Chris Curtis

AMD

Mauro Lourenco tells us about acid mine drainage, and the secondary impacts associated with its treatment

Acid mine drainage (AMD) – the flow of contaminated water from both active and inactive mines – is a worldwide problem and one of the most damaging forms of water pollution. Apart from being highly acidic, AMD is likely to contain toxic heavy metals and radioactive particles, which are dangerous to human health and the natural environment. Heavy metals are metals and metalloids that have a relatively high density compared to water, and include lead, cadmium, chromium, mercury and arsenic as some of the most toxic examples. Some heavy metals, such as iron, copper and zinc, are essential trace elements for our health at very low concentrations but are toxic at high concentrations.

To understand how AMD occurs, one should imagine the processes occurring in a mine whilst it is still active. Mine workers dig deep into the earth, often below the water table, to extract mineral ore during mining operations, so water is constantly pumped out to ensure the mine does not get flooded and workers are kept safe and dry. Once the mineral ore resource has been depleted and the mine is abandoned, the need for pumping stops, and groundwater as well as ingress from rainfall runoff and surface streams slowly fill up the mine voids that were created during mining. Now the ore that has been locked away in the underground rock for millions of years is exposed to air and water, causing oxidation of metal sulphides such as iron sulphide – commonly known as pyrite or 'fool's gold'.

The chemistry of pyrite oxidation is complex and a number of different chemical reactions may occur in sequential stages, the reaction rate being dependent on the pH and the presence of certain bacteria. The overall process can be summarised by the following reaction:

$$4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4Fe(OH)_3 + 8SO_4^{2-} + 16H^+$$
Pyrite + oxygen + water ⟶ 'yellowboy' + sulphate + acid

'Yellowboy', or ferric hydroxide, is a yellow-orange solid that precipitates out and discolours water. It is damaging to

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The distinctive orange colour of acid mine drainage is due to 'yellowboy', a precipitate composed mainly of iron(III) hydroxide, also known as ferric hydroxide.

plant and animal life, and toxic to consume. The release of hydrogen ions lowers the pH, generating acidity. The acidic water then reacts with other minerals, releasing additional heavy metals and other elements, many of which stay in solution because the metals do not precipitate easily under acidic conditions. The water slowly moves through the mine voids, encountering other exposed rock faces, and eventually decants (pours out) at the surface.

What's more, as ore material from underground is brought to the surface for processing, mines typically store the ore waste – called tailings – in a tailings dam or mine dump. The tailings material is exposed to the elements, resulting in further oxidation and acidity generation.

Both sources of AMD may pollute the surrounding environment, often causing species decline or mass mortalities in rivers and wetlands, and eventually rendering them practically lifeless.

South Africa's mining legacy

In South Africa, AMD is mainly associated with gold and coal mines. Understanding the problem requires us to travel back in time and appreciate the context of mining in the rainbow nation.

Gold was first discovered in 1886 in the Witwatersrand Basin, triggering the Witwatersrand gold rush and the development of Johannesburg, aptly nicknamed The City of Gold. The discovery changed the country's identity from a principally agricultural economy and society into the largest producer of gold in the world – a title South Africa held until finally being overtaken by China in 2007. South Africa has since fallen out of the top 10 in terms of production.

Although small-scale commercial coal mining had begun in Molteno in the Eastern Cape in 1870, the gold rush dramatically increased demand for coal, and large quantities were extracted from new mines on the Highveld coal fields. South Africa still relies on coal for energy production and export revenue, and the coal sector employs over 90 000 people, but many mines have been abandoned over the years, and more closures are on the horizon as countries transition to renewable energy sources.

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The Tweeloopiesspruit decant point in the Witwatersrand Western Basin in February 2017. Here the 'yellowboy' precipitate is a darker orange-brown colour.

https://www.dws.gov.za/iwrp/AMDFSLTS/

The mining basins of the Witwatersrand.

AMD was reportedly recognised as a threat as early as 1903, but the issue came to a head after the Western Basin of the Witwatersrand gold fields began decanting in 2002. By 2010 the water level in the Central Basin was rising by about half a metre per year, so an Inter-Ministerial Committee on AMD was set up in September of that year and a team of experts appointed.

