysis. The combined mineral occurrence database is then used to find relationships and distances against different spatial maps including vegetation, water streams, population and infrastructure. The results showed that spatial analysis of neglected mines at a State scale can be useful for identifying areas that are potentially impacted by neglected mines, and can be used to prioritise further research.

1 INTRODUCTION

From the influx of population during the Victorian gold rush in the late 19th century; to the electricity created from brown coal mines in the La Trobe Valley; mining has played an important part in shaping Victoria. Excluding coal, mineral extraction in Victoria produced a total sales value of 641.2 million dollars (State Government of Victoria, 2017c). This does not include the economic benefit associated with the mining industry, including the Government fees, royalties/taxations, jobs created and the minerals end use.

Although mining in Victoria creates vast benefits to the State economy, it can also bring about negative environmental effects that can last up to 100 years after the mine has finished production. Mines that have received little to no rehabilitation can be a substantial risk towards the environment, community, and economy. The potential damage caused by unrehabilitated mines depends on the mine characteristics and the surrounding environment. These unrehabilitated mines can cause issues and hazards such as leftover tailings, acid mine drainage and an increased risk in land subsidence. Unrehabilitated quarries that are mined for sand, stone and clay are not exempt from any risk or environmental concern. Leaving legacies such as unstable cliff edges, poor vegetation and exposed surfaces that may contain acid sulphate soils. Mines and quarries that are inactive and have not been terminated are known as a neglected (including abandoned or legacy) site.

The negative impacts of neglected mines and quarries in Victoria is relatively unknown due to; the lack of data that was obtained during mining operation; the lack of historic regulatory framework for rehabilitation; and the lack of understanding of local environments surrounding the mining occurrences. The exact number of neglected mines in Victoria is difficult to quantify due to many unrecorded historical workings. Unger *et al* (2012) found that Victoria had approximately 19,000 neglected mines and across Australia there were more than 50,000. Neglected mines are not just Australian issues but worldwide with the United Kingdom and Canada both having just over 10,000 neglected mines (Worrall, Neil, Brereton, & Mulligan, 2009).

This report aims to combine multiple mine and quarry databases to help quantify and find the status of mining occurrence sites. Spatial analysis will be used to help find areas in Victoria that may have potential negative impacts caused from neglected mines and quarries. This is done through the analysis of multiple spatial maps and datasets using Geographical Information System (GIS) mapping software.

2 METHOD

2.1 *Victorian mining occurrence database*

2.1.1 *Mining occurrence database resources*

The Victorian mine and quarry database was created using various internet sources including publicly available Victorian Government Resources and datasets (State Government of Victoria, 2017h) shown in Table 1. The *Features of Interest (FOI)* dataset was changed from a polygon to a point source to ensure all mapped mines were point coordinates. The two heritage datasets and the *FOI* dataset (Table 1) contained various sites irrelevant to mining. For the *FOI* dataset sub-categories were present and the mines and quarries could be filtered. The two heritage datasets had no information to distinct between a mine, quarry or another heritage site therefore keywords such as "mine", "shaft" and "quarry" were used on the points to filter out the mining occurrence sites. Some obvious double-ups (same name and location) were deleted to a single site in the combined database hence Table 1 and Figure 1 site counts not being consistent.

Table 1. Mining occurrence datasets that were used to create a combined database. All datasets were from 'data VIC' (State Government of Victoria, 2017a) apart from the Australian Mine Atlas (Australian Government, 2015).

Dataset Name	Mine/quarry points	Date dataset last updated	Status Information	Commodity Information	Dataset Accuracy
Mines and Mineral Occurrences	17844	30/1/2017		✓ (Incomplete)	1m to 5km
Features of Interest	3141	1/1/2017	✓		10m
Heritage Inventory	2060	1/1/2017	✓	*	0.1m
Heritage Registry	115	1/1/2017	✓	*	0.1m
Australian Mine Atlas	16	1/1/2014	✓	✓	Unknown

*Commodities can be found on the Victorian Heritage website (Victorian Heritage Council, 2017)

2.1.2 *Mining occurrence status and definitions*

The word "neglected" in this report has been adapted from the Canadian National Orphaned/Abandoned Mines Initiative definitions (NOAMI, 2004) and defined as a "mine or quarry site that has not been terminated and has no obvious owner." The NOAMI mining occurrence hierarchy (NOAMI, 2004) was also adapted to include Heritage and Care and Maintenance sites (Figure 1). The one care and maintenance site was found though self-research. Because a neglected site has not been terminated it can be assumed that there has been little to no rehabilitation. The term "neglected" is used in this report to encompass other terms such as abandoned and legacy sites. This follows the same idea that Pepper, Roche, Mudd (2014) and Worrall *et al* (2009) used, where they classified "mining legacies" as an umbrella term (Pepper et al., 2014).

To define the mine and quarry statuses two spatial maps were used; *Mineral Tenements* (State Government of Victoria, 2017e) and *Crown Land* (State Government of Victoria, 2017g). Mines that were within the area of these two datasets were given their respective attributes through the join and relate function in ArcMap (Figure 2). The analysis assumes that all mining occurrences that weren't within an active tenement were Inactive, in Care and Maintenance, or Heritage Listed. With the two heritage site datasets automatically being given a site status as "Heritage". The analysis also assumes that all mining occurrences within an active tenement are active regardless of whether the licensee believes workings are finished at the location (Figure 2). The analysis focuses more on neglected sites than active sites due to the combined database potentially not containing points within active licenses and work authorities (Figure 2). Due to the lack of available data regarding terminated mines under the Mineral Resources Act 1990 (State Government of Victoria, 2017d) some sites may have been classified as a Neglected site. Any sites that were terminated before the Act (1990) can be assumed to have received little to no rehabilitation and therefore classified as neglected. Neglected sites can be reverted to Terminated, Care & Maintenance or Heritage site upon further investigation into the owner and mineral site.

2.2 *Spatial analysis*

Spatial analysis has been used in a variety of ways to help visualize and understand the relationship between the environment and mining. Boggs *et al* used (2001) GIS software to assess the possible impacts of mining on the Ngarradj catchment; Khalil *et al* (2013) assessed mine pollution from abandoned mines in Morocco with the help of GIS software; and Kivinen (2017) used GIS software to examine post-mining landscapes.

GIS analysis of mining impacts are typically done at a local and regional scale with the environmental impacts of Victorian neglected mines only being analysed at a regional level (Bycroft et al., 1982; Noble et al., 2010). One notable exception is by the Environmental Protection Authority (2016); where they used GIS at a State Government Scale to help find historical gold mining hotspots near fishing streams in Victoria, Australia.

The *Population density grid* map was sourced from the Australian Bureau of Statistics (Australian Bureau of Statistics, 2016). The *Acid Sulphate Soils* (*ASS*) map is from CSIRO (CSIRO, 2017) whilst all other maps can be found in the Victorian Government data resource database (State Government of Victoria, 2017a). Figure 8 did not use the combined database, instead used the *Historical Mining Activity* dataset obtained from the Victorian Government database (State Government of Victoria, 2017a).

