CHAPTER 7

When gold mining ends: An environmental catastrophe for Johannesburg?

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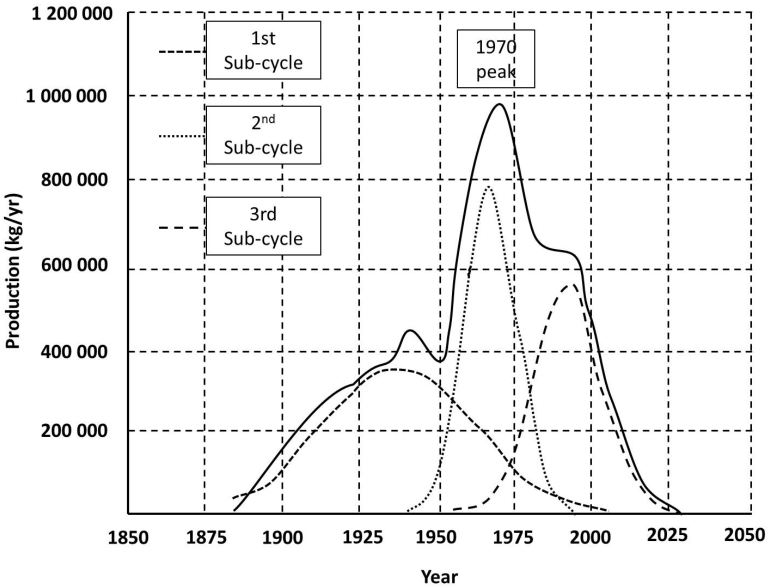
As South Africa enters its third decade of democracy, the economic heartland centred on Johannesburg is facing a major crisis. The drivers of this crisis are complex, potentially providing a perfect storm as they converge. The public remains largely ignorant of what awaits them and the regulatory response has been muted, muddled and misguided at best. This chapter seeks to describe, in layperson's terms, the environmental disaster unfolding around the financial hub of Africa as three key drivers – the end of the production life of the gold mining industry, the failure of the regulatory environment over the last century adequately to plan for a post-mining future and a transition to a water-constrained national economy – come together. The chapter will argue that these three drivers are converging at the same time that government's capacity to respond seems to be at its weakest in the history of our young democracy.[1] The main focus will be on an analysis of the environmental and social issues associated with the legacy of gold mining to show that Johannesburg is the epicentre of a slow onset disaster, and is increasingly going to be known as the most uranium-contaminated city in the world – unless we can reverse this trend through policy reform to attract investment into the many brownfields mining sites that now dominate the landscape.

THE GOLD MINING DILEMMA

A staggering 40 per cent of the gold ever produced on the entire planet in all recorded history comes from the Witwatersrand goldfields (Hart 2013). The discovery of gold in 1886 changed the trajectory of the South African economy forever (Turton *et al.* 2006). Triggering the Second Anglo-Boer War that led ultimately to the decimation of the Afrikaner nation, not on the field of battle, but in the squalor of the concentration camps arising from the scorched earth policy instituted by the British (Porch 2000), this whole process created a civil service and a legal system designed to maximise profits from mining by externalising all environmental and social liabilities (Turton 2009, 2015). That bureaucracy functioned with ruthless efficiency from the Act of Union in 1910 until the transition to democracy in 1994 (Turton 2010, 2015). It is now those environmental and social liabilities, so skilfully externalised for more than a century (Adler *et al*., 2007) and legally removed from the balance sheets of all mining houses through apartheid-era government policy, that are now about to become constraints to the future social cohesion and economic wellbeing of a young nation.

The production cycle of gold is shown in Figure 1. This dataset gives a stark but graphic representation of the meteoric rise and imminent fall of an extractive economy so innovative that it enabled enormous wealth to be wrested from the bowels of the earth in some of the deepest mines in the world – while simultaneously failing so dismally to prepare for a future after mining.

Figure 1. South African gold production life cycle

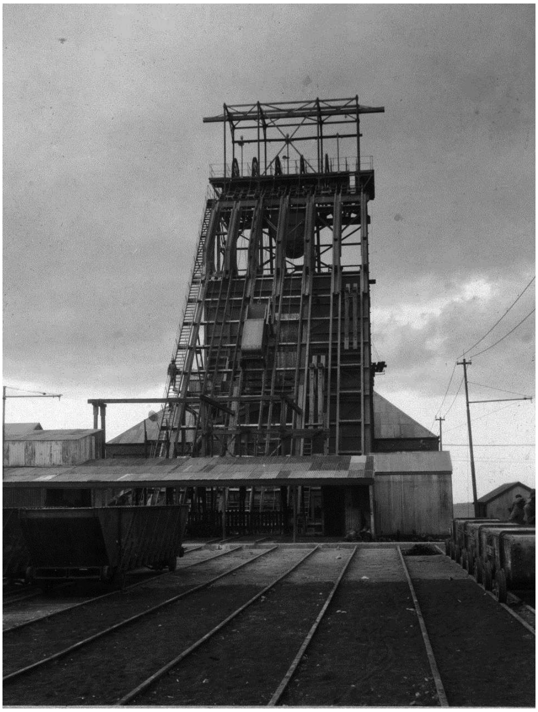


Source: Hartnady C (2009) South Africa's gold production and reserves. *South African Journal of Science*, 105.

Two specific aspects relevant to the argument presented in this chapter are evident in Figure 1. The first is the presence of a roughly bell-shaped curve, peaking in 1970 but crashing dramatically in the post-1994 era of democracy. All things being equal, the demise of the industry is more or less inevitable by as early as 2020, at least in the eastern, central and western basins of the Witwatersrand goldfields.[2] It will later be argued that we need to reinvent the business case for closure mining by changing, through policy reform, the logic that has underpinned the industry since its birth in 1886.

