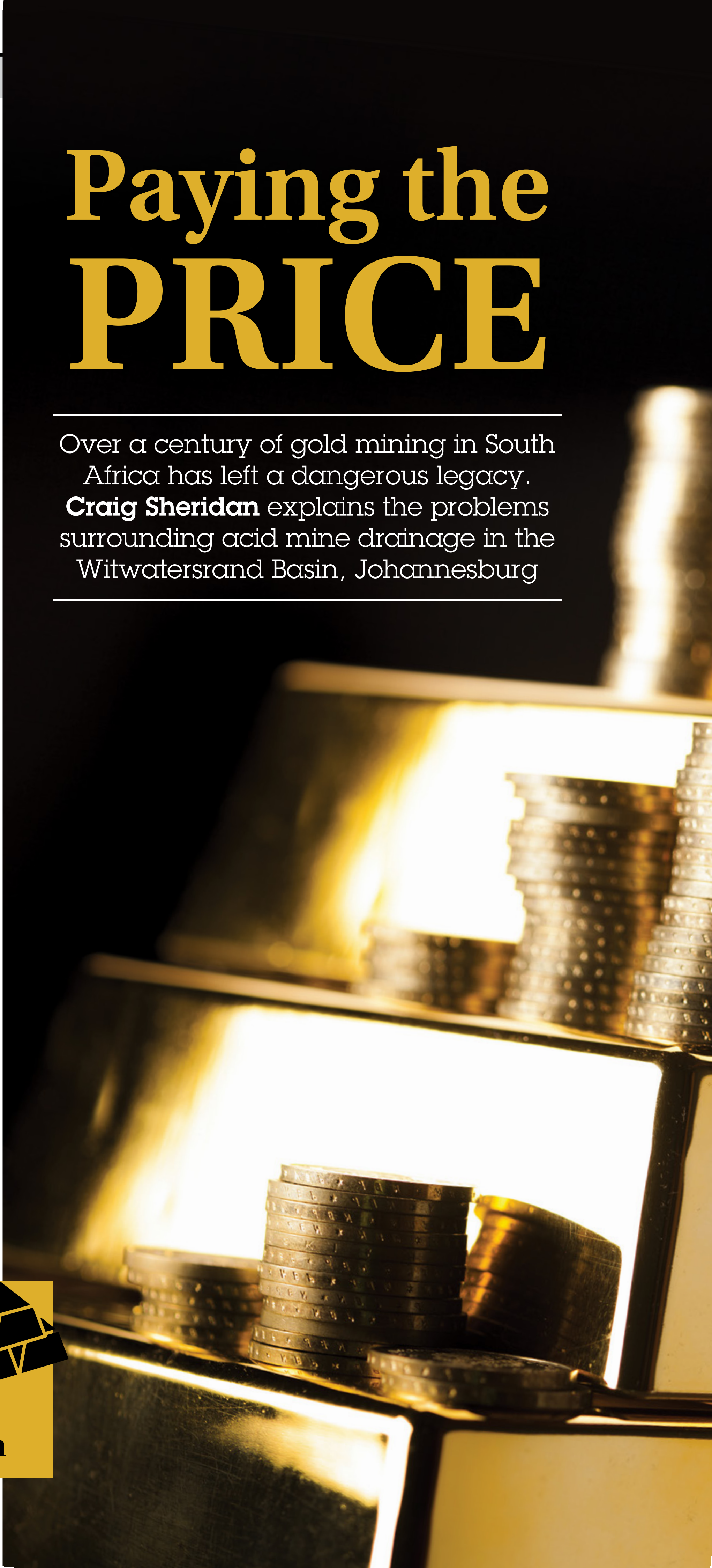
Paying the PRICE

Over a century of gold mining in South Africa has left a dangerous legacy. **Craig Sheridan** explains the problems surrounding acid mine drainage in the Witwatersrand Basin, Johannesburg



IN 1886, discovery of the world's largest gold reserves in South Africa's Witwatersrand Basin near Johannesburg led to a gold rush and prosperity like no other the country had seen. Yet just over a century later, the story is very different – the bulk of the gold underneath Johannesburg has been mined out, leaving an unwelcome legacy of spent mines containing vast quantities of acid. And while technology to deal with this is being developed, experts have been unable to suggest what the full cost may be.

the problem

The source of the problem lies in the fact that the ore body from which we extracted our gold is rich in iron pyrite, which can lead to the generation of acid.

In the case of Witwatersrand, the gold-bearing reef outcropped (ie protruded) at the surface just south of the city centre of Johannesburg and dipped from north to south and east to west. As the reef was mined, the operations became deeper and ground dewatering was required. Currently this practice continues to the west of Johannesburg where mining operations are the deepest in the world – reaching nearly 4 km underground.