All distances, joins and relates were done through the "join and relate" function in ArcMap. The Inverse Distance Weighted (IDW) function was used for the education map (Figure 9) for better visualisation. The water risk score (Figure 13) is calculated from two databases including the *Vicmap hydro* and the *Water supply protection areas* (State Government of Victoria, 2017a). The method to calculate the score is shown in (Figure 12).

Ten mining occurrence sites were visited to check the consistency and accuracy of the analysis.

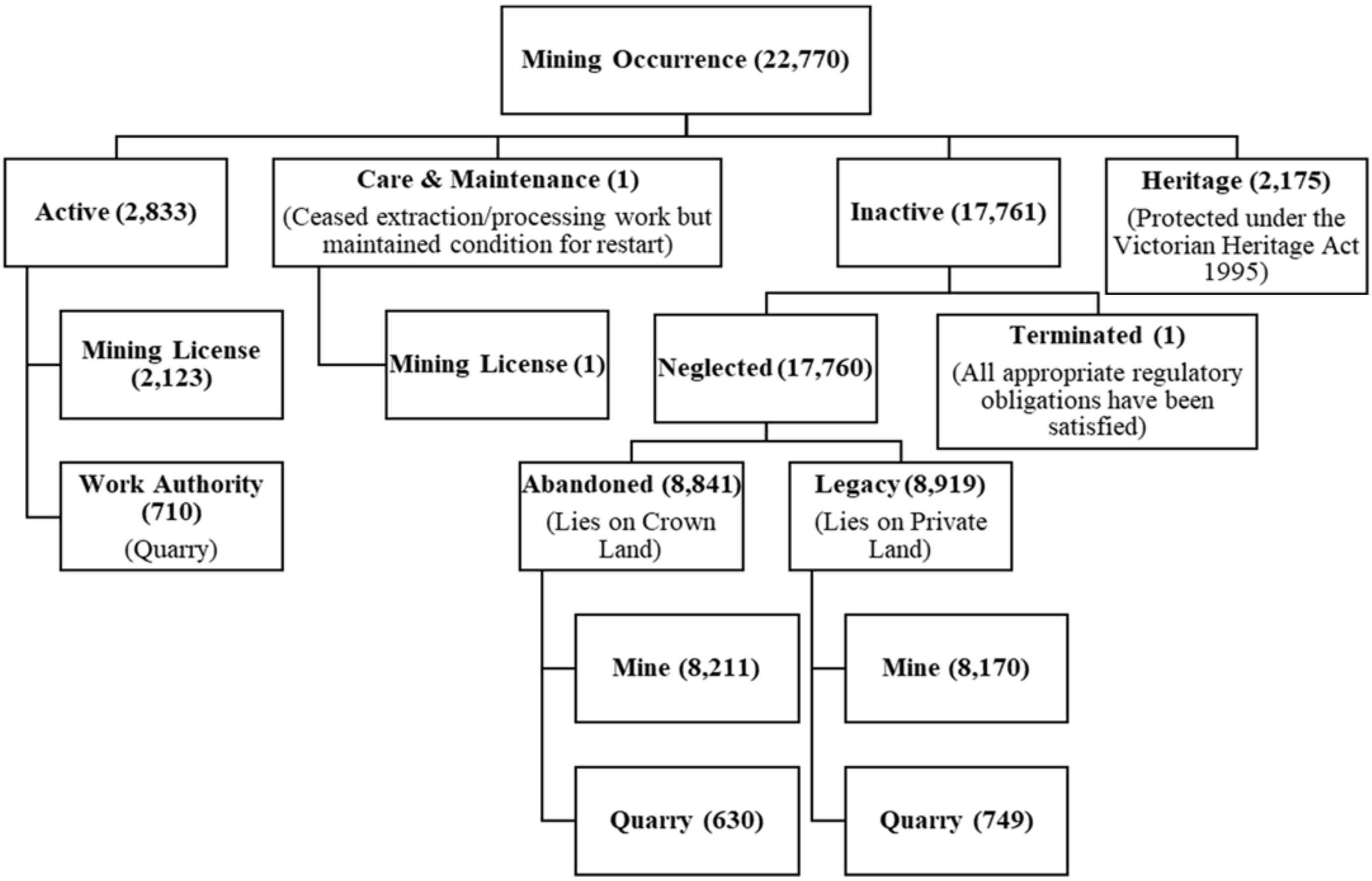


Figure 1. Victorian mining occurrence hierarchy (including number of sites) based on NOAMI framework (NOAMI, 2004)