The second aspect is more interesting, because embedded in the total distribution curve for gold production are three discrete but unique sub-cycles. These are relevant to the logic of closure mining, so it is important to grasp their significance. The first peak in the mid-1930s was driven by the consolidation of surface rights into highly mechanised capital-intensive underground mining operations, but all working at relatively shallow depth (less than 1 000 metres below the surface). This era was characterised by company names that reflected the consolidation of surface rights (Davenport 2013) – Goldfields Consolidated, Johannesburg Consolidated Investment, West Rand Consolidated – and many of these operations were centred on decline shafts along the dip of reef into relatively shallow ore bodies such as that in Photo 1.

Photo 1. West Shaft at the West Rand Consolidated Gold Mining Company was a large six-compartment decline shaft shown here as it existed in 1929. This was typical of the first sub-cycle shown in Figure 1, where industrial production on an unprecedented scale took place in relatively shallow ore bodies.



Source: West Rand Consolidated Gold Mining Company, 1929 report to shareholders.

The second sub-cycle peaking in 1970 was driven by the opening of the deep-level mining operations, most notably in the far western basin of the Witwatersrand goldfields, but also in the Free State (Davenport 2013). These deep-level mining operations were made possible only after a viable technical solution could be found to the dolomite water 'problem' in the far western basin. The 'problem' arose from the fact that the world's richest deep level gold deposits lay underneath one of the world's largest karstic aquifer systems (Buchanan 2010) which meant that the risk of flooding and mudrush incidents could only be mitigated by dewatering the aquifer system, a solution mandated by the Jordaan Commission of Inquiry that reported to the minister of water affairs in 1960 (Jordaan *et al.* 1960). This enabled deep-level mining to commence in earnest, characterised by sophisticated vertical and sub-vertical shafts (no more declines to surface), driving the spike in production a decade later.

The third sub-cycle is the most significant, however, because it is driven by technical improvements to the metallurgical processes associated with the recovery of gold from tailings dams. Stated simply, the old mine dumps contain around 0.3 grams of gold per tonne of tailings because of the inefficiencies of earlier metallurgical processes. Nowadays, with more modern technologies available, and underpinned by the higher gold price (Davenport 2013; Hart 2013), this gold can be recovered in a way that potentially enables the downward leg of the production bell-curve shown in Figure 1 to be extended by at least twenty more years, averting an environmental and social catastrophe while buying time to collectively invent our way out of the impending calamity.

AN ENVIRONMENTAL AND SOCIAL CATASTROPHE?

Why does the data shown in Figure 1 suggest an impending environmental and social catastrophe? The answer to this simple question is complex (as with everything else in the mining sector), but is best understood in the context of the externalisation of liabilities that arose after the Second Anglo-Boer War when the legal and institutional frameworks were established in such a way as to maximise profits by allowing the self-regulation of the industry (Turton 2015). What is generally not known to decision makers and the public is that for every tonne of gold recovered in the Witwatersrand goldfields over time, between ten and a hundred tonnes of uranium were also removed, depending on the reef being mined (Winde 2009, 2013). The significance of this startling fact is that for most of the life of the gold mining operations, uranium had no commercial value so it was simply discarded as waste into the tailings dams. In places where the uranium concentrations were really high, such as in the western basin centred on Krugersdorp and Randfontein, it was removed in a secret operation that enabled the South African government, then a pariah, to evade some of the comprehensive economic sanctions being applied at the time. Krugersdorp used to be known as 'uranium city' because of the high levels of uranium found in the gold mines. It is actually more accurate to describe the Krugersdorp mines as uranium mines in which gold was also present, as opposed to the majority of the other mines where gold was recovered and uranium merely discarded.

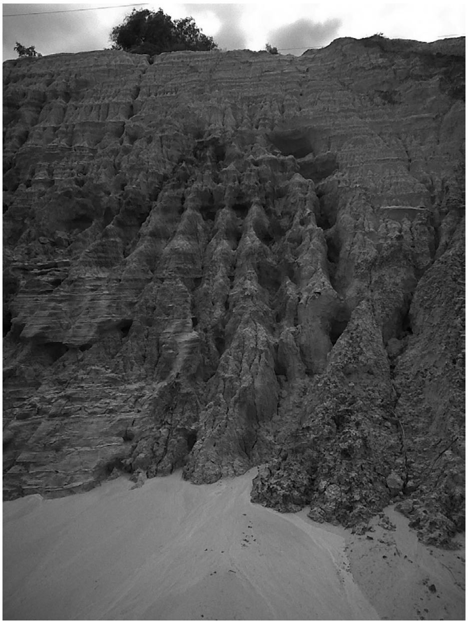
The reason that an environmental and social catastrophe is imminent relates to the presence of uranium. There is a staggering 600 000 tonnes of uranium that has been discarded in the combined mine dumps of the Witwatersrand goldfields (GDARD 2011), all of which will again be mobilised as soon as the few remaining gold mining companies still active become insolvent. While uranium is only mildly radioactive, it is known to be chemotoxic, with two exposure pathways evident in mammals – ingestion with food and water, and inhalation as dust – both of which generally attack the kidneys although other organs can also be damaged.[3] It can bio-accumulate in certain forms but, given the complex chemistry, often passes through the body as a metabolite. Significantly, little research has been done globally on the human health implications, which merely serves to elevate the risk because of this inherent uncertainty.

Environmental mobilisation is inevitable, because the assumption underpinning the safe management of any tailings disposal facility (TDF) is the constant need to maintain the shape of the structure by mechanical means. If there is no cash available through insolvency, then the first casualty is the TDF, which succumbs to the natural forces of erosion by wind and rainwater in a matter of days. This also means that as soon as the remaining companies cease to be viable there is no effective strategy in place to prevent the dumps they manage from collapsing, triggering the slow but systematic release of their hazardous contents into the environment. There is insufficient capital set aside for rehabilitation post-closure (Van Zyl *et al.* 2012), so in effect the liability has already been nationalised. Current policy seeks to reverse this by demanding a massive cash deposit to offset historic liabilities, which destroys any intention of investing into old brownfield sites (Turton 2015) and will mean that a government without technical capacity will need to manage a complex problem without the necessary means, forcing significant taxation on an increasingly unwilling population – a significant risk generally not appreciated by environmental activists as they call for the aggressive imposition of the Environmental Trust Fund (ETF) envisaged by the Mineral and Petroleum Resources Development Act (MPRDA). All it does is pose an additional burden on marginal mines (hastening the onset of the disaster) by applying logic relevant to greenfields operations to brownfield cases at the end of their natural commercial lives (Turton 2015).