Each mine would dewater their operations to expose the gold-bearing reef (and the iron pyrite-rich rock) and if a mine closed down, the pumping requirements would shift to adjacent mines. This led to the tenuous situation where the last-man-standing was responsible for keeping the mine void free of water.

In 2008 the last pump shut down in the central area and ever since, the groundwater levels have been recharging. If nothing were to be done, uncontrolled decant (ie overspill of acids) at the surface would occur in late 2013 or 2014. The groundwater is recharged through a combination of groundwater flow and surface ingress through the mine workings. Surface water, especially, is oxygen rich and as the oxygen-rich water comes in contact with the exposed pyrite, acids are produced (see *Acids from ores*, over).

Thus, as the groundwater recharges, it generates an acidic solution, with a high concentration of sulphate.

Nearly HALF of all the gold ever mined has come from the extensive Witwatersrand Basin

Chris Eason/ Wikipedia

Top to bottom: The Witwatersrand is a large sedimentary range of rocky hills in South Africa. The rocks of the "Rand" or reef, as the Witwatersrand is sometimes known, are rich in uranium and gold; mining acid damage

In addition, at these conditions (low pH), most heavy metals are mobile and the decant therefore contains elevated levels of heavy metals and radioactive elements (in those instances where the ore body is radioactive, such as in the Witwatersrand Basin). Surface-based slimes dams (ie dumps of waste slurry formed from crushed rock) are also sulphate rich, and run-off from these dumps may significantly contribute to the contamination of the groundwater.

This acidic upwelling of groundwater (known as acid mine drainage, or AMD) could decant into surface watercourses, and currently poses a significant threat to Johannesburg. Where decant has already begun in the Western Basin (towards Krugersdorp, west of Johannesburg), the pH ranges from 2–3 and the sulphate concentration is around 3,500 ppm. Thus, the legacy of over a century of mining activities finally has a real and significant price tag, which was certainly not envisaged in 1886 when the outcrop of gold was first exploited.

the solutions

The treatment of AMD can be broadly classified into three types. These include physical, chemical and biological treatment or a combination of the three, as follows:

- **physical treatment** – uses differences in the physical properties between anions and water to enact some kind of separation. The different systems for treating AMD include reverse osmosis (RO), nano-filtration, ion-exchange (liquid/liquid, resins or charcoal), and eutectic freeze crystallisation. Anglo American has, within the last few years, installed a large reverse osmosis operation near eMalahleni (previously known as Witbank, located around 100 km east of Johannesburg) to treat coalfield-based AMD. Currently 25m l/d of AMD is being treated to potable standards and this is being used to supplement the municipal water supply.
- **chemical treatment** – as the name suggests, chemical treatment relies on chemical reactions to effect treatment; normally pH neutralisation. Remediation occurs through an adjustment of pH by the addition of a basic/alkaline reagent leading to a rise in pH and thus to precipitation of the metals in solution. This treatment is also able to remove some sulphate, normally through precipitation as gypsum. However, due to solubility constraints, even after complete precipitation the sulphate load remains at approximately 400 mg/l. Thus, whilst most metals are removed, there is always a residual sulphate concentration.
- **biological treatment** – uses plants or microbes (or both). The mechanism of sulphate removal may be via dissimilatory sulphate removal (DSR), which is an anaerobic process. DSR proceeds according to the following reaction:

$$SO_4^{2-}(aq) + 2CHO_2(aq) \rightarrow H_2S\,(aq/g) + 2HCO_3^{-}(aq)$$

In South Africa, there are many examples of biologically-remediated AMD, which include the Biosure process which was developed at Rhodes University, bioreactors, constructed wetlands, and of course the natural processes of attenuation would classify as some form of bioremediation. The limitation with biologically-enabled remediation is that kinetics are slow.

governance

The threat of acid mine drainage is being taken seriously; and a response at government level is ongoing. A collaborative team of experts from several ministries has been established, and its initial recommendations for the Witwatersrand are:

- **decant prevention and management** – pumping out groundwater to hold the level at an environmentally critical level (ECL) would prevent decant into the environment. This water is currently acidic, and would be further treated by a high density sludge process (HDSP) to neutralise the acidity and remove heavy metals, but some sulphate would remain). In HDSP, lime is added to the AMD and a portion of the sludge produced is recycled;

Acids from ores

Pyrite in the mined ore comes into contact with oxygen-rich water:

$$2FeS_2(s) + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4H^+ + 4SO_4^{2-}$$