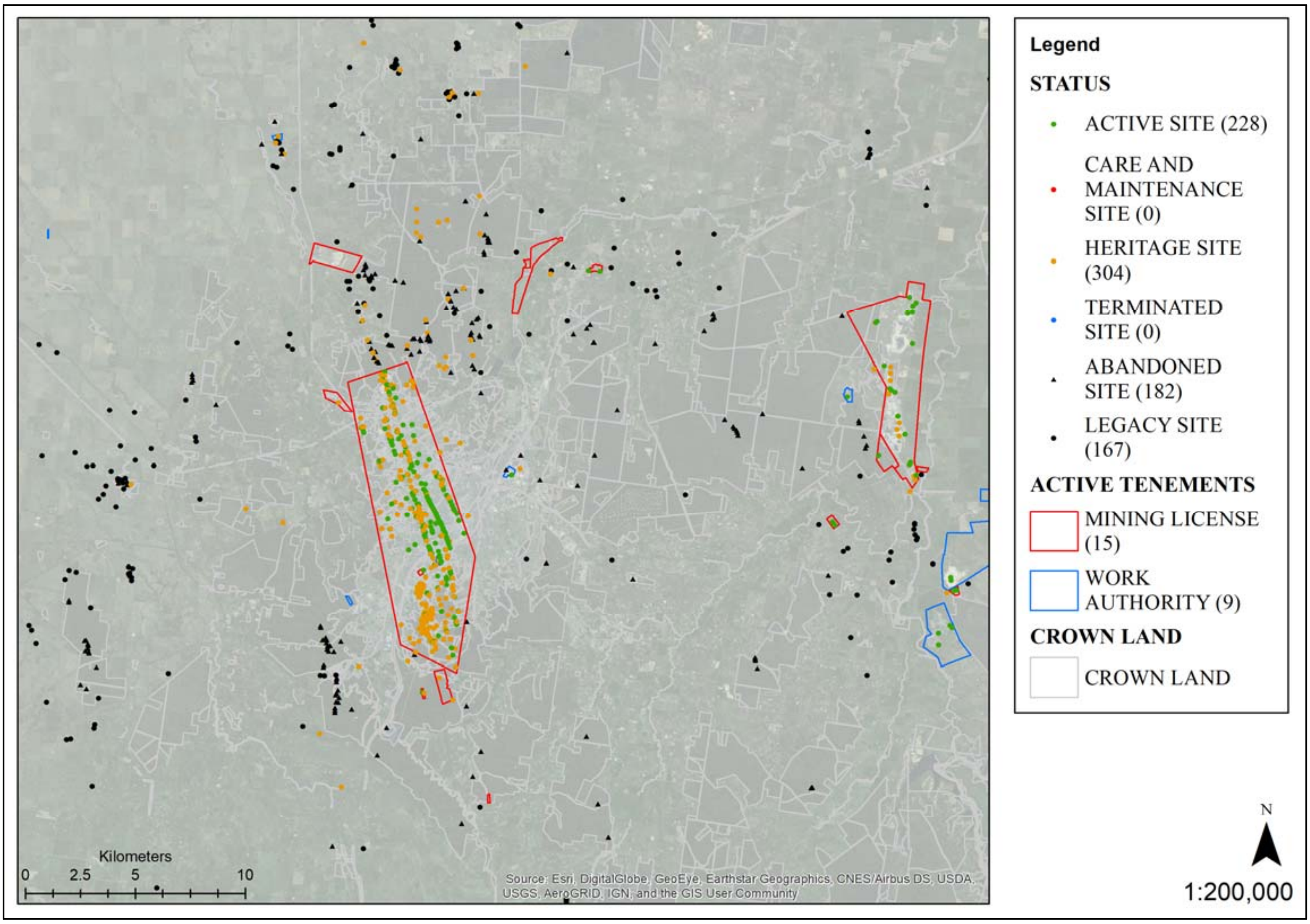


Figure 2. Bendigo region map showing how mining occurrences were categorised according to the hierarchy.

ACCURACY

The *Mines and Mineral Occurrences* dataset showed the largest variation in accuracy and proved to be the most problematic for analysis. Mining occurrence points that had poor spatial accuracy had a higher chance of obtaining an inaccurate site status (Figure 2). Although the use of multiple datasets can be used to compare the accuracies of the mineral occurrence points, it should be noted that duplicate data increases the mine density analysis of an area. The heritage datasets overlapped with the other datasets far more frequently, with heritage sites in the Bendigo region overlapping with the other datasets by up to 60% (Figure 2). A major benefit from the analysis was the commodity information within the *Mineral Tenements* layer, which was used to validate the commodities of the different datasets.

3 RESULTS & DISCUSSION

3.1 *Environment*

3.1.1 *Clearing of Vegetation*

One of the most obvious negative effects of open pit mining on vegetation and soil is the loss of vegetation from the clearing of land (Figure 3). Quarrying causes huge losses in vegetation cover due to mostly being large scale and open pit (Akanwa, Okeke, Nnodu, & Iortyom, 2017). According to the Guidelines for Environmental Management in Exploration and Mining (2004), revegetation is usually the primary objective of rehabilitation and is often the measure of success. Out of the 2106 quarries within the database, 1379 (66%) are neglected. Underground quarries in Victoria are uncommon, therefore it can be assumed that all these quarries are open pit and currently have poor vegetation regrowth from the lack of rehabilitation. The lack of vegetation cover on unrehabilitated sites can also cause an increase in dust pollution to nearby vegetation and residents. 353 (26%) of the neglected quarries were less than 500 metres away from endangered vegetation.

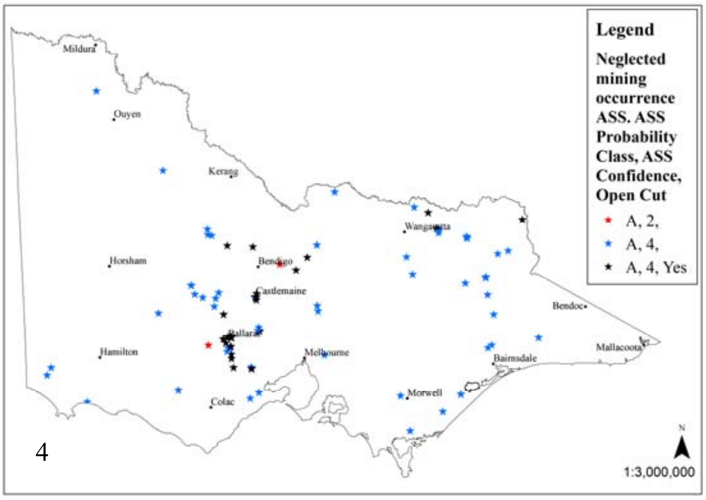
The Strategic Biodiversity Score (SBSv3) is a decision-support tool created by the Department of Environment, Land, Water and Planning (DELWP) to help identify priority areas for protection based on the importance of the natural values in a specific lo location (State Government of Victoria, 2017b). These protection values are rated from 0 to 100 and calculated from factors such as habitat importance, native vegetation location risk and condition of native vegetation. The higher the SBSv3 value the higher the perceived biodiversity importance. The analysis showed that 25% of neglected quarries were less than 500 metres away from land that had an SBSv3 value greater than 63.5.

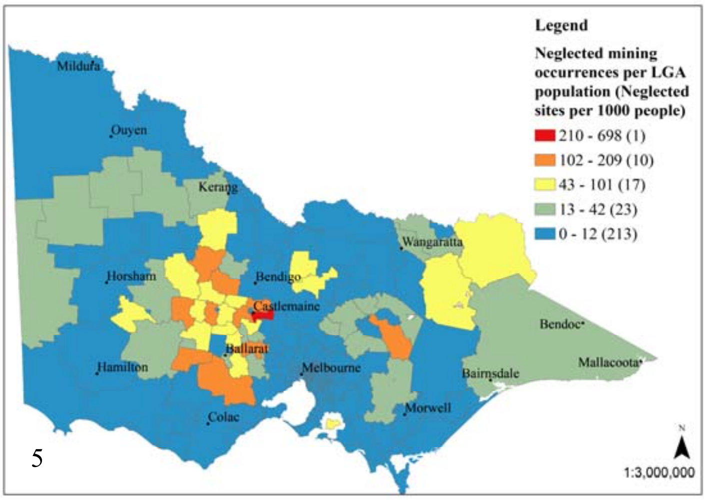
The *Mines and Mineral Occurrences* database provided information (potentially incomplete) on whether sites were open cut. 7514 (46%) of the 16,381 neglected mines were recorded as open cut. Out of the 7514 open cut neglected mines 1823 (24%) were less than 500m away from endangered vegetation.

