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The decanting of acid mine water in the Gauteng City-Region: analysis, prognosis and solutions

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The decanting of acid mine water in the Gauteng city-region

Analysis, prognosis and solutions



PROVOCATIONS

by Prof Terence McCarthy

School of Geosciences,
University of the Witwatersrand,
Johannesburg

GCRO
Gauteng City-Region Observatory

DISCLAIMER

The Provocation series is meant to provoke and enlighten on key issues of the day. We are attempting to bring the best academic knowledge on key issues to a wider audience. The views or opinions presented in this document are solely those of the author/s and do not necessarily represent those of the Gauteng City-Region Observatory or any of its partners.

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ABOUT THE PROVOCATION SERIES

Provoke | *to stimulate, incite, stir up, challenge, irk, exasperate, vex*

The Gauteng City-Region Observatory's Provocations is an on-going series of think-pieces that give a platform to cutting edge thinking on current issues of the day, written and presented in non-academic style and format. Each Provocation is offered by an academic or practitioner for reading by a wide audience, with the hope of shedding light on key topics relevant to researchers, policy-makers, business people, activists and members of the public.

The series aims to challenge conventional understandings, stimulate new thinking, stir up debate and incite readers to respond with interpretations of their own. At times, the thoughts offered will exasperate, perhaps even anger. Each piece goes through rigorous editing, but the analysis, views and opinions presented are solely those of the author.

FOREWORD

As early as 1987, the US Environmental Protection Agency recognised that "...problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk. The release into the environment of mining waste can result in profound, generally irreversible destruction of ecosystems."[1]

In 2011, possibly 2012, acid mine drainage (AMD) will seep up through the main shaft at Gold Reef City, and the underground facility will be forced to close. At the same time, Boksburg could see AMD rising up through drainage points, spewing toxic filth into the town. The 'void' – the large hole left by mines stripping out rock, and formerly kept in balance by pumping out water – will have filled, and water carrying sulphuric acid, heavy metals and any number of toxins, will spill out and could compromise our cities and towns, our economy and environment, our reputation and, arguably, our future.

There is still time to act – though not much. There seems also to be a will to act. This brief piece aims to clarify the scientific facts behind the issue of decanting of acid water from mines on the Witwatersrand. It goes further and makes recommendations for action. The basic thrust is that what matters now is action, not talk.

Mining has long been a cornerstone of South Africa's economy, although its economic power is slowly waning. In particular, gold mining in the Witwatersrand has been a key sector in the province since 1886 and was the initial reason for Johannesburg's existence. Mining made Johannesburg 'the city of gold' and helped make Gauteng a wealthy province. A century of mining has had many positive economic impacts – some individuals, shareholders and companies became spectacularly wealthy, the state gained significant revenue through taxes (on companies and workers), jobs were created, and militant and organised trade unions were a focal point of resistance - but not all its impacts have been positive. The social and environmental impacts were not

[1] http://www.csir.co.za/nre/docs/BriefingNote2009_2_AMD_draft.pdf

given much focus in the past, written off as a necessary cost of business. And not all the problems were immediately visible.

An unsustainably managed mine will see future generations having to deal with the impacts. We are that generation, and right now, rising water levels in the mine void and the looming threat of decanting acid water in the Gauteng city-region is the problem we have been bequeathed.

The problem is not new for Gauteng. While there have been numerous news reports on acid mine drainage for over a decade, it has been difficult and confusing to separate fact from fear tactics.

Recent news reports on acid mine drainage in Gauteng have given wildly conflicting views from being the 'single most significant threat to South Africa's environment'[2] to mere hysteria by 'private sector interests'.[3] Some reports suggested that "the immediate crisis with AMD in the Witwatersrand started in 2002 with the flooding of the western basin at a rate of 20-million litres a day".[4] In 2009, it was reported that the liquidation of Pamodzi Gold had led to the shut down of mining activities and thus acid water problems were experienced at the East Rand operations.

The Water for Growth and Development Framework (WGDF), launched in March 2009 by the Department of Water Affairs highlighted that AMD from abandoned mines could result in catastrophic ground and surface water pollution. In October of 2008, East Rand Propriety Mines Ltd. (ERPM) ceased pumping and the void – the space underground created by extracting rock, and kept in balance by pumping out water - began to fill. Since then the water level in the void has risen and currently lies at a depth of about 600m below the surface. This could rise faster as we enter our rainy summer season. The average rate (across the year as a whole) is about 15m per month. At this rate of rise, the void will be completely filled in about two and a half years from now. At that point, decanting of acid water will be a widespread reality.

Given the urgency as well as the possible threat to the economy, health and environment, decant of acid water in Gauteng is indeed an appropriate starting point to launch the Gauteng City-Region Observatory (GCRO) *Provocations* series. The purpose of the series is to foster open and frank debate on current issues, by making expert academic views accessible to a wide audience. Each 'provocation' is meant to

2 http://www.miningweekly.com/print-version/in-the-midst-of-a-disaster-2009-05-08
3 http://www.newstime.co.za/SouthAfrica/Trevor_Manuel_calls_for_rational_debate_on_acid_mine_water/9100/
4 http://www.miningweekly.com/print-version/in-the-midst-of-a-disaster-2009-05-08

provoke a response from the reader while simultaneously providing clear information. The series is commissioned and edited by GCRO but does not necessarily reflect the views of the GCRO.

In this first edition of our *Provocations* series, Professor Terence McCarthy of the School of Geosciences at the University of the Witwatersrand provides a clear description of filling and decanting of the mine void in Gauteng, including a detailed description of AMD, its formation, the affected areas, an assessment of the threat, and what needs to be done. Appropriately, some of the arguments are provocative and worthy of further discussion and debate.

The first is related to the solutions being proposed. The Department of Water Affairs has agreed to put one new pumping station[5] and upgrade a high-density sludge treatment operation to stop acid mine water rising up in Johannesburg and causing an environmental disaster. McCarthy argues that at least two pumping stations are required to pump the water to the surface for treatment – the proposed solution, in his view, falls short.

According to McCarthy, we need one pumping station in the Germiston area and another in Florida, so that the water level is maintained at 300m below surface at these two points. He also suggests that a private contractor be appointed to establish and carry out the pumping, allowing for proper performance and cost auditing.

...the void will be completely filled in about two and a half years from now.

But the 'one pump or two' debate should not obscure the fact that long-term, integrated solutions are needed – the problem will not respond to once-off band-aids, however expensive they happen to be. An integrated range of measures would include active water treatment, passive water treatment systems, and controlled placement of acid-generating mine waste, amongst others. According to Mariette Liefferink,[6] AMD water can be treated by reverse osmosis - another extremely expensive process – but one that mines can afford to pay, in her view. Here she differs markedly from McCarthy.