But what of the social aspects of this impending environmental catastrophe? Again this is a profoundly complex issue. Undoubtedly the most serious issue is the absence of clear policy regarding the management of so-called mine residue areas (MRAs). An MRA is defined as an area of land that has as a key component what can best be called a waste dump of some description in the form of sand, slimes or rock. The geographic location of these MRAs is a swathe of land running south of Johannesburg, approximately a hundred kilometres long and two kilometres wide, straddling the Main Reef Road. No policy exists on the management of these lands, which are increasingly becoming the only land left for human settlement. All are heavily contaminated by uranium and many are geotechnically unstable because of shallow undermining and the presence of open shafts (GDARD 2011). The most coherent work on this topic was first done by American researchers, who raised the issue of post-closure rehabilitation (Tang and Watkins 2011), identifying 5 445 hectares of land capable of being rehabilitated, while also quantifying the presence of around 1.6 million people living in informal settlements in areas that were patently unsuitable. This triggered research by Tahira Toffa (2012), who began to develop technical expertise at the University of the Witwatersrand in the role of landscape architecture in a mining-affected region.

The absence of coherent policy triggered a research initiative that identified a series of risks to government as the mining industry entered its twilight years (GDARD 2011).

Photo 2 (a) (left) shows water erosion on the surface of a TDF after one extreme rainfall event in January 2014. During this specific event, damage to various dumps was widespread. Photo 2 (b) (right) shows natural water erosion off the side of a TDF.



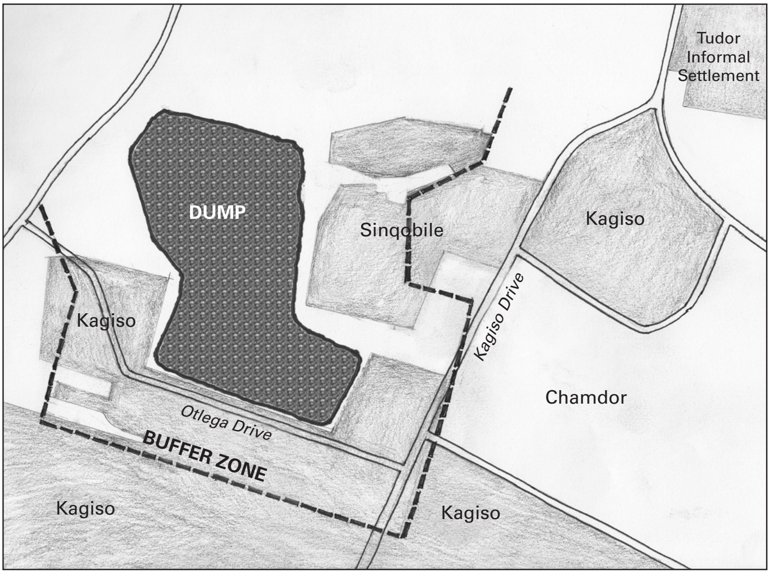
The presence of 1.6 million people was identified as a major concern, with the suggestion that the government had only two choices to deal with the problem – they could either move the people from the hazard or remove the hazard from the people – if they were to prevent the angry backlash that was more or less inevitable. Central to this issue was the least-risk option: removing the hazard from the people. In essence, this means that tailings dams will increasingly need to be removed, particularly where they pose a direct hazard to housing development. Possibly the best example of the tinder-box nature of this hazard is found in the western basin, most notably in the urban development known as Kagiso (Cox 2014). This is shown in Photo 3 and Map 1.

Photo 3 shows new housing being developed directly alongside a tailings dam in the absence of a formal policy for MRA rehabilitation. Map 1 shows the starkest example of a formal settlement that has been allowed to develop within the 500-metre buffer zone of the TDF known as 1L 13-15 in the western basin (GDARD 2011). This specific TDF contains 818 tonnes of triuranium octoxide (U_3O_8) but the inhabitants remain unaware of the risk.

The story told by Map 1 speaks to the unresolved implications of allowing formal housing development to take place within the proposed 500-metre buffer zone of the TDF known as 1L 13-15 in what is known as the Randfontein Cluster. This specific dump is relatively small, containing a mere 18 million tonnes of tailings, but it hosts 818 tonnes of uranium as U_3O_8 (triuranium octoxide), with other species also being present (UO_2 = uranium dioxide). This image was generated during the GDARD MRA policy proposal project where it was used to alert government officials to the risk associated with allowing residential areas to be established in such close proximity to hazardous tailings facilities, without due regard for the implications. It is therefore significant that this specific area of Kagiso became the epicentre of the anti-mining rioting that occurred in December 2013 and January 2014. The ostensible reason for the rioting was damage caused to houses by hail after a massive storm;[4] the focus shifted to mining activities (Cox 2014; Ncana 2014) as a more tangible target to vent anger was sought by activists. The underlying reason, however, was the fact that houses built in the redlined areas are considered by financial institutions to be high risk, so insurance and finance facilities cannot easily be raised against the collateral of the asset, and this makes these houses unbankable, uninsurable and therefore largely unsellable on an open market, rendering them ineffective as poverty eradication initiatives launched by the state. This is the unintended consequence of an inadequate policy, still largely ignored by decision-making elites in government, despite various warnings by technical specialists.

Photo 3

Map 1



The outcome of the Gauteng Department of Agriculture and Rural Development (GDARD) MRA policy proposal project has been inconclusive, leaving the issue unresolved at the time of writing. In the interim, the 1.6 million people identified by Dorothy Tang and Andrew Watkins (2011) is growing steadily, exacerbating the problem to the point where rioting is more or less inevitable when angry citizens realise the implications of their direct exposure to uranium contamination. The 2013/2014 Kagiso riots (Cox 2014) thus provide a natural precursor from which we can better understand the dynamics of what is likely to become a widespread phenomenon as more houses are built on MRA land across Gauteng province in the absence of appropriate policy.