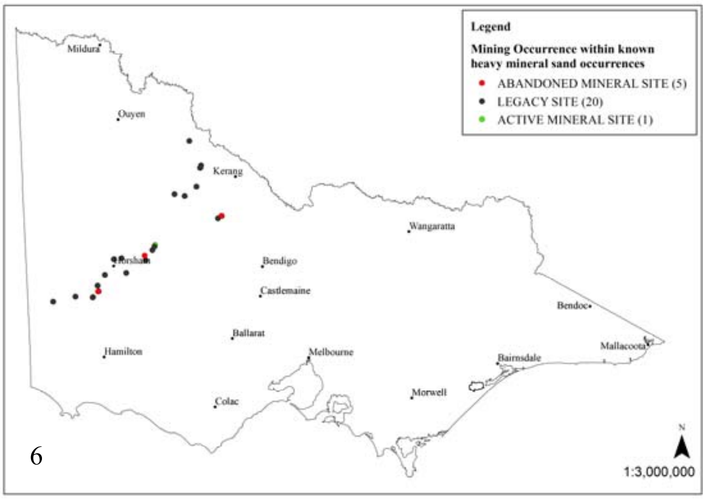
3.1.2 *Mine Tailings, Mercury & Arsenic*

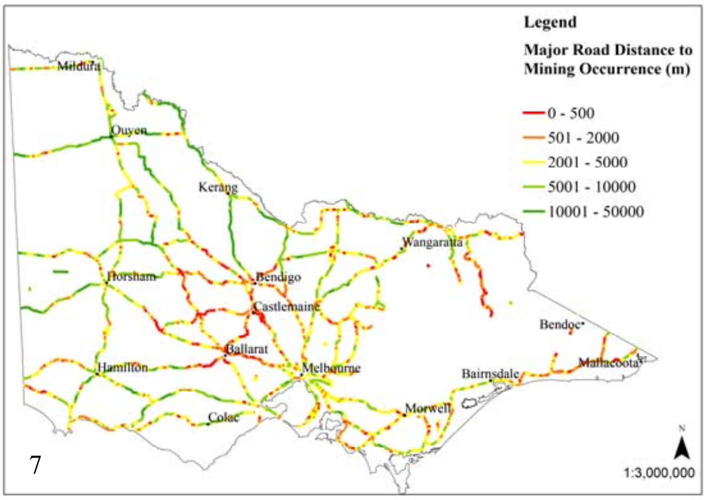
Arsenic is a naturally occurring compound found in rock and is extremely toxic in high doses to humans, wildlife and vegetation. During the operation of gold mines, tailings containing unwanted minerals are left in piles on the soil surface or thrown into nearby waterways. Gold mine tailings can hold high levels of arsenic due to the similar solubility of arsenic and gold in the ore forming fluids (Lottermoser, 2007). People that are downwind from nearby neglected mines may be at an increased risk of Arsenic exposure via inhalation and/or ingestion pathways (Martin et al., 2016). Historical goldfield areas such as Ballarat pose an important public health risk due

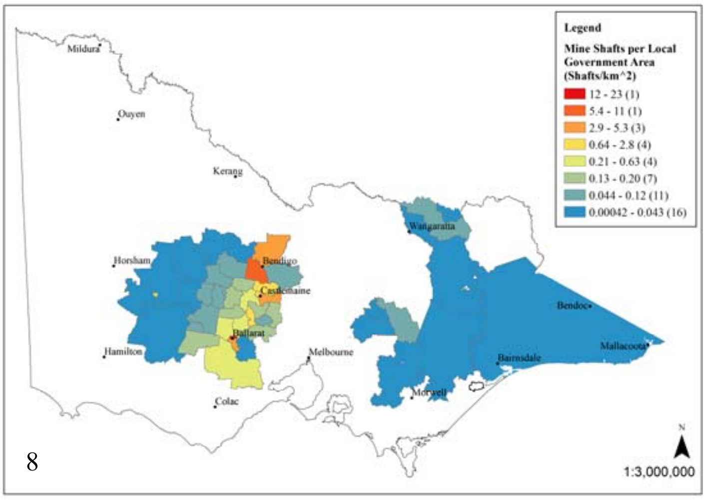
Figure 3. An abandoned quarry in the *FOI* database. Note the vegetation thickness immediately beside the quarry. Analysis found this site to be 125m away from endangered woodland. Photo taken on 09/09/2017 by the author (A. Miller).

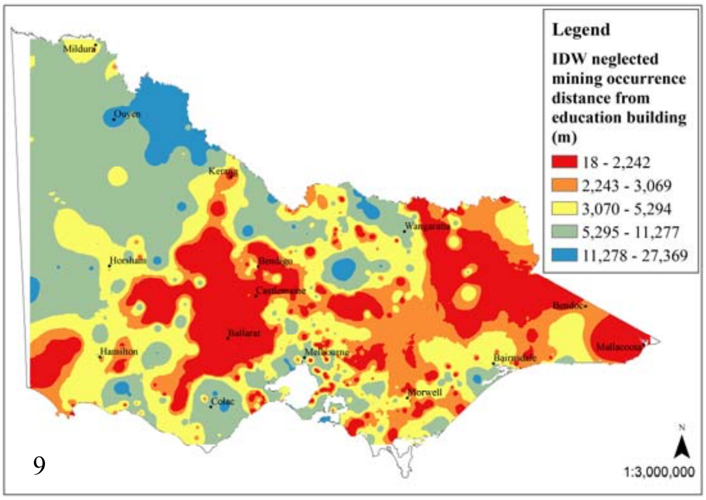


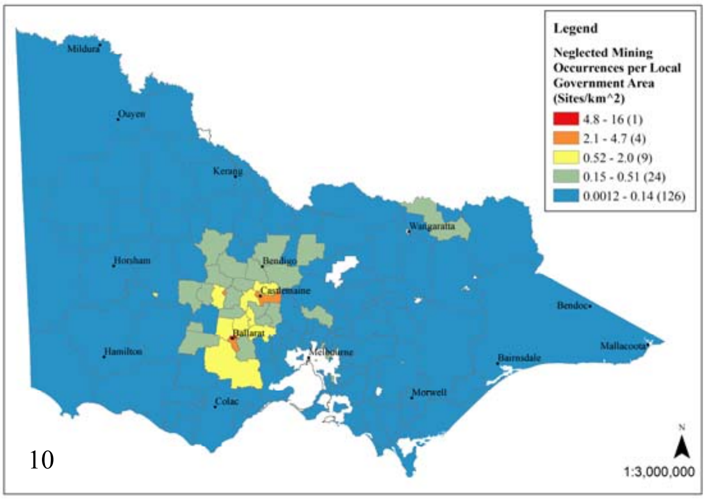


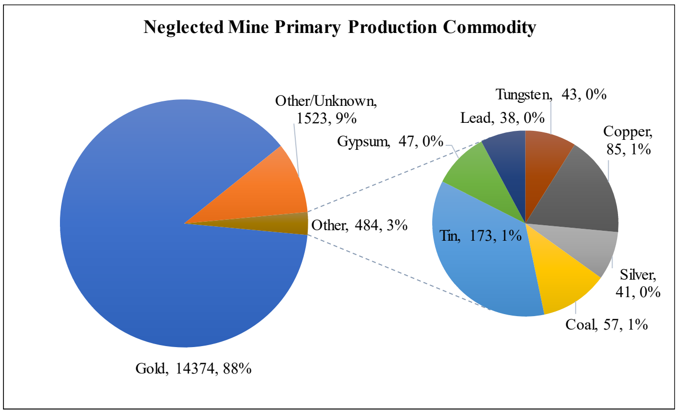












Figures 4-10. Spatial analysis of mining occurrence sites
Figure 11. (Immediately above) primary commodity of neglected mines