[5] Pumping is not time-delimited and will have to continue indefinitely.
[6] Liefferink is chief executive of the Federation for a Sustainable Environment and was quoted in http://www.mg.co.za/article/2010-09-07-mines-must-take-prime-responsibility-for-acid-drainage

The measures proposed may amount to more than R2,5 million a month for a treatment plant.[7] McCarthy argues strongly that the cost should be borne by the state. Government has for decades been paying pumping subsidies to mines to cover the cost of pumping inflow from defunct, adjacent mines as it is; and he notes that "Government is invariably the largest single beneficiary of mining ventures through the state share of profits formulae, taxation of company profits and taxation of salaries paid to workers."

However, civil society activists believe that mines have enriched themselves without any acknowledgment of the costs to the environment, and are continuing to enrich themselves while doing little for the environment – damage is a 'cost of business'. Many believe that a policy of 'the polluter pays' should apply.

While these arguments are morally sound, McCarthy asks the question: which mines should pay? AMD is the result of a century and more of environmental damage, and hundreds of mining companies have long closed down - so which companies must be held accountable for centuries of pollution? Mines in many affected areas are no longer operational, making it difficult to enforce compliance. But if we accept McCarthy's point, how then must government ensure that companies currently mining are not allowed to sidestep culpability for the destruction of the environment because some of their predecessors are not around to foot the current bill? Again, an integrated and balanced solution (with state and existing mines contributing) rather than an 'either/or' approach seems most appropriate.

...government has had AMD on its 'urgent' agenda since 2009, but has yet to act.

A third issue raised in the document alludes to what is seen as slow action by government. The flurry of press coverage in 2010 has seen a seemingly quick response by government, but there is considerable scepticism regarding the gap between words and deeds, and the speed with which government will transform the former into the latter. An inter-ministerial committee was established and a task team convened in 2009. In addition, mining companies and the Department of Water Affairs have agreed to co-operate to 'fight' acid mine drainage. In February 2010, it was reported that a contract to deal with mine pollution between government and the mining houses had been signed and funding would be apportioned between the parties.[8] In August 2010 it was reported that the Minister of Water Affairs had been mandated to urgently convene a special task team to investigate acid water drainage in some provinces. In other words, government has had AMD on its 'urgent' agenda since

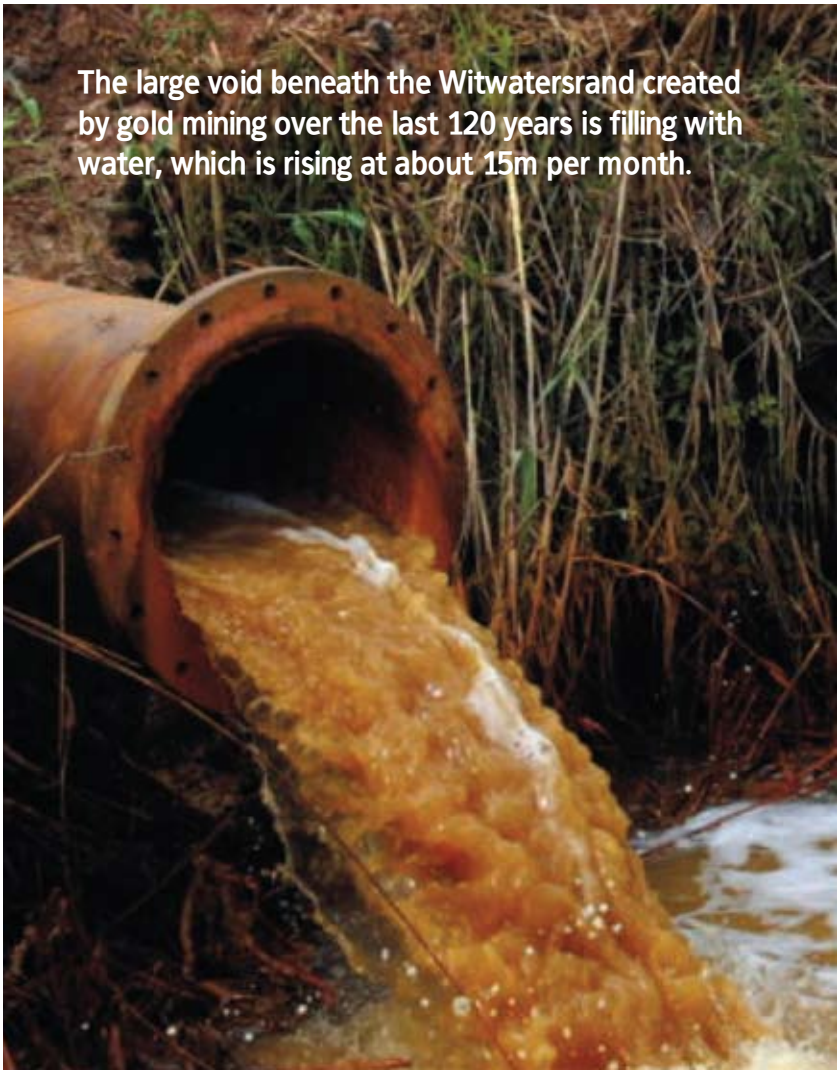
[7] Ibid.
[8] Ibid.

2009, but has yet to act. Whether this is due to the nature of government, or the proximity of government to mining companies and their revenue, or the impact of BEEllionnaires in the mining sector, is beyond the scope of this brief piece to argue, but these issues deserve attention – and resolution. Mining must be regulated, efficiently and effectively. Action cannot be delayed.

The threat of decant in Gauteng should be an eye-opener for all stakeholders – business, government and civil society. The way we work must be proactive and not reactive. The continued stripping of ore-bearing rock and leaving behind a destroyed environment and a shrinking, often ill or injured labour force - year after year – is not a sustainable or a desirable way of operating. The sooner we move the economy of the Gauteng city-region (GCR) onto a sustainable (environmentally, socially and economically) footing, the sooner we will find long-term solutions to our problems, not just stop-gaps that buy time.

GCRO

November 2010



The large void beneath the Witwatersrand created by gold mining over the last 120 years is filling with water, which is rising at about 15m per month.