Both short-term interventions and long-term solutions were ultimately identified over the following three years, and the Department of Water and Sanitation (DWS) appointed the Trans-Caledon Tunnel Authority (TCTA) to implement them. Nevertheless, complete AMD treatment is difficult to achieve, and extensive rehabilitation and restoration is needed at each location, requiring water boards, water treatment companies, engineering firms and environmental groups to band together.

The Springs AMD story

The story of AMD treatment in the mining town of Springs started in 1996 and has not yet come to a conclusion. Springs is situated in the Eastern Basin of the Witwatersrand gold fields, and the Grootvlei Proprietary Mines Ltd operated a gold mine there from 1934 until 2010. The mine is located within the Blesbokspruit wetland – designated a Ramsar Wetland of International Importance in 1986 – and is upstream of the Marievale Bird Sanctuary.

The Grootvlei gold mine started major pumping in 1995 but was ordered to stop within a few months, after orange-red AMD sludge was observed in the Blesbokspruit wetland. Due to this contamination, in 1996 the wetland was placed on the Montreux Record, which lists threatened, degraded or endangered Ramsar wetlands, and it remains on this register today. Pumping was permitted to resume in 1996 on condition that Grootvlei treated underground water in a small high-density sludge (HDS) processing plant.

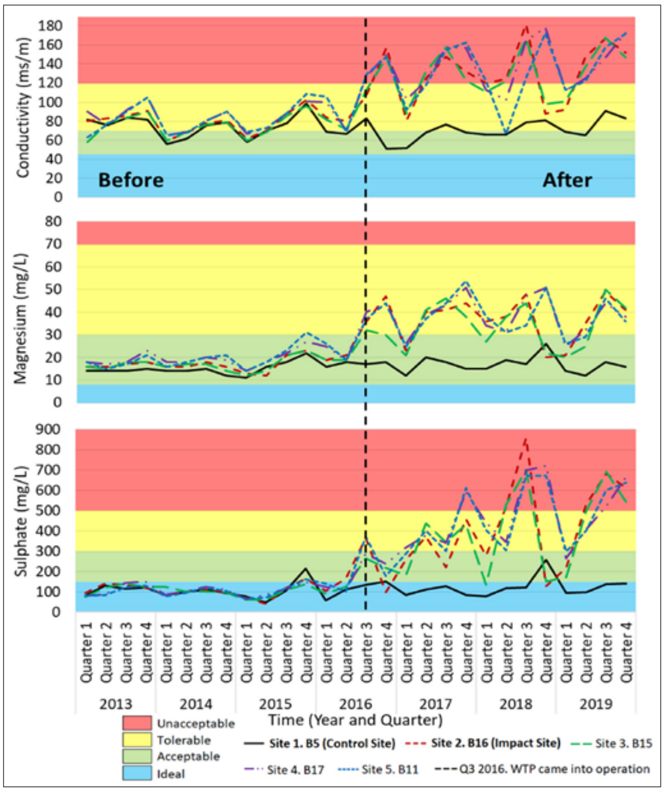
The HDS process is designed to raise the pH of the acidic mine water so that heavy metals precipitate out and can be removed. The original HDS plant improved the quality of effluent, which was discharged downstream after passing through settling ponds, but it still had a high dissolved salt content.

After closure of the mine in 2010, pumping ceased, which meant that AMD water would ultimately decant at the surface. In August 2016 the Eastern Basin AMD treatment plant was launched after two years under construction, at a total cost of R1 billion. The purpose of the plant, one of the largest of its kind in the world, is to prevent AMD decant and treat the pumped water through a bigger HDS plant.

The water is first mixed with limestone ($CaCO_3$) as a pre-neutralisation step, and then agitated and aerated to oxidise the ferrous iron and manganese. Lime ($Ca(OH)_2$) is added to raise the pH further, followed by polymers that act as flocculating agents – causing solid particles to aggregate – in the gypsum crystallisation tank. Here, metals precipitate as metal hydroxides, while sulphate ions and calcium ions form gypsum ($CaSO_4 \cdot 2H_2O$). In the thickeners section, the effluent is clarified as the solids are settled out as a sludge consisting of metal hydroxides and gypsum. Some of the sludge is recycled back to the start of the process to aid neutralisation and precipitation, and the rest disposed down the old Grootvlei No. 1 shaft. The treated effluent is discharged into the Blesbokspruit.

Impact of the treatment plant

Unfortunately, the current situation at Grootvlei is similar to when the original small HDS plant was operating. The issue is due to basic chemistry: when we neutralise something acidic – in other words, we add a base to an acid – we generate salt and water.