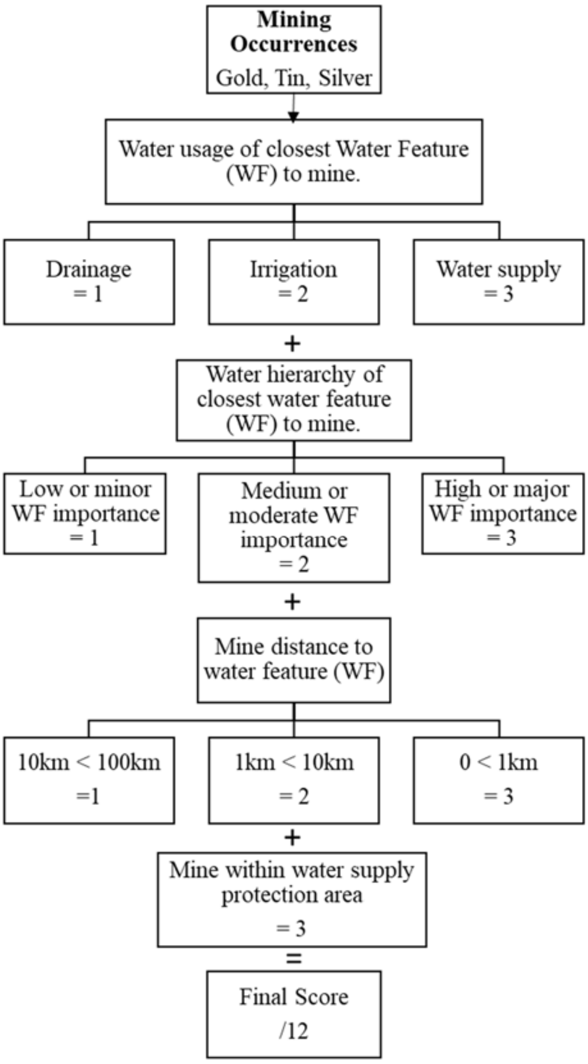


Figure 12. Method for calculating water risk score. The higher the score the higher the water pollution risk to humans

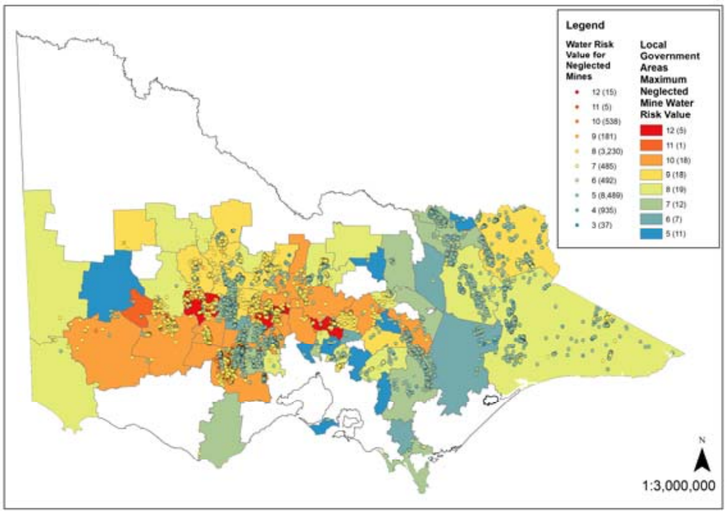


Figure 13. Water risk analysis of neglected mines (gold, tin, silver)

to the arsenic uptake from soil during childhood (Pearce et al., 2012). A study by Pearce, Dowling, & Sim (2012) found a small but significant increase in cancer risk associated with soil arsenic levels in more socioeconomically disadvantaged areas in the goldfields region of Victoria.

Amalgamation is a method used by the mining industry to adhere mercury (Hg) to gold, forming pasty amalgams (Lacerda, 1997), where the amalgam is diverted along a separate path than the waste ore (Peter Davies, Susan Lawrence, & Jodi Turnbull, 2015). The alloy gold amalgam is then mixed with water to disperse it promoting better contact between the gold and mercury (Peter Davies et al., 2015). This method had been used intensively during the Victorian gold rush to improve the rate of recovery of gold (Peter Davies et al., 2015) and for Tin and Silver. By 1893 nine-tenths of the gold produced worldwide was recovered by the amalgamation process (Birrell, 2004).

Because the amalgamation process contains mercury, the potential environmental damage caused by abandoned gold mines is high. Neglected gold mines in Victoria account for 88% of the mine sites (Figure 11). For the period between 1868 to 1888 at least 121 tons of mercury was lost in the Victorian minefields (Peter Davies et al., 2015). The amalgamation process was not only restricted between these dates, with the potential for mercury to be lost decades before and after within the environment.

In developing countries mercury is still being used in artisanal and small scale gold mining, contributing to 35% of global mercury emissions in 2010 (UNEP, 2013). The Minamata Convention on Mercury was established in October 2013 to help protect human health and the environment from the adverse effects of mercury (Santana, Medina, & Torre, 2014); which is one of the worst hazards among anthropogenic impacts upon the global environment (Dhindsa, Battle, & Prytz, 2003). The Convention provides recommendations, further research and development into removing and reducing mercury from artisanal and small-scale gold mining. Australia is a signatory to the convention but is yet to ratify it.

Mercury binds to organic particles and settles out in sediments (EPA Victoria, 2016). It is easily transformed into stable and highly toxic methylmercury, where Hg accumulates strongly in aquatic biota (Lacerda, 1997). This results in contamination of rivers, water bodies and the aquatic life. Using only neglected mine types (gold, silver, tin), Figure 13 shows neglected mines that may have higher potential impacts to humans from waterways contaminated with heavy metals, arsenic and mercury pollution.

Brown coal mines in Victoria are typically open pit besides the historic Wonthaggi State Coal Mine which is now a tourist mine. Current coal mines in Victoria are mined to extensive areas and depths. Because of the open pit coal oxidation occurs when coal bearing rocks are exposed to the atmosphere (Lottermoser, 2007). This can cause acid mine drainage (AMD), particularly from the oxidation of pyrite embedded within the coal.

Closed and abandoned coal mines that haven't been rehabilitated run risk of causing AMD due to their exposed mine surfaces. Neglected mine tailings can also generate acidic water through the oxidation of pyrite and other sulphide materials (Camden-Smith & Tutu, 2014). AMD causes substantial changes in the structure and function of benthic communities and food webs (Hogsden & Harding, 2012) through contamination in groundwater and surface water systems. Ecological values of national significance are affected by neglected mines where AMD has negative impacts on aquatic ecosystems, birds, and other fauna reliant on water sources (O'Callaghan & Graetz, 2017).

Acid sulphate soils (ASS) are naturally occurring soils and sediments which when disturbed or exposed to air oxidation occurs and sulphuric acid is produced (Stone, Ahern, & Blunden, 1998). Areas with a higher risk of acid drainage is shown in Figure 4. Figure 4 only shows mining occurrences that lay within a high probability of ASS (>70% chance of occurring). Greater attention should be paid to mining occurrences that lay within ASS and are open cut. These sites are located near Ballarat, with other sites of interest being red star points in Figure 4 that have a higher confidence score of ASS.

Neglected mining sites that are within heavy mineral sand occurrences pose a higher risk to the environment due to the potential of heavy metal and radioactive contamination to the surrounding water and soil. Figure 6 shows the 25 neglected mining occurrences that lay within the heavy mineral sand map (State Government of Victoria, 2017a).