The second issue is the absence of a formally accepted mine closure strategy that is implemented in a coherent manner and financially resourced to the point where the prognosis for success is reasonably good. Many efforts have been made to generate such a formal closure policy (Strachan *et al.* 2008; Van Tonder and Coetzee 2008; Van Tonder 2008), but all have come to nought despite international best practice (ICMM 2006; Smith undated). More significantly, Hugo Van Zyl *et al.* (2012) have shown that insufficient capital has been set aside to fund the rehabilitation needed post-closure. We are thus confronted by a perfect storm because there is no formal policy on MRA rehabilitation at provincial and local level, specifically in so far as human habitation is concerned; while at the same time there is no national level strategy on mine closure that ring-fences the finances needed to rehabilitate mining-affected land so that it is fit for purpose post-closure.

The third issue is the presence of shallow undermining in all of the MRAs of the Witwatersrand goldfields. There are a number of surface striking reefs stretching from Randfontein in the west to Springs in the east, each with a holing to surface approximately 100 metres apart from each other. This results in literally tens of thousands of openings into the old underground workings. Of greater significance to the risk profile is the fact that these openings allow the continued but haphazard mining of these old workings by illegal artisanal miners known as Zama Zamas. Photo 4 (a) shows some of these old workings that have been revealed by open cast mining operations in the western basin. In this specific location it is known that extensive shallow workings are currently being developed by artisanal miners below a railway line and a national highway, with the strong probability of structural failure in the near future. The propagation of this geotechnical instability to surface is evident in Photo 4 (b) as the progressive collapse of ground above a shallow stope revealed by open cast operations. This remains invisible to those on surface, but it is a growing hazard.

In the absence of a formal policy on both mine closure and MRA rehabilitation, human settlements will increasingly be at risk of geotechnical instability and therefore subject to damage from land subsidence. It also means that banks and other financial institutions will increasingly protect themselves by redlining such areas as a way of managing their exposure to this undisclosed and thus unquantified risk. This has serious implications for the owners of these houses, most notably regarding the inability of the asset to be acceptable as collateral for a loan and thus ineffective as a tool for poverty eradication.

Photo 4 (a) (left) shows shallow underground workings that have been revealed through open cast operations in the western basin. Photo 4 (b) (right) shows the propagation of geotechnical instability to surface from shallow stoping revealed by open cast mining.

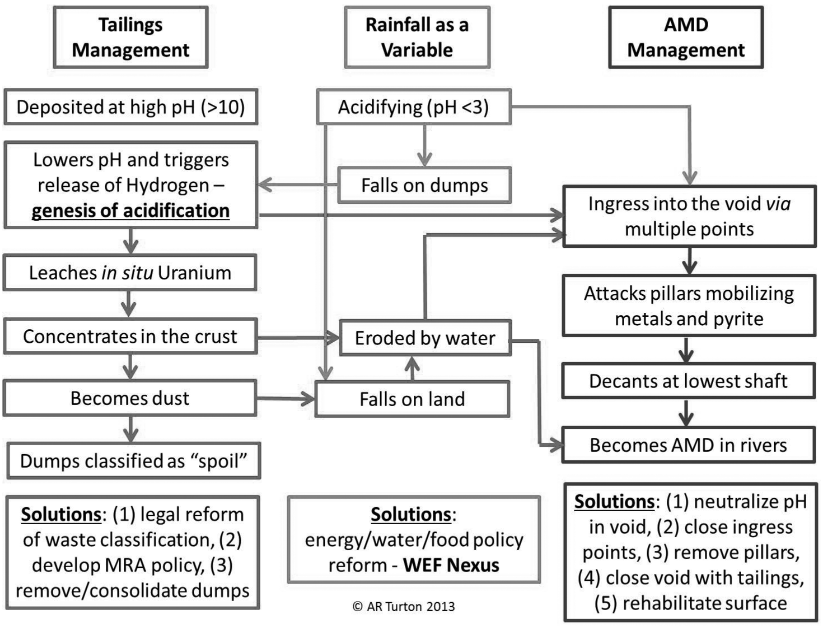
Furthermore, the recent (December 2013 and January 2014) Kagiso riots (Cox 2014) suggest that people become angry when they realise that damage to their houses cannot be claimed from an insurance company, so they actively seek a third party to blame. This focuses the attention of their anger initially on the local elected officials, who then rapidly deflect this onto the local mining company, which becomes the scapegoat for the absence of a coherent policy on MRA land rehabilitation – and it raises the question about what that anger would be once the residents start to realise that they are also exposed to uranium, an invisible hazard that will take long to manifest but, once present, is likely to be evident on a scale unprecedented in South African history.

The fourth issue of serious concern is associated with the growing presence of illegal artisanal miners (Wolmarans 2014). Recent experience in the central basin has shown that turf wars which have the capacity to rapidly escalate into extreme levels of violence,[5] break out between rival gangs.[6] Finally, a serious problem is associated with the environmental consequences of unplanned closure. This will be dealt with in greater detail in the next section, because while it is the least risky of the immediate concerns in the short term it is from here that the gravest risk arises to the largest number of people in the long term. It also poses a grave risk to increasingly fragile investor confidence in Gauteng as an economy, with strategic implications for long-term job creation.