Lourenco and Curtis, 2021

Time-series charts for conductivity, magnesium and sulphate monitored by Rand Water at Blesbokspruit sites for the period 1 January 2013 to 31 December 2019. The colours on the charts correspond to the Blesbokspruit Forum water quality guidelines for each specific variable. The dashed black line indicates the quarter in which the treatment plant came into operation (Q3 2016).

AECOM/ NGAGE

The Eastern Basin AMD treatment plant, designed by AECOM for the Trans Caledon Tunnel Authority (TCTA), is one of the largest high-density sludge (HDS) plants in the world, with a maximum treatment capacity of 110 ML/d.

I researched the influence of the new treatment plant on the Blesbokspruit wetland for my MSc degree, awarded by the School of Geography, Archaeology and Environmental Studies at the University of the Witwatersrand. An analysis of data from Rand Water, which conducts regular sampling at a number of sites within the wetland as part of a monitoring programme, shows that all the sites had similar seasonal patterns of conductivity, magnesium and sulphate levels before the AMD treatment plant came into operation. After the treatment plant started, however, these parameters increased dramatically at sites 2, 3, 4 and 5, which are all downstream of the plant, and conductivity and sulphate have reached unacceptable levels. Site 1 is upstream, so it does not show evidence of changing water quality through time.

In general, salts that dissolve in water break into positively and negatively charged ions. The major positively charged ions are sodium (Na^+), calcium (Ca^{2+}), potassium (K^+) and magnesium (Mg^{2+}). The major negatively charged ions are chloride (Cl^-), sulphate (SO_4^{2-}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), nitrate (NO_3^-) and phosphate (PO_4^{3-}). Conductivity is the ability of water to conduct an electrical current, and the dissolved ions are the conductors. Salinity is a measure of the amount of salts in the water. Because dissolved ions increase salinity as well as conductivity, the two parameters are related.

The evidence of a highly saline environment downstream of the treatment plant are clear to all who visit Marievale Bird Sanctuary, as salt crusts can be observed on soil surfaces where water has evaporated. Highly saline environments are not only potentially damaging to species that cannot tolerate the salty conditions, but the Blesbokspruit is also a tributary to the Vaal River System, an important water source. Although the Blesbokspruit joins the Vaal River below the Vaal Dam, which is the main drinking water supply for the people of Gauteng, water already has to be released periodically from the Vaal Dam in order to dilute

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At Marievale Bird Sanctuary downstream of the treatment plant, salt crusts can be seen on soil surfaces where highly saline water has evaporated.

water released from the Vaal Barrage further downstream, to ensure it is not too saline for irrigation and other uses. This means that increasing salinity in the Vaal River is a threat to water security because more water would need to be released from the Vaal Dam, rather than being stored for use in Gauteng. It is therefore important that the desalination process recommended as part of the long-term solution is implemented at the Eastern Basin AMD treatment plant in order to produce acceptable water quality for the area.

In September 2020 the Minister of Human Settlements, Water and Sanitation, Lindiwe Sisulu, gazetted the Reserve for the water resources in the Vaal Water Management Area. The Reserve includes the Ecological Water Requirements (EWR) and the Basic Human Needs Reserve (BHN) for the rivers in the management area. As such, it stipulates the water quality ecological specifications – including the concentration of various inorganic salts – that must be maintained at an EWR site on the Blesbokspruit below the Eastern Basin AMD treatment plant, and also makes recommendations to improve the ecological state of the wetland.

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Acid drainage also flows from tailings – the ore residues after mineral processing – and in South Africa this is typically referred to as acid rock drainage (ARD).

Historical issue: future problems

AMD is a historical mining issue in South Africa. The numerous problems associated with many abandoned mines and some of the largest tailings dumps in the world, including acidity, biodiversity loss, threatened water resources and health risks, were born over 100 years ago and are predicted to continue for the foreseeable future. In our water-scarce nation, these AMD impacts cannot be ignored, and will require ongoing management action.

- Lourenco, M and Curtis, C 2021. The influence of a high-density sludge acid mine drainage (AMD) chemical treatment plant on water quality along the Blesbokspruit wetland, South Africa. *Water SA* 47(1): 35-44. https://doi.org/10.17159/wsa/2021.v47.i1.9443

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Mauro Lourenco collecting water samples at Marievale Bird Sanctuary in 2018.

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