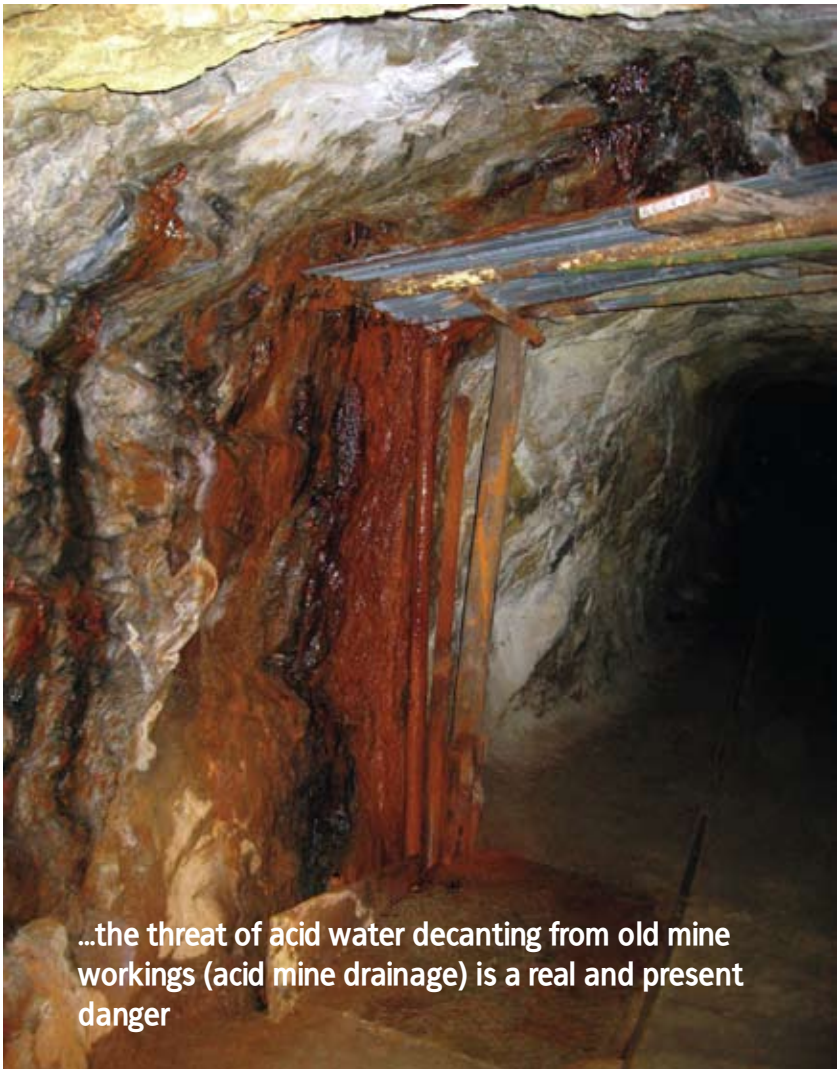




EXECUTIVE SUMMARY

The large void beneath the Witwatersrand created by gold mining over the last 120 years is filling with water, which is rising at about 15m per month. The void will fill and water will begin to leak out (decant) on surface in about three years from now. It is likely that multiple decant points will develop in municipal areas across the Witwatersrand from Roodepoort to Boksburg. Experience on the West Rand has shown that the quality of the water is likely to be poor and toxic. The prime risk area where decant points are likely to develop is in a zone about 500m wide straddling Main Reef Road and the M2 motorway, plus a secondary zone some two kilometres to the south. Deep basements of buildings and other sub-surface infrastructure in the risk zones could experience flooding and the underground facility at Gold Reef City, a national treasure, will be lost.

The problem can be solved by establishing pump stations at shallow depth in the mining belt to keep the water at a safe depth below surface. A depth of 300m is recommended in order to protect the Gold Reef City facility. The technological capability to do this is readily available, and the necessary water treatment processes are well established. Although initially expensive, the pumping operation may ultimately generate a profit. Moreover, the cost of not pumping may ultimately vastly exceed the cost of timely intervention. Establishing the necessary pumping and water treatment infrastructure will take considerable time, and therefore immediate action is required.



...the threat of acid water decanting from old mine workings (acid mine drainage) is a real and present danger







INTRODUCTION

There has been extensive media coverage recently concerning the rising water level in the mine void beneath Johannesburg and neighbouring municipalities and the threat of flooding that this now poses to buildings and other infrastructure in the city-region. There has been some disinformation, some accurate information, some understanding of the urgency of the problem and some attempts to write off the issue as 'alarmist'. There has also been some understandable confusion. This brief piece aims to summarise what we know, to highlight what we don't know but need to find out, and recommendations for action across different spheres of government, and society more generally.

The basic argument put forward here is that the threat of acid water decanting from old mine workings (acid mine drainage) is a real and present danger. It poses a threat to our economy, environment, health and history. The solutions are expensive, though not technically daunting – and must be implemented within a matter of months, if we are to prevent acid mine water at different points in the GCR.

Finally, while it would be easy to point fingers at the mining sector, the present problem is the result of over a century of mining by literally hundreds of companies, the majority of which have long since ceased to exist. Clearly, they cannot be held responsible (and financially liable) for footing the bill. In reality, taxes on past mining activities have benefitted all of us – the infrastructure we enjoy in the GCR has been funded in no small part by mines that are now defunct. As such, the bulk of the bill must come from the national fiscus – existing mines that continue to contribute to the problem must also contribute on a *pro rata* basis, as must local and provincial spheres.

THIS BOOKLET

In the general media coverage of the issue of acid mine drainage, what has been lacking is a concise explanation of the origin of the problem, how it may unfold and which areas are potentially at risk. There has also been much disinformation circulating, making it difficult for citizens and policy-makers alike to distinguish fact from fiction. It is in everybody's interests that there is a general understanding of the nature of the problem, which is what this article sets out to achieve. Although at first glance the issues involved may appear to be technical, they are actually quite simple and straight-forward.

There are several facets to the problem that need to be explained in order to understand what is happening and how it will unfold. These include how the gold occurs, how it was mined, how water gets into the mines and why this has only now become a potential problem more than 120 years after mining started.









THE OCCURRENCE OF GOLD ON THE WITWATERSRAND

Witwatersrand gold occurs in layers of pebbly rock called **conglomerate** that were deposited as river gravels about 2 800 million years ago. These were termed **reefs** by the early prospectors, a name that is still used today. The Earth's atmosphere at that time was different from today in that it contained no oxygen. This is important because of the effect oxygen has on minerals. Certain minerals deposited along with the gold decompose in today's atmosphere and dissolve, either wholly or partly. These minerals include iron sulphide (called **pyrite**, also known as **fool's gold** because of its resemblance to gold), other minor heavy metal sulphides and uranium oxide (**uraninite**).

Not all of the conglomerate layers or reefs carry economic concentrations of gold. On the Witwatersrand, only three or four of the reefs contained significant gold, and even then not everywhere. The important gold-bearing reefs were the Main Reef, Main Reef Leader, South Reef and the Kimberley Reef. The thickness of the gold-bearing reefs varied from a few centimeters to a few metres, but average about a metre.

...important gold-bearing reefs were the Main Reef, Main Reef Leader, South Reef and the Kimberley Reef.