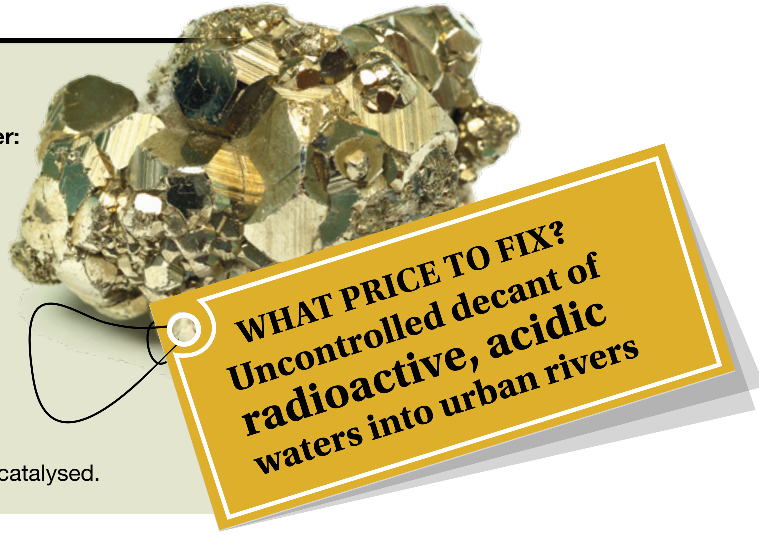
The ferrous iron proceeds to react with oxygen and acidity to produce ferric iron:

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$$

The ferric iron subsequently reacts with iron pyrite and water and this reaction produces the majority of the acid:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

To add to the problem, these reactions can also be microbiologically catalysed.



- **ingress control** – to reduce the rate of flooding and the eventual decant volume. This would be achieved by sealing as far as possible points of surface ingress into the subsurface aquifer (such as sealing old mine shafts); and
- **water quality management** – the water pumped from the aquifer would be acidic, however instead of uncontrolled acidic decant, the mine drainage would be within a manageable system and would therefore be treatable.

Subsequently, a short-term solution has been implemented by the Trans-Caledon Tunnel Authority (TCTA) which has been instructed by the Ministry of Water Affairs to assist. The TCTA is a state-owned enterprise normally responsible for building dams and trans-continental pipelines. The short-term solution consists of pumping the aquifer water to maintain groundwater levels at the ECL and this water is to be treated using HDSP. The capital cost of this process is large – R320m (US$32.5m) followed by long-term running costs to purchase lime to treat 27m l/d, 57m l/d and 82m l/d in the Western, Central and Eastern basins respectively.

where next?

Unfortunately, the HDSP doesn't reduce sulphate levels to less than 400 mg/l and as a consequence, in excess of 150m l/d of this water will be released into the rivers in and around Johannesburg. Of course the quality of this water is certainly much better than untreated acidic decant. However, agricultural users downstream may potentially not be able to use this water for irrigation due to more stringent legislation in receiving markets such as those in the EU. In addition, the sludge produced by the HDSP may be radioactive (since the ore body beneath Johannesburg contains uranium and some mine drainage has uranium present at concentrations in excess of 5 mg/l) and therefore there may be significant difficulties with the handling of the sludge produced.

Our multi-disciplinary research group, the Industrial and Mining Water Research Unit (IMWaRU), based at the University of the Witwatersrand, currently has a suite of research projects targeted towards considering ways either of replacing the lime, or of treating the residual sulphate concentrations. We are researching the potential use of basic oxygen furnace slag, the use of constructed wetlands as well as identifying other carbon sources (electron donors) for DSR. Unfortunately, there is still much research which needs to be conducted and if novel processes are found, there are still substantial time lags between demonstrating proof-of-concept in a laboratory and successful scale-up.

The long-term solution to the problem faced in South Africa – and how much it will cost – has yet to be determined. Fortunately we have many highly competent people working on it, and we hope that our solution may potentially help other mining countries (such as the US, Australia, South America and Russia) facing similar problems with sulphide ores. tce

Craig Sheridan (craig.sheridan@wits.ac.za) is a co-founder of the Industrial and Mining Water Research Unit, and senior lecturer in the School of Chemical and Metallurgical Engineering, University of the Witwatersrand, Johannesburg

further reading

1. *Mine water management in the Witwatersrand Gold Fields with special emphasis on acid mine drainage*, report to the inter-ministerial committee on acid mine drainage, 2010, http://bit.ly/15zqOMz
2. Vermeulen, A, "Tackling the Witwatersrand AMD problem", *Mining Weekly*, http://bit.ly/16XuVOV
3. McCarthy, T, *The decanting of acid mine water in the Gauteng City-Region*, GCRO report, September 2010, http://bit.ly/1c37nzd