WHEN THE INVISIBLE BECOMES THE GREATEST RISK: THE DILEMMA OF ACID MINE DRAINAGE AND URANIUM

When the paucity of factually based media coverage became evident, I developed a simple model capable of being understood by the layperson (Turton 2013). This is shown in Figure 2. Read from top to bottom and left to right, there are three columns entitled 'Tailings Management', 'Rainfall as a Variable' and 'AMD Management' indicating that there are at least three conceptually distinct components that interlink at different points both spatially and temporally. Starting from the left we have conventional tailings management, where we note that the residue material from the gold recovery process called barren tailings is deposited to the dump at a very high pH (more than ten). The reason for this is that a highly alkaline environment is needed for the metallurgical extraction process to work. The tailings particle consists of a round milled piece of quartzite that contains some residual pyrite (FeS_2), around which a hydroxide coating is created. The best way to understand this is to think of a Smartie, with the chocolate centre representing the quartzite particle and the coloured outer coating representing the hydroxide. This hydroxide coating protects the core particle from being further oxidised, but it becomes damaged over time as the relentless sun bakes the particle until tiny cracks start to appear. Recorded rainfall occurring on the flat-topped TDF has a pH of around 4 (highly acidic). This acidic water attacks the residual pyrite on the quartzite particle, because of the damage to the hydroxide coating. This acidic rain thus lowers the initial pH on the surface of the dumps, generating the first flush of acid. However, the tailings particle also contains uranium and other metals. Uranium is highly sensitive to acid, becoming mobile as a liquid as soon as the pH value crosses a threshold of five. This leaches the residual uranium, which now concentrates in the dust on the flat-topped surface of the dump. Sunlight desiccates this dust and repeated exposure to cycles of acidic rain and dryness creates a crust of uranium-rich residue. This crust is then vulnerable to attack by wind, manifesting as uraniferous dust mobilised over an as yet undefined fallout footprint (Melville 2014). This is the main risk in my opinion, but it is as yet totally absent from the public policy discourse on mine closure and MRA rehabilitation.

Figure 2. Schematic representation of the overall AMD process showing how acid rain is the genesis of acidification that results in the leaching of uranium that is later deposited over an as yet ill-defined fallout footprint.



It is only once the acidic water, now rich in dissolved uranium, flows across the landscape and into the underground mining void that it becomes the acid mine drainage (AMD) that the media currently speak about. This water enters the void via multiple ingress points, including artificial openings to surface created by mining, as well as natural geological features such as dykes and faults intersected by rivers and wetlands. Once in the mine void, it attacks the remaining pillars and abandoned stopes, where it further converts the residual pyrite into hydrochloric acid. This is assisted by the presence of a bacterium known as thiobacillus feroxidans, that converts the sulphur found in pyrite into acid (Wild 2014). This acid in turn mobilises more uranium (and other metals including arsenic, cadmium, nickel and lead) which eventually flows from the lowest opening to surface when the void fills up completely. This is known as decant.

What the concept shown in Figure 2 means in public policy terms is that our current thinking on AMD is deeply flawed (Naidoo 2014) because it ignores the role of acid rain in the initial genesis of acidification. It also ignores the issue of uranium solubilisation by acid rain and subsequent concentration in the crust, later to be dispersed over a widespread fallout zone to then be remobilised in a series of episodic events of which we as yet have no accurate knowledge. More importantly, from a public policy perspective, this means that we have no real evidence-based policy-making processes over an issue of grave consequence to an increasingly large population. Of even greater concern is the as yet unknown implication of changes to uraniferous dust fallout after mining companies become insolvent, as they are likely to become in the near future if we take cognisance of the data in Figure 1.

Given the strategic importance of this problem from a public policy perspective, I developed an additional model that helps to guide decision-making processes. AMD as a purely technical issue is always described by means of more than one chemical equation (Coetzee, Winde and Wade 2006). This suggests that AMD arises from a series of processes, better described as episodic events occurring in nested but discrete sub-systems, each with slightly different biophysical conditions and hence manifesting as different chemical processes. In an effort to unravel these nested sub-systems, I developed the concept of flow pathways shown in Figure 3.

Figure 3 is the same concept shown in Figure 2, but expressed graphically as a two-dimensional map capable of isolating the four discreet flow pathways with their own unique chemical equation to describe them. Stated simply, rainfall with a low pH falls on either the landscape or the flat-topped tailings dam containing hydroxide coated quartzite residue along with residual pyrite and uranium not removed during the metallurgical process used to recover gold.

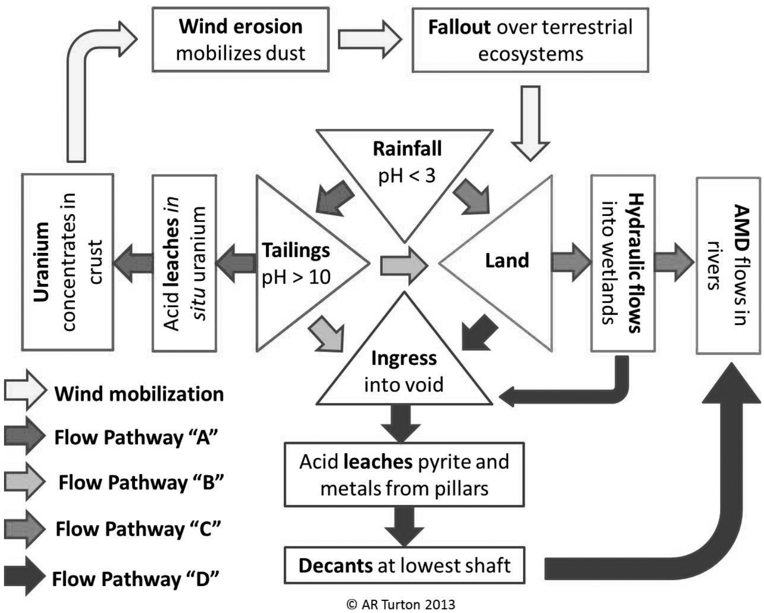
The portion described as flow pathway 'A' is physically located on the TDF itself. This is the portion that becomes the genesis of acidification for the rest of the nested sub-systems, but it is also the origin of uraniferous dust arising from the leaching and subsequent concentration of uranium in the surface crust. Chemically this is described as the oxidisation of pyrite (FeS_2) to form an acidic solution of ferrous iron and sulphate.