The conglomerate layers are separated by layers of a rock called **quartzite**, which were originally deposited as layers of sand. Cementation and heating of the sand over millions of years converted it into hard, quartzite rock. In addition, layers of **shale** (formerly silt and mud layers) were also laid down between the layers of sand. These various sedimentary rocks were deposited on a floor of rock consisting mainly of granite. The combined thickness of the quartzite, shale and conglomerate layers is approximately seven kilometres. The gold-bearing conglomerate reefs occur in the upper two kilometre portion of the package. The sedimentary layers were buried by lava that rose up from deep in the Earth along cracks known as **dykes** some 2 700 million years ago, terminating the gold-forming event.

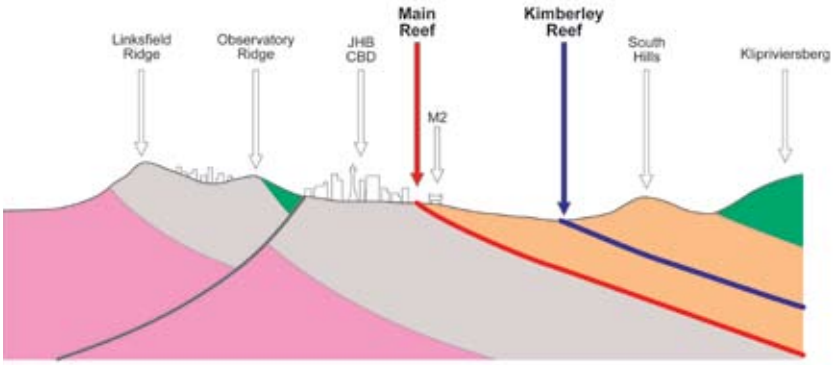
The layers of rock later became tilted and were partly eroded, and they now dip towards the south at angles varying from 20° to about 80° from the horizontal, but averaging about 30°. They extend from Randfontein in the west to Boksburg in the east. Some of the quartzite layers are very hard and they form ridges such as the low range of hills which forms the Witwatersrand escarpment extending from

Krugersdorp to Germiston (including Northcliff and the Brixton–Observatory ridge). The lavas are also quite resistant and form the Klipriviersberg hills along the southern margin of the city. The other quartzites generally form less prominent topographic features (Figure 1, 2).

Figure 1: *Simplified geological map of the Witwatersrand showing the distribution of the main rock types. The red and blue lines mark the outcrop positions of the main gold-bearing reef layers.*



Figure 2: *Geological cross-section orientated in a north-south direction showing southerly dip of the layers of sedimentary rock which host the gold-bearing reefs (shown in red and blue). Most of the mining activity was centred along the Main Reef layer with more limited mining of the Kimberley Reef.*



GOLD MINING ON THE WITWATERSRAND

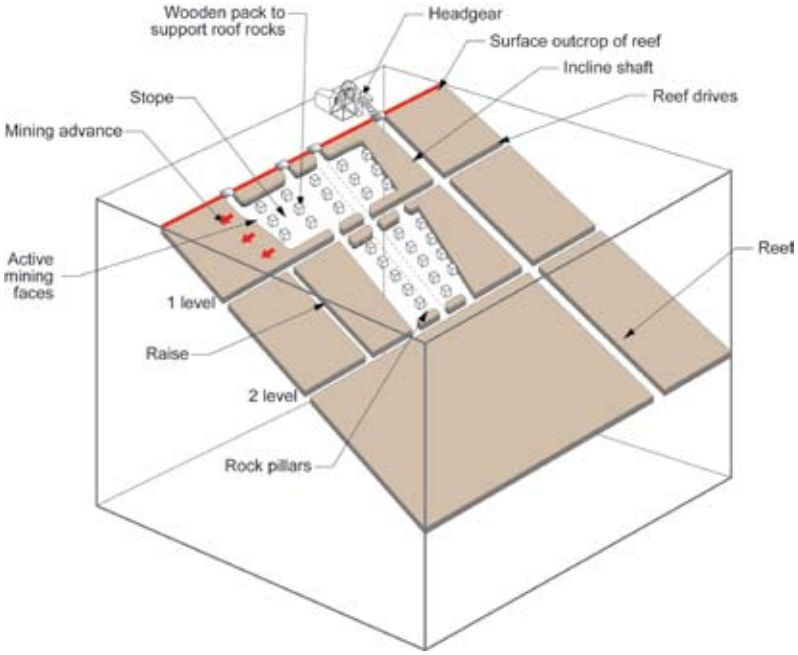
Gold was discovered in one of the conglomerate reefs at Langlaagte in March 1886. Within a few months, the gold-bearing reefs had been traced the full 50km length of the Witwatersrand from what is now Roodepoort in the west to Germiston in the east. Mining commenced in about September of that year.

The mining method used to extract the gold-bearing rock was very simple. A tunnel, or more correctly a shaft (called an **incline shaft**), was sunk down on the plane of the reef. At vertical depth intervals of about 50m (called **levels**), horizontal tunnels (called **reef drives**) were dug perpendicular to the shaft along the reef plane. Tunnels (called **raises**) were then dug up the reef plane at intervals to meet the reef drive on the level above. The walls of the raises were then mined sideways creating open spaces called **stopes** and the broken reef rock passed down to the reef drive below where it was loaded into wagons (**cocopans**) and transported to the shaft for removal to the surface.

...the gold-bearing reefs had been traced the full 50km length of the Witwatersrand...

Pillars of reef were left adjacent to the reef drive to support the roof. The roof rock in the stopes was supported by **wooden support packs** (Figure 3). The minimum width of the mine opening is one metre, because people cannot work in a narrower space. Where the conglomerate layers were thinner than one metre, a one metre opening was made nevertheless. Where the conglomerate was thicker, the entire layer was usually mined, sometimes up to two metres or more. The average width of the mined layer was of the order of a metre.

Figure 3: *Mining methods used in the early days of gold mining on the Witwatersrand. A shaft was sunk down on the gold-bearing reef layer and at intervals (called levels) horizontal tunnels were dug laterally on the reef. From these, tunnels (called raises) were dug up to the level above. These raises were then widened sideways on the reef to create stopes. The broken reef rock was fed down to the level below and taken to surface where the gold was extracted.*



As the mines grew deeper, incline shafts became inefficient and were replaced by **vertical shafts**. Horizontal tunnels were dug from the shaft to the reef (called **cross-cut drives**) where reef drives were dug as before. For safety reasons, reef drives were eventually abandoned in favour of tunnels dug parallel to, but below, the reef layer. As mining progressed, further shafts were sunk from underground (called **sub-vertical or sub-incline shafts**) ultimately taking mining to depths more than 3 000 m below surface (see Figure 4 and Figure 5). In the process, the layers of gold-bearing reef rock were extracted, and an extensive cavity was created which is known as the **mine void**.