3.2 *Infrastructure & Public Safety*

3.2.1 *Subsidence*

Mine subsidence is the movement of the surface caused by any mine activity (Galvin, 2016). The consequences of mine subsidence can be substantial within the community, changing the risk profile of a natural or man-made feature (Galvin, 2016).

Most neglected underground mine shafts during the Victorian goldrush were covered with timber after the mines life. As the timber gives way these shafts reveal open holes (Willman & Wilkinson, 1992). Mine shafts ranged in depth in Victoria, with Bendigo mines commonly reaching depths between 300 to 600 metres deep (State Government of Victoria, 2017f). During a wet year such as 1974 the Bendigo region can receive up to 30 mine subsidence complaints per year (Willman & Wilkinson, 1992). With the real number of mine subsidence events expected to be much higher due to unreported subsidence cases on private land dealt with by the land-owners. Landowners in Victoria are responsible for repairing damage caused by neglected mine subsidence (City of Greater Bendigo, 2016; Whitney Harris, 2010). Local Government areas that have a higher risk of shaft collapse and subsidence are Mt Alexander, Greater Bendigo, Ballarat, Indigo, Central Goldfields, Hepburn & the Golden Plains (Figure 8 & 10).

In the Latrobe Valley heavy rainfall triggered movements in the ground within and surrounding the Hazelwood Mine in Victoria (State Government of Victoria, 2011). A stretch of the Princes Freeway which ran between the mine and township of Morwell (Figure 7) was closed for seven months (ENGIE, 2017). The traffic diversions and road fixtures comes at a cost to the Victorian economy.

Although many factors can contribute to subsidence (type, size, geology), Figure 7 assumes the smaller the distance of a mining occurrence (inactive or active site) to a major road, the greater the potential risk of subsidence of the road. The results showed that 2753 (12.1%) mining occurrences were less than 1km away from a major road. Infrastructure such as major gaseous pipelines can be at risk from subsidence. Results showed 1267 (5.6%) of mining occurrences were less than 1km away from major gaseous pipelines. Helm, Davie, & Glendinning (2013) stressed that even shallow neglected mining subsidence can have a significant impact on transport infrastructure.

Areas such as Newcastle in New South Wales (NSW) have had multiple mine subsidence incidents caused from underground coal mines. The Subsidence Board NSW provides compensation for surface improvements adversely impacted by mine subsidence in the affected areas (Subsidence Advisory NSW, 2016). Areas dense with underground mines in Victoria such as Ballarat and Bendigo would benefit greatly from a similar Victorian Board, providing information on subsidence prone areas and to provide compensation where necessary.

3.2.2 *Population*

From the early 1850s the Victorian gold rush helped create some of the largest cities in Victoria including Ballarat and Bendigo. The gold rush population peaked at 150,000 by the end of 1858, where over half were British immigrants and 40,000 were Chinese (Mccarty, 2003). The race for diggers to find their riches continued in the Victorian gold fields till the 1860s where the rush had basically finished and they had moved onwards to NSW (State Government of Victoria, 2015). Many towns in Australia have had population increases due to mining in the area. Roxby Downs, a rural mining town situated in South Australia had an average annual increase in residency population by 4.1% during the mining boom between 2006 and 2011 (Australian Bureau of Statistics, 2013). These mining towns are much more prone to the negative effects of neglected mines due to their proximity to the mine. Areas with high densities of neglected sites to population were found (Figure 5) using the combined mining occurrence database and the Victorian population grid (Australian Bureau of Statistics, 2016). The gold rush regions (Ballarat, Castlemaine) all have a greater amount of neglected mining occurrences per local government area (LGA) population than the rest of the state (Figure 5).

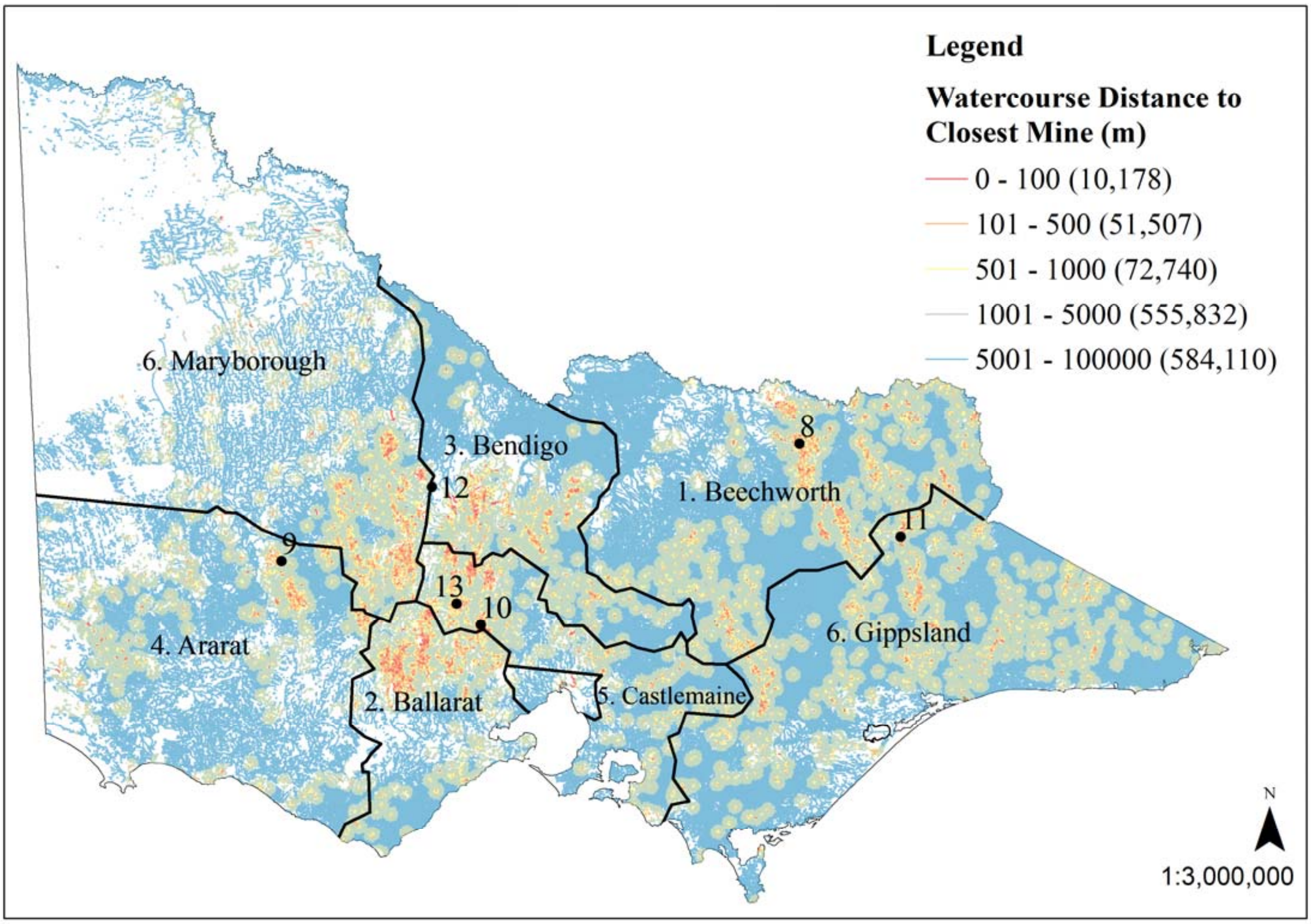


Figure 14. Watercourse distance to closest mine and location of pollution case studies in Table 2. Mining districts are to be taken as approximations and were redrawn from (P. Davies et al., 2015).