Flow pathway 'B' is a gate-keeper in the sense that it determines whether the flow of acidic water from the TDF enters either the void via shallow stopes and surface holings, or the aquatic ecosystem typically via wetlands found adjacent to mine dumps. Chemically this is described as the further oxidisation of ferrous iron to form ferric iron, more slowly at lower pH values. It occurs at the base of the dump that continues to flow either vertically into the void or laterally across the landscape into the nearest wetland or perennial watercourse.

Flow pathway 'C' takes place on surface in the aquatic ecosystems where ferric iron precipitates out as ferric hydroxide, producing further acid. Flow pathway 'D' takes place underground where surface flows are intercepted by multiple ingress points collectively channelling the acidic water into the abandoned workings where additional feedstock to the chemical process in the form of pyrite and uranium is located. This leg of the process is totally invisible and only shows up once AMD reports to the surface, either through contaminated boreholes or as decant from the lowest lying shaft in a given basin.

This model is currently being used by graduate students to construct mathematical models capable of explaining and predicting the flow of water and the speciation of heavy metals within different flow pathways. The first publishable results of this collaboration are starting to become available (Camden-Smith *et al.* 2015; Melville 2014; Wild 2014) but many more are in the pipeline.

Figure 3. Conceptual model showing the relationship between four discreet but nested sub-systems called flow pathways 'A' to 'D'.



PUBLIC POLICY IMPLICATIONS

This ongoing research has major public policy implications, because if the various hypotheses underlying the model presented in Figures 2 and 3 are validated then we are likely to be on the very brink of an environmental catastrophe. For example, J. Melville

(2014) has demonstrated that it is theoretically possible for one TDF (1L 28) to leach one tonne of uranium per month on average, if precipitation levels of 150 mm per month occur. From the perspective of evidence-based policy research, there are major gaps in our knowledge, so we do not even know what it is that we do not yet know. In an effort to help formulate the policy research programme needed, the following are offered as a set of issues that will help to focus our research.

The biggest gap in our knowledge relates to our understanding of AMD as part of a bigger picture (Naidoo 2014), as opposed to merely a flow of dirty water from an abandoned mine void. The following three key research questions are based on my own experience and observation in this field.

Research question 1: Is uranium mobilisation a risk to human health and food security? If so, then the following gaps in our knowledge need to be closed:

- The fate and pathway[7] of uranium and other metals mobilised from TDFs is as yet unquantified and largely unknown, but without this key piece of the jigsaw puzzle no informed policy reform can be initiated. Applying the precautionary principle, we must anticipate the worst, while failure to act could imply criminal negligence on behalf of company executives and government officials mandated to protect citizens from environmental and other risks.[8]
- The mobilisation of uraniferous dust is as yet unquantified to the level of accuracy needed to inform public policy on the rehabilitation of MRA land and the potential entry of metals into the food production chain: either by animals eating fodder that has been contaminated by fallout or as the result of metals entering cereals and vegetables destined for human consumption. Current government initiatives to promote food gardens along contaminated rivers are thus ill-informed and highly risky over the long term.
- The mobilisation of uraniferous dust is most probably driven by extreme events such as major wind storms that have the capacity to mobilise more material than hydraulic processes. Until we actually quantify the volumes involved, as well as the fallout plumes generated, we are unable to reform policy to mitigate the unknown risks.
- The speciation of uranium and other metals contained in the fallout of dust from TDFs is unquantified and largely unknown. One PhD student from Wits University (Camden-Smith *et al.* 2015) is currently doing some work in this regard, but it is focused more on the speciation chemistry of aquatically-mobilised uranium than the fallout of uraniferous dust onto farmland. There are major gaps in our knowledge in this area.
- The absence of a clear policy for the rehabilitation of MRA land multiplies the risk by exposing increasingly large numbers of people to an ill-defined uranium hazard. The very absence of a risk-based assessment is an unnecessary risk in its own right, because in effect we do not yet know what it is we need to know to make an informed policy decision. Again this could imply criminal negligence on behalf of government officials if the Bill of Rights (Chapter 2 of the

Constitution) is invoked by human rights lawyers acting on behalf of affected communities. The Tudor Shaft informal settlement case gives us a sense of how this might unfold in future, but on a larger scale.

Research question 2: What is the most appropriate way to rehabilitate mine-affected landscapes and ecosystems to the point where they no longer pose a hazard to human habitation post-mining?

- The process of leaching and concentrating uranium in the surface crust is dependent on various factors including pH, Eh[9] and alternating periods of wet and dry, so this is an episodic series of events rather than a single process. We do not yet understand how, or indeed if, uranium is mobilised as dust off the tops of unrehabilitated mine dumps. We have no idea of scale and magnitude of the problem, and are therefore unable to make policy-based interventions to prevent exposure of the non-mining population to this invisible and unquantified risk.
- MRA land is naturally contaminated, so it is not suitable for human habitation without effective rehabilitation. This poses the question of what to do with the existing population living on such land. In this regard the GDARD (2011) work needs to be taken to the next level.
- A natural feature of MRA land is the mining of shallow stopes manifesting as geotechnical instability that has significant implications for the construction of all buildings on unrehabilitated land. Nowhere does this feature as a policy-related issue, yet all indications are that as formal mining becomes uneconomic there is likely to be a significant expansion of illegal mining activities and thus an escalation of geotechnical instability (Turton 2015).
- Houses built on unrehabilitated MRA land are likely to be regarded by banks and other financial institutions as being high risk, and this can undermine poverty eradication initiatives. It carries substantial risk to the owners of such houses (Ncana 2014). to the government as providers of assistance to new owners and to the financial institutions needed to provide loans against such assets if existing poverty alleviation policy is to be viable.

Research question 3: How can the government incentivise the investment of the capital needed for rehabilitation back into brownfields mining sites?