Figure 4: *As mining progressed to deeper levels, vertical shafts replaced incline shafts. The layers of gold-bearing reef rock (shown in red and green) were extracted in the process, leaving behind open space which is known as the mine void.*

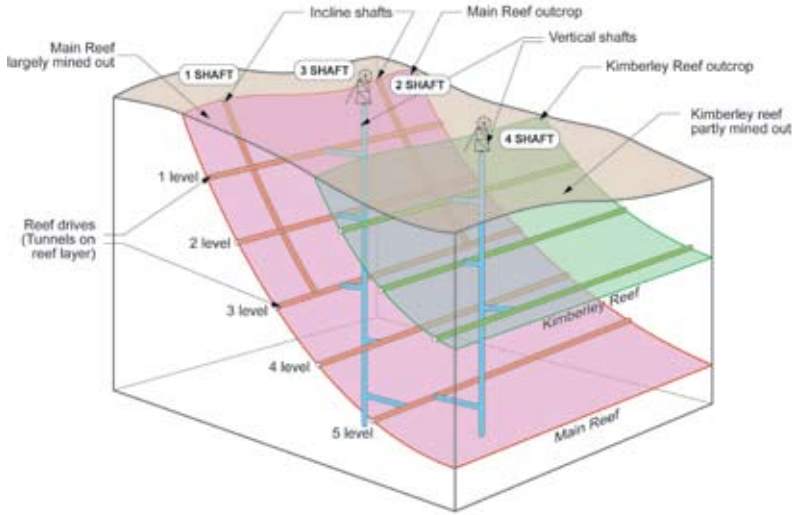
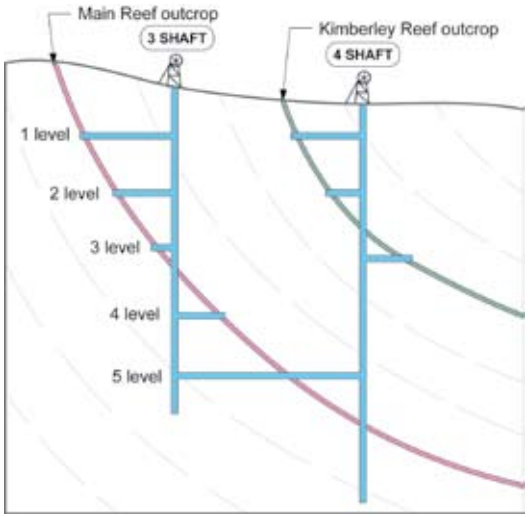


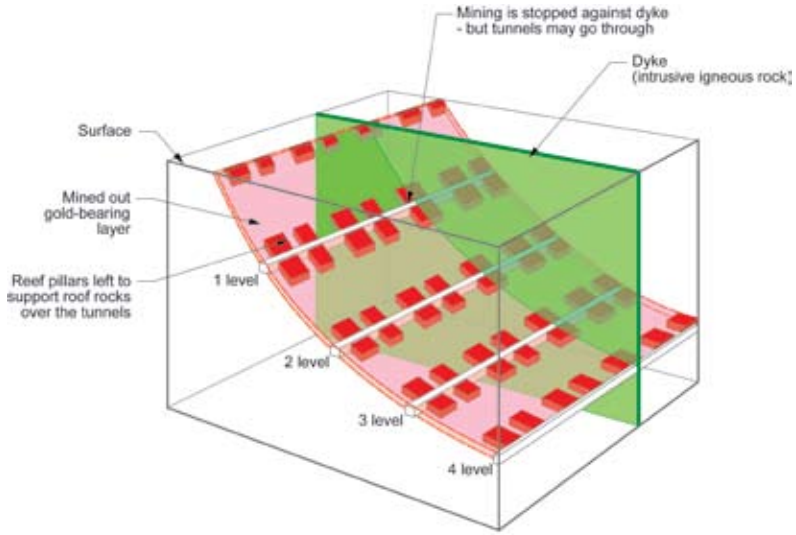
Figure 5: *Cross-section through a typical Witwatersrand mine (such as the one shown in Figure 4) illustrating the manner in which reefs were accessed from the vertical shafts. Shafts and the reef layers were extensively inter-connected underground.*



Supplying fresh air to workers underground is an obvious necessity. To achieve this, the flow of fresh air to, and stale, dusty air away from the working areas is carefully planned. Control of the movement of air requires the erection of barricades in the old workings, and some parts of the void are used to channel fresh air to the workers and others for removal of stale air. The air-flow paths are constantly changed to keep pace with the mining as it advances; so new barricades are constantly being erected.

Along most of the Witwatersrand, more than one reef was mined – some extensively, others more sporadically because of less favourable gold content. The reefs that were mined were a lower group consisting of the Main Reef, Main Reef Leader and South Reef, generally located within a zone a few tens of metres apart, and the Kimberley Reef a few hundred metres above. The Main Reef Leader was particularly extensively mined. Dykes that cut across the reef layers were not mined as they contained no gold (Figure 6).

Figure 6: *Dykes cutting across the reefs contained no gold and consequently were not mined, as is illustrated in this diagram. Excavation ("stoping") was stopped when a dyke was encountered. Tunnels were usually extended through the dykes, however, and stoping resumed on the other side as illustrated here.*



In the past, it was theoretically possible to walk underground all the way from Roodepoort to Boksburg, because adjacent mines generally interconnected their workings. In practice, however, this was not possible because reef drives and other

tunnels that were no longer needed were blocked off with brick walls or wooded barricades. This was done to prevent workers from straying into old and dangerous areas, and especially to restrict air-flow to the active working areas. The tunnels were generally not completely sealed, however, as drain holes were left at the base of the barricades to allow water to flow through. What was a safety and efficiency measure in the past has come back to haunt us now.

In order to keep track of the mining, plans of the mine workings were kept by mine surveyors. A **mine plan** is a projection of the underground excavations onto a horizontal surface as is illustrated in Figure 7. An example of portion of a mine plan is shown in Figure 8. A plan of the entire mined out area on the Witwatersrand is shown in Figure 9.

Figure 7: *Accurate plans of underground workings are produced by projecting the mined areas onto a flat, horizontal surface, as illustrated here.*