Table 2. Case studies of pollution from neglected mines in Victoria

ID	Region/River System	Case Study	
1	Beechworth	6.83 tons Hg	Minimum Hg lost between 1868-1888 (P. Davies, S. Lawrence, & J. Turnbull, 2015).
2	Ballarat	7.394 tons Hg	
3	Bendigo (Sandhurst)	3.35 tons Hg	
4	Ararat	10.36 tons Hg	
5	Castlemaine	11.16 tons Hg	
6	Gippsland	11.48 tons Hg	
7	Maryborough	19.14 tons Hg	
11	Big River	As & Hg above ISQG low trigger values and As above high ISQG trigger values for Big River (EPA Victoria, 2016).	
12	Loddon Valley River		
13	Sailors Creek		
-	Central Goldfields	Found a small but significant increase in cancer risk associated with soil arsenic level in more socioeconomically disadvantaged areas in the Goldfields (Pearce, Dowling, & Sim, 2012).	
8	Reedy Creek sub-catchment	Hg still prevalent in water and surface sediments of streams 100 years after mining ceased (Churchill, Meathrel, & Suter, 2004).	
9	Stawell	As, Cr & Pb enriched soil compared to regional soil background and crustal averages. As, Cr & Pb considered to pose minimal human health risk (Noble, Hough, & Watkins, 2010).	
10	Lerderderg River	Tailings provide continuing source of elevated mercury levels. Elevated mercury levels in river Blackfish (Bycroft, Coller, Deacon, Coleman, & Lake, 1982).	

Open shafts, cliff edges and contaminated soil/water are all dangerous hazards especially for children. Spatial data of educational buildings and hospitals were obtained from the *Points of Interest* dataset where each buildings distance was calculated to the nearest neglected mining occurrence (Figure 9). 2,337 (13%) of the neglected mining occurrence sites are less than 1km away from an educational building. Whilst 361 (2%) of the neglected mining occurrence sites are within 1km of a hospital.

4 CONCLUSION

The report successfully categorises the neglected mines into different landowners. Understanding who owns the land can help prioritise rehabilitation of certain sites and find risks on public land such as parks. Spatial analysis helped find areas that may be affected by the negative environmental impacts from neglected mining occurrences. Impacts from historical mining are still being felt today due to the lack of rehabilitation and poor mining practices. The analysis showed areas with potential negative impacts include the Central Goldfields region (Ballarat, Bendigo, Castlemaine) and areas near the Alpine regions (Beechworth, Walhalla, Bright) due to the high density of gold mines. State level spatial analysis can be used as a tool to help find areas that have been impacted by neglected mines. The analysis can also help find areas in need of further research and risk mitigation strategies.

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REFERENCES

Akanwa, A. O., Okeke, F. I., Nnodu, V. C., & Iortyom, E. T. (2017). Quarrying and its effect on vegetation cover for a sustainable development using high-resolution satellite image and GIS. *Environmental Earth Sciences, 76*(14), 505. doi:10.1007/s12665-017-6844-x

Australian Bureau of Statistics. (2013). Towns of the mining boom. Retrieved from http://abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4102.0Main+Features10April+2013

Australian Bureau of Statistics. (2016). Australian Population Grid. Retrieved 15/5/17, from State Government of Victoria http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3218.02015-16?OpenDocument

Australian Government. (2015). Australian Mines Atlas. Retrieved from http://www.australianminesatlas.gov.au/

Birrell, R. W. (2004). The extraction of gold by amalgamation and chlorination. *Journal of Australasian Mining History, 2*, 17-34.

Boggs, G., Devonport, C., Evans, K., Saynor, M., & Moliere, D. (2001). Development of a GIS approach to mining risk assessment. Supervising Scientist report 159.

Bycroft, B. M., Coller, B. A. W., Deacon, G. B., Coleman, D. J., & Lake, P. S. (1982). Mercury contamination of the Lerderderg River, Victoria, Australia, from an abandoned gold field. *Environmental Pollution Series A, Ecological and Biological, 28*(2), 135-147. doi:https://doi.org/10.1016/0143-1471(82)90099-X

Camden-Smith, B. P. C., & Tutu, H. (2014). Geochemical modelling of the evolution and fate of metal pollutants arising from an abandoned gold mine tailings facility in Johannesburg. *Water Science and Technology, 69*(5), 1108-1114. doi:10.2166/wst.2014.028

Churchill, R. C., Meathrel, C. E., & Suter, P. J. (2004). A retrospective assessment of gold mining in the Reedy Creek sub-catchment, northeast Victoria, Australia: residual mercury contamination 100 years later. *Environmental Pollution, 132*(2), 355-363. doi:https://doi.org/10.1016/j.envpol.2004.03.001

City of Greater Bendigo. (2016). Residents urged to report mine shafts that have opened up after rain. Retrieved from https://www.bendigo.vic.gov.au/About/News-and-media/Media-Releases/residents-urged-report-mine-shafts-have-opened-after-rain

CSIRO. (2017). Atlas of Australian Acid Sulphate Soils. Retrieved from https://data.csiro.au/dap/landingpage?list=BRO&pid=csiro:6181&sb=RELEVANCE&rn=2&rpp=25&p=1&tr=15&bKey=tn&bVal=Natural%20Resource%20Management&dr=all

Davies, P., Lawrence, S., & Turnbull, J. (2015). MERCURY USE AND LOSS FROM GOLD MINING IN NINETEENTH-CENTURY Victoria. *Proceedings of the Royal Society of Victoria, 127*(2), 44-54. doi:10.1071/RS15017

Davies, P., Lawrence, S., & Turnbull, J. (2015). Mercury use and loss from gold mining in nineteenth-century Victoria. *CSIRO, 127*, 44-54.

Dhindsa, H. S., Battle, A. R., & Prytz, S. (2003). Environmental Emission of Mercury During Gold Mining by Amalgamation Process and its Impact on Soils of Gympie, Australia. *Pure and Applied Geophysics*(160), 145-156.

ENGIE. (2017). History of Hazelwood. Retrieved from http://www.gdfsuezau.com/media/UploadedDocuments/Hazelwood%20Closure/History/Hazelwood%20History%20Brochure.pdf

EPA Victoria. (2016). *Mercury and arsenic in Victorian waters: a legacy of historical gold mining.* Retrieved from http://www.epa.vic.gov.au/our-work/publications/publication/2016/november/1637

Galvin, J. M. (2016). *Ground engineering - principles and practices for underground coal mining.*

Helm, P. R., Davie, C. T., & Glendinning, S. (2013). Numerical modelling of shallow abandoned mine working subsidence affecting transport infrastructure. *Engineering Geology, 154*(Supplement C), 6-19. doi:https://doi.org/10.1016/j.enggeo.2012.12.003

Hogsden, K. L., & Harding, J. S. (2012). Consequences of acid mine drainage for the structure and function of benthic stream communities: a review. *Freshwater Science*(31), 108-120.