- The most important challenge is the fact that greenfields logic underpins our current legal and policy framework. This implies that significant cash deposits are needed before any new investor can start to mine on brownfields sites. The logical outcome of this is disinvestment from brownfield sites, which in effect nationalises the liability (Turton 2015). What is therefore needed is policy reform that brings the existing liability onto the balance sheet in a transparent manner, but then also allows for the quantification of any rehabilitation work that might be done under the auspices of closure mining. This will enable an offset benefit to be quantified and regulated by the state, while attracting investment into highly affected mining sites. To make such projects financially viable for any savvy investor, the multiplier generated downstream from rehabilitation of upstream brownfields sites can also be brought to bear. This means that a new business model will emerge for brownfields sites, based on the offset trade between current known liability and the unquantified benefit of rehabilitation multiplied by the downstream cascade effect. This will attract investment into the most heavily affected sites in the headwaters of the Vaal and Crocodile river systems draining the Witwatersrand goldfields.

If these three questions are considered as a foundation for research, then their yield will be sufficient to generate the evidence needed to inform policy reform and thus avert the disaster that will in all probability occur.

CLOSURE MINING AS A SOLUTION

The complexity of the problem arising from unplanned mine closure and the absence of clear policy on the rehabilitation of MRAs generate a sense of futility and doom. In reality, however, the current situation gives some cause for optimism. South Africans seem to have the capacity to pull the proverbial rabbit from a hat just when things appear to be reaching a point of chaotic collapse into anarchy. This is also true in the gold mining space where there a new concept is starting to take shape. It is called closure mining and it is based on a fundamentally different model from traditional mining.

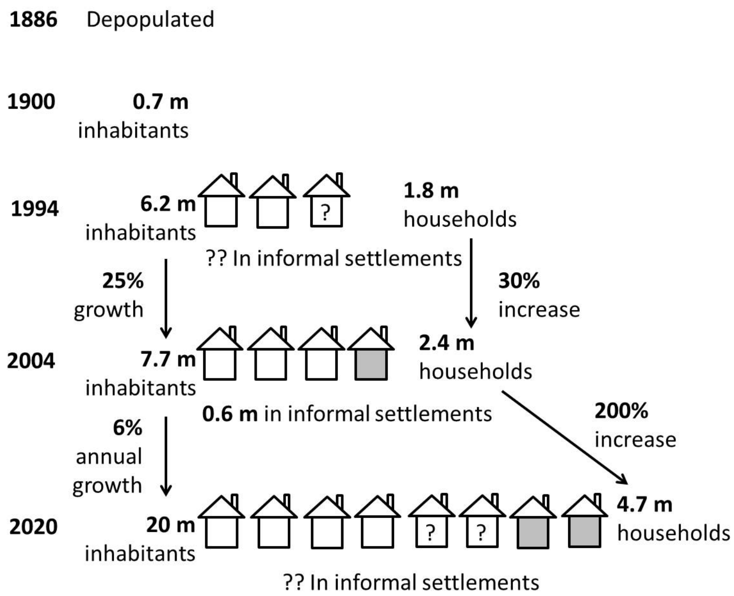
Closure mining can be defined as the deliberate long-term planning to optimise all mining-related processes and operations with a view to aligning the final outcome with the broader interests of society, in collaboration with all key stakeholders in a post-mining future, and guided by the triple bottom line associated with sustainability reporting. Traditional mining, which has been practised in the Witwatersrand goldfields for more than a century (Davenport 2013), maximised profits by externalising liabilities (Adler *et al.* 2007) through the optimisation of all mining processes and operations at the level of the shaft or pit via a company-centric approach that naturally favoured short-term profits over long-term sustainability.

Closure mining, which is not yet in widespread use in the Witwatersrand goldfields, maximises benefits to society over time as historic externalities of mining, now manifesting as constraints to future development, are systematically dealt with in partnership with key stakeholders. In essence this optimises the outcome of current mining at the level of society rather than at the level of the shaft or pit, by internalising historic externalities that are now constraints. As such it embraces the essence of sustainability by internalising the triple bottom line of people, profits and planet. In order to succeed however, it needs policy reform to attract the level of investment needed into brownfield sites (Turton 2015).

The outcome of closure mining is a rehabilitated landscape and functional ecosystem capable of supporting humans and other species while mitigating all legacy issues to the extent that they no longer act as constraints on future socioeconomic development.

The closure mining model is one possible response to the guaranteed demise of the gold mining industry represented by the data in Figure 1. It is based on the notion that land is likely to be in increasingly short supply in Gauteng in the near future, so the value of rehabilitated land will dramatically increase. This is shown schematically in Figure 4.

Figure 4. Schematic representation of the potential for rehabilitated land on the growing population pressure



Source: Tang D and A Watkins (2011) Ecologies of gold: The past and future mining landscape of Johannesburg.

Rehabilited land thus becomes the outcome of the closure mining process and all operations are coordinated to ensure that this is achieved. The eloquent aspect of the model is the fact that it is largely self-financed as the recovery of gold left in old tailings dams is leveraged to benefit society as a whole. This is possible because the old dumps from the early phase of mining still contain enough residual gold to make their recovery technically and financially feasible. This gold is found in values of around 0.3 grams per tonne of tailings, which means that to recover one kilogram of gold, 3 300 tonnes of tailings need to be moved. This cleans up the footprint of old TDFs, ultimately making land available for subsequent economic and social use, even if it is an initially messy process. However, for every tonne of tailings moved, there is between 50 and 200 grams of uranium also present. This means that between 166 and 666 kilograms of uranium can potentially also be removed for every kilogram of gold recovered. This is done either by recovering the uranium (economically possible only in the higher conentrations, more than 100 grams of uranium per tonne of tailings) or by sequestering it in a format that makes it chemically stable and thus unlikely to be mobilised in future. Given the public benefit that arises from this activity, there is a possible case to be made for a subsidy to be given to marginal mines to assist them in generating a public benefit from the closure mining process. This is why policy reform is necessary because capital investment into this concept is currently constrained (Turton 2015).