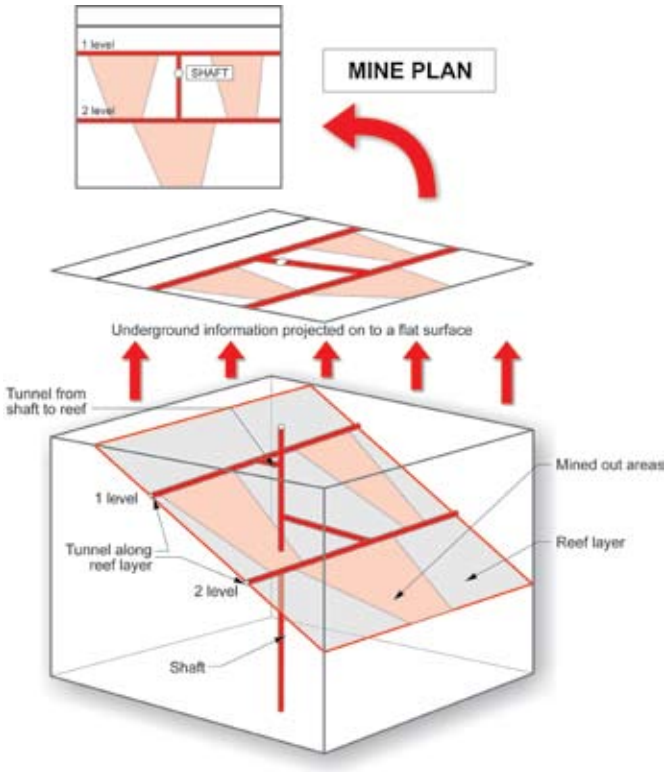
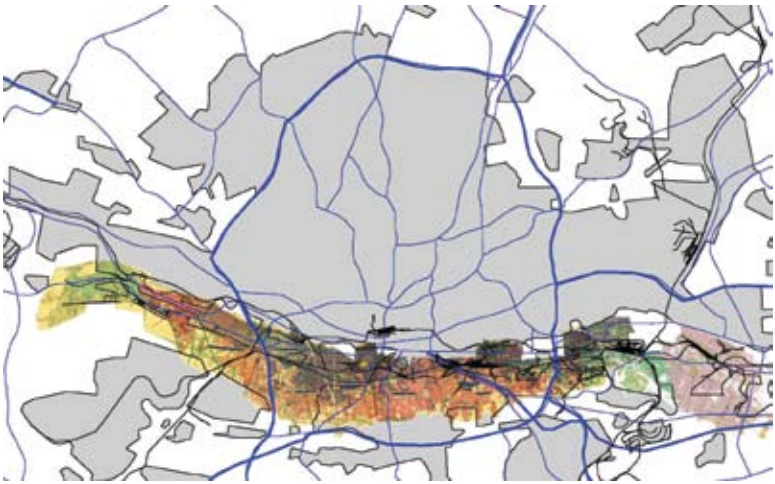


Figure 8: *Portion of the mine plan of the East Rand Proprietary Mines Limited (issued in 1982). Areas coloured pink and pale greens represent reefs that have been mined out (each reef mined is designated by a different colour); yellow areas represent patches of economic reef that have yet to be mined; and dark green stripes crossing the mined out areas represent dykes [source: ERPM Ltd.].*



Figure 9: *Map showing the mined out reefs across the entire Witwatersrand from Roodepoort to Boksburg.*



Over the life of the Central Rand mines, a total of 1 300 million tones of rock was brought to surface from underground, and from this rock, 12 220 710kg of gold was extracted. The volume of rock mined amounts to a cube 800m x 800m by 800m. In crushed and processed form the rock volume becomes even larger, which is why there are so many large dumps of mine waste along the Witwatersrand.

The iron pyrite and other sulphide minerals were not extracted, however, nor was most of the uraninite, and these went onto the dumps. Decomposition of the sulphides and the uraninite in these dumps is producing acidic water, which is enriched in uranium and other heavy metals such as cobalt, nickel, manganese and aluminium. Seepage of this polluted water (Acid Mine Drainage) from the dumps is a serious problem on the Witwatersrand and other mining areas.

...a total of 1 300 million tones of rock was brought to surface from underground, and from this rock, 12 220 710kg of gold was extracted.

During mining, the roof rocks above the stopes were supported by wooded packs (Figure 3). These were left in place as the mining advanced. As time passed, the wood decayed and the roof rocks eventually collapsed and broke up into large blocks. When mining was close to surface (generally less than 200m deep), collapse of the workings sometimes caused **surface subsidence**, and often cracks appeared in the ground above the workings due to the breaking up of the rock mass below. Erection of buildings immediately above old workings is therefore problematic, and building restrictions have been imposed in this zone across the Witwatersrand.

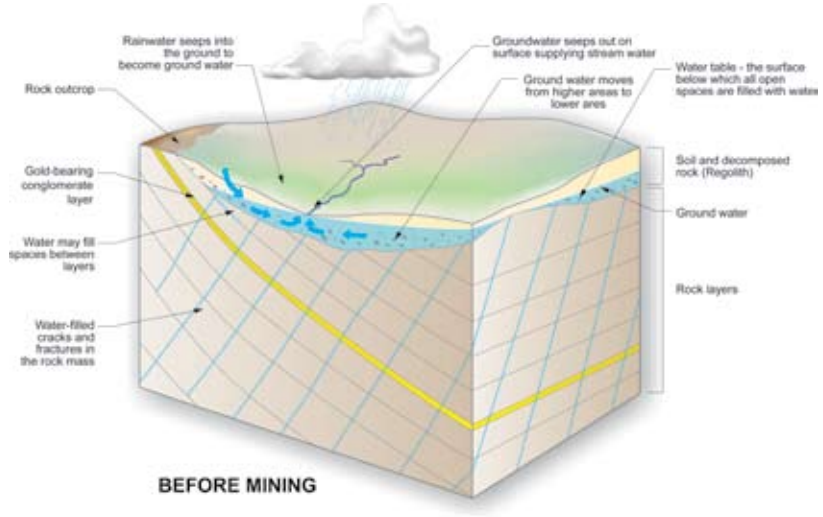
GROUNDWATER

The rock mass down to a depth of several kilometres is usually cut by cracks and zones where the rock has been crushed or fractured (called **joints** and **faults** respectively) which are formed as a result of earth movements. Occasionally rock may extend all the way to the surface, resulting in rocky outcrop. More commonly, however, the rocks closer to the surface have decomposed to form a loose, granular material and soil layer. This layer of soil and fragmented, partly decomposed rock is known as the **regolith**.

Rain falls on the surface and about ten percent of it runs off and collects in streams, eventually flowing to the ocean. The rest soaks into the ground, but most of this does not penetrate very deeply and is returned to the atmosphere by **evapotranspiration**. About five percent of the water soaks deep into the ground to become **groundwater**.[9]

Deeply penetrating water percolates downwards filling all available open spaces and thus all cracks and fractures become filled with water. The water also collects in the openings between the grains in the regolith that overlies the solid bedrock. All openings are filled up to a certain depth, called the **water table**. The water below the water table and the material that hosts it, is called an **aquifer**. We often divide the aquifer into two parts: the **regolith aquifer** above and the **fractured rock aquifer** below. In rural areas, boreholes are drilled down into these aquifers to obtain groundwater (Figure 10).

Figure 10: *Some rainwater soaks into the ground to form groundwater, which fills all available open spaces. Some of the water fills cracks in the rock mass, whilst some fills spaces in the layer of decomposed rock near the surface (called the regolith).*



[9] These proportions vary with the climate and the nature of the soil: the figures given are more or less appropriate to the Witwatersrand.