Khalil, A., Hanich, L., Bannari, A., Zouhri, L., Pourret, O., & Hakkou, R. (2013). Assessment of soil contamination around an abandoned mine in a semi-arid environment using geochemistry and geostatistics: Pre-work of geochemical process modeling with numerical models. *Journal of Geochemical Exploration, 125*(Supplement C), 117-129. doi:https://doi.org/10.1016/j.gexplo.2012.11.018

Kivinen, S. (2017). Sustainable Post-Mining Land Use: Are Closed Metal Mines Abandoned or Re-Used Space? *Sustainability, 9*(10), 1705.

Lacerda, L. D. (1997). Global mercury emissions from gold and silver mining. *Water, Air and Soil Pollution*(97), 202-221.

Lottermoser, B. (2007). *Mine Wastes* (Vol. 2). Germany: Springer.

Martin, R., Dowling, K., Pearce, D. C., Florentine, S., Bennett, J. W., & Stopic, A. (2016). Size-dependent characterisation of historical gold mine wastes to examine human pathways of exposure to arsenic and other potentially toxic elements. *Environmental Geochemistry and Health, 38*(5), 1097-1114. doi:10.1007/s10653-015-9775-z

Mccarty, J. W. (2003). Gold rushes *The Oxford Companion to Australian History*: Oxford University Press.

NOAMI. (2004). Definitions. Retrieved from http://www.noami.org/definitions_e.php

Noble, R. R. P., Hough, R. M., & Watkins, R. T. (2010). Enrichment and exposure assessment of As, Cr and Pb of the soils in the vicinity of Stawell, Victoria, Australia. *Environmental Geochemistry and Health, 32*(3), 193-205. doi:10.1007/s10653-009-9275-0

O'Callaghan, T., & Graetz, G. (2017). *Mining in the Asia-Pacific: Risks, Challenges and Opportunities*: Springer.

Pearce, D. C., Dowling, K., & Sim, M. R. (2012). Cancer incidence and soil arsenic exposure in a historical gold mining area in Victoria, Australia: A geospatial analysis. *Journal of Exposure Science and Environmental Epidemiology, 22*(3), 248-257. doi:http://dx.doi.org/10.1038/jes.2012.15

Pepper, M., Roche, C. P., & Mudd, G. M. (2014). *Mining Legacies - Understanding Life-of-Mine Across Time and Space*. Paper presented at the Life-Of-Mine 2014 Conference, Brisbane, QLD.

Santana, V., Medina, G., & Torre, A. (2014). *The Minimata Convention on Mercury and its implementation in the Latin America and Caribbean region*. Retrieved from

State Government of Victoria. (2004). *Rehabilitation Plans & Other Environmental Aspects of Work Plans*. Retrieved from http://earthresources.vic.gov.au/earth-resources-regulation/licensing-and-approvals/minerals/guidelines-and-codes-of-practice/rehabilitation-and-environmental-aspects-of-mining-and-extractive-work-plans.

State Government of Victoria. (2011). Morwell Land movement: Public Information Sessions. Retrieved from http://earthresources.vic.gov.au/earth-resources-regulation/information-for-community-and-landholders/mining-and-extractives/latrobe-valley-coal-mines/regulatory-reviews/morwell-land-movement/morwell-land-movement-public-information-session-aug-2011

State Government of Victoria. (2015, 12-3-2015). History of gold mining in Victoria. Retrieved from http://earthresources.vic.gov.au/earth-resources/geology-of-victoria/exhibitions-and-Imagery/history-mining-victoria

State Government of Victoria. (2017a). data.vic.gov.au. Retrieved 13/3/17 https://www.data.vic.gov.au/

State Government of Victoria. (2017b). *Decision-support tools to help biodiversity managers protect Victoria's environment*. Retrieved from https://www.environment.vic.gov.au/__data/assets/pdf_file/0023/49046/NaturePrint_Brochure_WEB.pdf.

State Government of Victoria. (2017c). *Earth Resources Regulation, 2015-16 Statistical Report*.

State Government of Victoria. (2017d). *Mineral Resources (Sustainable Development) Act 1990*.

State Government of Victoria. (2017e). Mineral Tenements. Retrieved from https://www.data.vic.gov.au/data/dataset/mineral-tenements

State Government of Victoria. (2017f). Old mines get the shaft. Retrieved from https://www2.delwp.vic.gov.au/media-centre/media-releases/old-mines-get-the-shaft

State Government of Victoria. (2017g). Public Land Management (PLM25). Retrieved from https://www.data.vic.gov.au/data/dataset/public-land-management-plm25

State Government of Victoria. (2017h). Victoria's open data directory. Retrieved from https://www.data.vic.gov.au/

Stone, Y., Ahern, C. R., & Blunden, B. (1998). *Acid Sulfate Soils Manual 1998*. Wollongbar, NSW, Victoria: Acid Sulfate Soil Management Advisory Committee.

Subsidence Advisory NSW. (2016). *Mine Subsidence Board - Annual Report 2015-16*. Retrieved from http://www.subsidenceadvisory.nsw.gov.au/sites/default/files/uploads/2015-16_annual_report_msb.pdf

UNEP. (2013). *Global Mercury Assessment 2013: Sources, Emissions, Released and Environmental Transport*. Retrieved from Geneva, Switzerland: https://wedocs.unep.org/bitstream/handle/20.500.11822/11401/GlobalMercuryAssessment2013.pdf?sequence=1&isAllowed=y

Unger, C., Lechner, A. M., Glenn, V., Edraki, M., & Mulligan, D. R. (2012). *Mapping and Prioritising Rehabilitation of Abandoned Mines in Australia*. Paper presented at the Life-of-Mine Conference, Brisbane, Australia. https://cmlr.uq.edu.au/filething/get/18451/LOM%20Paper%20Unger%20et%20al%20July%202012-1.pdf

Victorian Heritage Council. (2017). Victorian Heritage Database. Retrieved from http://vhd.heritagecouncil.vic.gov.au/

Whitney Harris. (2010). Bendigo mine shafts collapse. Retrieved from http://www.bendigoadvertiser.com.au/story/710347/bendigo-mine-shafts-collapse/

Willman, C. E., & Wilkinson, H. E. (1992). *Bendigo Goldfield - Geological Survey Report No 93*. Retrieved from http://earthresources.efirst.com.au/product.asp?pID=646&cID=39

Worrall, R., Neil, D., Brereton, D., & Mulligan, D. (2009). Towards a sustainability criteria and indicators framework for legacy mine land. *Journal of Cleaner Production, 17*(16), 1426-1434. doi:https://doi.org/10.1016/j.jclepro.2009.04.013