A few basic facts about the technical aspects of gold processing: simply put, AMD is removed from the void and used as process water. The acidic water is neutralised by exposing it to the high pH of barren tailings causing a precipitation of sludge onto the quartzite particle, which is then co-disposed into a void or onto a mega-dump engineered to twenty-first-century standards. This low-cost industrial grade process water is now safe for use in hydraulic mining, where the remaining TDFs are processed to recover the residual gold – it causes a reduction of the tailings dumps over time, leading ultimately to the removal of significant hazards from society and with that an increase in the prognosis for the non-contested development of MRA land. More importantly it means that hazardous AMD need not be treated to potable water standards as is currently the thinking within government (DWA 2013). In order to improve grades at the mill, remaining ore bodies are also mined. The most notable of these are surface striking reef packages (Photos 4 (a) and (b)), which have the added benefit of closing out access points for illegal artisanal miners while also removing a perpetual source of geotechnical instability. The eventual benefit to society is the restoration of the surface integrity of the MRA land, reducing the impact of structural damage caused by land subsidence while countering the proliferation of criminal syndicates associated with illegal mining. Remaining underground resources are also mined. These generally contain reasonably high grades of gold, but are in low quantities, making them ideal for surgical-styled extraction using modern methods. The flooding of the voids has sterilised most of the underground resources still remaining, so the only viable reef left is in the shallow stopes above the decant level. Significantly this also makes the case for the lowering of void water to environmental critical level (ECL), which will achieve two objectives: it will reduce harmful environmental flows to surface and it will also increase gold resources needed to cross-subsidise rehabilitation work. More importantly, these voids can now also be backfilled with high-density paste to close out the void in perpetuity (Grice 1998) preventing the future generation of AMD from both the surface and the void while also restoring geotechnical stability at the same time as preventing illegal artisanal miners from gaining future access.

In order for the closure mining model to succeed, there are three constraints that need to be overcome. First, there is no institutional arrangement in place between all major stakeholders that supports a cooperative desire to achieve a common vision. All attempts thus far to establish a robust enough institution have ultimately failed for a variety of reasons. Aggressive nongovernmental organisations (NGOs) polarise opinion rather than uniting it around a common vision. Talks are ongoing with the German Development

Agency and other donor agencies to support this initiative under the International Water Stewardship Programme, but they are reluctant to enter a highly polarised arena. The recent revival of the Remediation Action Committee (RAC) of the Wonderfontein Spruit Forum, under the active leadership of the Department of Water and Sanitation, gives cause for optimism, because it seeks to depolarise the stakeholder engagement to the point where convergence is possible. It is in this context that research question Number 1 will become a technical foundation for much of their work in future.

Secondly, there is no scientific, engineering and technology basis that is robust and coherent enough to form an uncontested foundation for rehabilitation. Therefore there is no consensus on how rehabilitation should actually be carried out. This drives social instability and also undermines the process of capital-raising needed to fund such activities and is why research question Number 2 is of great importance. Recently the Water Research Commission has entered into a memorandum of understanding with a mining company that is pioneering the concept of closure mining, to begin developing a national programme for the rehabilitation of mine-affected ecosystems. This is cause for optimism.

Finally there is no vision for a post-closure landscape capable of defining what the purpose of rehabilitation will be, and consequently the standard to which the rehabilitation should take place. It is in this context that research question Number 3 becomes relevant. The absence of clear policy on MRA rehabilitation and mine closure would be very helpful in creating such a vision. The first generation of studies arising from Wits University and the Katholiek Universiteit van Leuven outreach shows that we can potentially generate an uncontested post-closure vision (Juwet and Lyssens 2014). This progress also gives cause for optimism.

CONCLUSION

This chapter has sought to gain recognition for the need to create a coherent solution. Johannesburg is the epicentre of a slow onset disaster and will increasingly be known as the most uranium-contaminated city in the world, whether or not politicians choose to acknowledge this. Previous attempts to silence technical voices raised to alert the enlightened public of an impending disaster have stifled the development of robust evidence-based policy making in an area of great strategic importance. Around 20 per cent of the South African population is likely to be directly affected by the fallout of uraniferous dust arising from collapsing tailings dams in the near future, but nowhere is this issue evident in any discernible form in the media or public discourse on policy. The absence of science, engineering and technology is a worrying manifestation of the apparent decreasing capacity of the state to make proactive policy-related decisions needed to create a soft landing as we transition from an extractive economy in which environmental liabilities were externalised, to a new as yet ill-defined economy in which historically externalised liabilities will increasingly manifest as constraints to job creation and social cohesion.

The health hazards of uranium exposure are not well defined – which alone can drive panic, so even if it is safe to be directly exposed to uranium (which is highly unlikely to be the case) the probability of mass anger and loss of investor confidence still needs to be addressed.

NOTES

1 The recent appointment of Cuban specialists in the water sector and military speaks to the inability of the government to build the capacity needed to manage the affairs of state independent of foreign powers.

2 The far western basin still has significant gold resources and is the last location of proper deep-level mining with a life expectancy of a few more decades provided that labour and energy costs can be effectively contained.

3 See http://en.wikipedia.org/wiki/Uranium for more information.

4 http://www.looklocal.co.za/looklocal/content/en/krugersdorp/krugersdorp-mobile-news?oid=7990736&sn=Mobile-Detail&pid=4732859&Hail-damage-causes-riots

5 http://www.theguardian.com/world/2014/feb/16/south-africa-illegal-gold-miners-rescue

6 http://www.irinnews.org/report/95875/lesotho-illegal-migrant-miners-risk-lives-for-riches

7 The fate refers to the eventual destination of a given contaminant (say, in food) whereas the pathway refers to the chain of causation that moved the contaminant from source to the eventual location where it finally manifests as a hazard. A fate and pathway assessment is needed to inform public policy by defining where natural intervention points are needed to reach a desired outcome.

8 Chapter 2 (Bill of Rights) paragraph 24 states that 'everyone has the right – (a) to an environment that is not harmful to their health or wellbeing; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that – (i) prevent pollution and environmental degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.'

9 Eh refers to the reduction potential of metals measured as a voltage. A high positive Eh value indicates an oxidisation reaction, whereas a low Eh value indicates a reducing reaction. See http://en.wikipedia.org/wiki/Reduction_potential for more information. º

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