The water table generally follows the land surface, although it tends to be slightly deeper below hills and shallower in valleys. The water table may come to surface, which creates **springs**. It also usually comes to the surface in river valleys, where groundwater leaks out to form streams. Groundwater seeping out on the surface in valleys causes streams and rivers to flow throughout the year. Rainwater soaking into the ground replenishes (**recharges**) the groundwater, which slowly flows from higher areas to lower areas, where it **discharges** into streams.

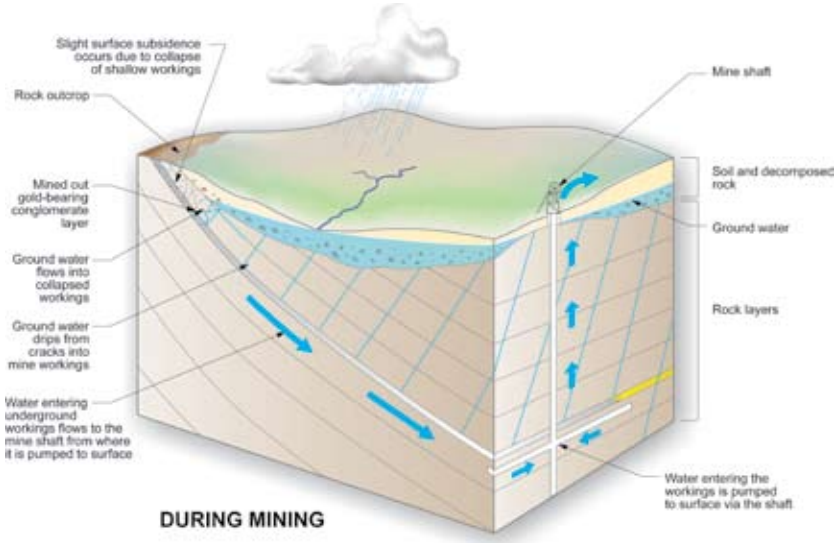
GROUNDWATER AND MINING

Mining involves the creation of open spaces below ground. In the course of mining, water-bearing fractures are intersected and near the surface the water-bearing regolith may also be intersected by the mining activity. Water therefore flows from these openings into the mine workings. Where the water flow is particularly strong, such as from heavily fractured rock zones, the inflow can be reduced or even stopped completely by drilling holes into the fracture and pumping in concrete under very high pressure – a process known as **grouting**. The water that seeps in more slowly, generally from narrower cracks, is channelled into gullies and eventually into ponds called **sumps** from where it is pumped to the surface via the shafts. The rate of pumping must obviously equal the rate of flow of water into the mine otherwise the mine workings will become flooded.

During mining of the Witwatersrand reefs the zone of surface disturbance was relatively narrow and severe inflows were curtailed by grouting and water inflow was relatively modest. Although groundwater did seep into the mine workings there was sufficient water available to maintain the regolith and fractured rock aquifers essentially in their pre-mining condition. Streams continued to flow and normal groundwater conditions prevailed above the deeper mine workings.

The miners created a void by extracting the gold-bearing rock, and by continuous pumping they ensured that the void remained filled with air. In doing so they in effect created an air bubble inside the fractured rock aquifer which grew ever larger as mining progressed (Figure 11). However – and this is where our current problems become clearer - to maintain the bubble required continuous pumping because water was seeping into the void. A balance was required to keep the water at bay. That balance has now been disturbed.

Figure 11: *During mining, water entering the mine void is channelled towards the shaft and pumped to surface to prevent flooding of the workings. If pumping were to stop, the void would slowly fill with water.*



THE END OF MINING AND FILLING THE VOID

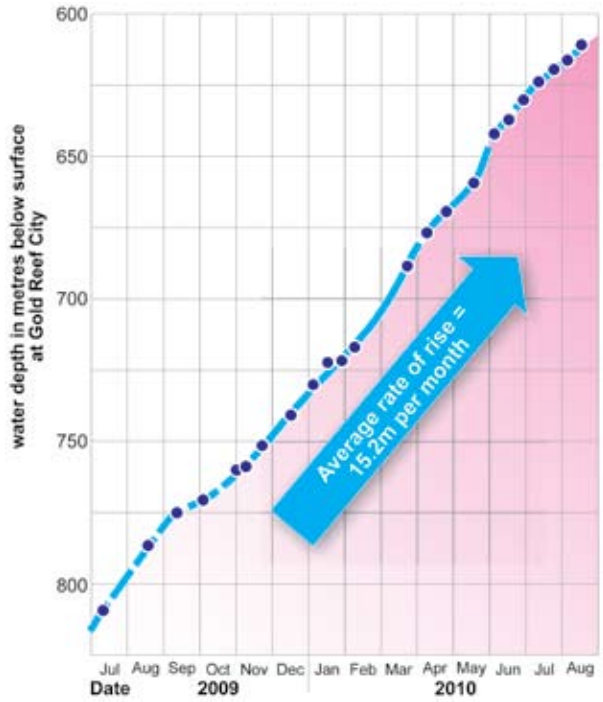
The mines on the Witwatersrand began to close in the late 1950s due to declining profits. Closure of a mine meant that pumping of water from the mine void ceased and water started accumulating in the deeper underground workings. From there it began to flow into adjacent mines, which took up the pumping responsibility of their defunct neighbours. Eventually, only one operating mine was left – East Rand Propriety Mines Ltd. (ERPM), which is situated on the eastern extremity of the Witwatersrand mining belt in Boksburg. This mine had to carry the burden of pumping out water that flowed from all of the defunct mines.

ERPM maintained the water level in their mining area at 1200 m below the surface. In order to do this it was necessary to pump an average of 40 million litres of water per day from underground. At that time, the water level 50km away at the western end of the Witwatersrand mine void (at the Durban Roodepoort Deep mine) had risen and stabilised at a depth of about 500m below the surface. Although the

underground excavations were continuous from Durban Roodepoort Deep to ERPM, the fact that an approximately 700m difference in water level was maintained across the mine void indicates that obstructions underground stopped the free flow of water through the void. These obstructions are provided by natural dykes and by barricades in the tunnels. Had the void been completely open, permitting free flow of water, the water level would have been the same throughout the void, because of course *water always seeks its own level.*

In October 2008, ERPM finally ceased pumping - and the void began to fill. Since then the water level in the void appears to have levelled off and currently lies at a depth of about 600m below surface. The water level in the mine void is regularly monitored at Crown Mines 14 Shaft (Gold Reef City) and is rising at a rate of 15m per month (Figure 12). At this rate of rise, **the void will be completely filled in about three years from now.**

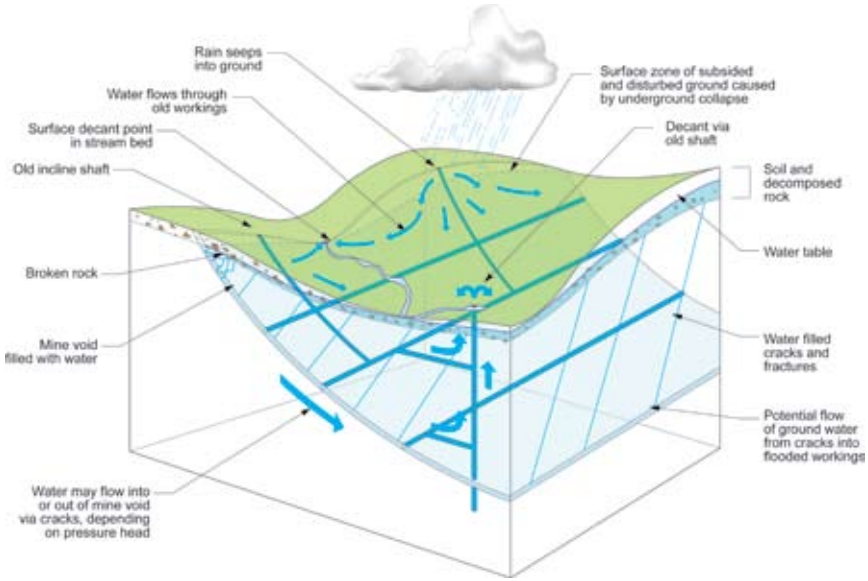
Figure 12: *Graph showing the rise of water level in the mine void, as recorded at 14 Shaft, Crown Mines (Gold Reef City).*



Once the void has filled, the water will begin to emerge from underground - **decant** will commence. Decant will occur because the mine void and openings connected to it, such as shafts, occur at a variety of elevations (Figure 13). Water will flow into the void in higher areas (called recharge areas) and decant at low (discharge) points. The inflow of water to the void before it became filled amounted to about 40 million litres per day, and the volume of decant water can be expected to be similar (probably slightly less).

The lowest large opening connected to the void is **Central Shaft** of **ERPM** in Boksburg, and if free flow of water through the void was possible, decant would take place only at this shaft. However, we have seen that the flow of water through the void is restricted, which will allow the water level in the void to stabilize at different levels in different parts of mining belt, as illustrated in Figure 13. Decanting water may emerge close to recharge areas or it may come from great depth via deep shafts.

Figure 13: *Diagram illustrating the processes causing decanting of water from a water-filled mine void. Inflow (recharge) will occur in the more elevated areas and water will emerge (decant) in the lower-lying areas such as via certain shafts and places where valleys cross the old working areas.*



THE NATURE OF THE DECANT WATER

We spoke earlier about 'fools gold' or iron pyrite, which can be found in the mined rock. When pyrite is exposed to oxygenated water, it forms sulphuric acid. In the acidic water, other minerals also break down and their metals dissolve into the water. Water draining or being pumped from the mines is thus often acidic with high concentrations of dissolved sulphate and metals - such as the water that is decanting from the flooded mines in the Western Basin. **The water is toxic and corrosive**.

exceptions could occur where water rises in shafts from great depths...

Water filling the deeper parts of the mine void eventually runs out of oxygen and the chemical reactions cease, capping the level of pollution. This situation will only occur in the very deep workings, however. Surface leakage will occur mainly from water entering and flowing through shallower mine workings. Exceptions could occur where water rises in shafts from great depths such as would occur via the shaft system as depicted in Figure 13.

Eventually, all of the sulphides in the rock will oxidize and the resulting dissolved material will be flushed out, so the quality of the water will steadily improve. Ultimately the decant water may become of sufficiently high quality that it could be used to augment the region's drinking water supply. **However, we have no idea how long this will take and could extend over many decades or longer.** In the immediate term, the water that will decant is potentially toxic.

AREAS OF POTENTIAL RISK

Although the void is very extensive, as shown in Figure 9, most of the excavations lie deep below the surface. This deeper part of the void will fill with water, but it will stay there and will not impact on the surface. The major risk is the region where the workings are relatively shallow - within about 200m of the surface. This will be where rainwater and water from other sources (e.g. leaking pipes and sewers) enters the workings, from where it will flow to discharge points at low elevations. The majority of discharge points will be **low-lying parts of the disturbed zone, especially where streams cross**. However, **many buildings have deep basements**, some of which could function as discharge points, susceptible to flooding when the mine void fills. Deep service tunnels may also be at risk from flooding.

The most important **risk zone** extends along **the Main Reef** and from there in a southerly direction over a width of about of about 500m. As a rough guide, it more or less follows Main Reef Road and in central Johannesburg, it runs along the northern side of the M2 motorway.

There is a **second risk zone** associated with the Kimberley Reef which lies approximately two kilometres to the south of the main risk zone. This reef was only sporadically mined and the zone is not continuous. Outside of these two zones, the flooding risk is low to negligible.

WHAT WE NEED TO KNOW

It is possible to compile a detailed risk map by combining information on the old mine workings (most of which were accurately surveyed), surface topography and the plans of buildings and other sub-surface structures in the risk zone. However, such a compilation has not previously been undertaken so at present we can only define the risk zone in fairly general terms.

Clearly, developing a detailed and accurate risk zone profile should be considered a priority for government and the mining industry.

THE SOLUTION TO THE PROBLEM

It would be very, very unwise to allow the mine void to fill, as flooding of buildings and strategic facilities could have serious economic consequences for the private sector and municipalities on the Witwatersrand, as well as negative socio-health consequences for the people living in the area.

...involves the establishment of pumping stations to pump the water to the surface for basic treatment.

The uncontrolled drainage of toxic water within the local municipal boundaries would be a major blow to our claim that Johannesburg and neighbouring municipalities are 'world class African cities' and a great embarrassment to South Africa internationally. Moreover, the underground mine at Gold Reef City will be lost, which is a unique and historic asset to the City of Johannesburg and the country as a whole.

The solution to the problem is relatively simple, however, and involves the establishment of pumping stations to pump the water to the surface for basic treatment. The shallower the depth from which the water is pumped, the lower the cost. Old mine shafts could be refurbished to access the water. The water treatment required has been carried out at Grootvlei, ERPM and at Randfontein for many years, and is well tried and tested. Although it does not produce good quality water, it greatly reduces or eliminates the toxicity.

The depth at which the water level should be stabilised needs to be carefully considered.

- To ensure **the security of the Gold Reef City** underground facility, the water level would need to be maintained at a depth of **at least 250m below surface** at this location.
- **Lateral flow** of water in the mine void is restricted, so for safety, it is recommended that **two pump stations** be established, one in the Germiston area and one at Florida, and that the water level be maintained at 300m below surface at these two points.
- This depth should ensure that the water level in the void along the entire risk zone remains deeper than 250m below surface.[10]
- It is also recommended that a private contractor be appointed to establish and carry out the pumping, allowing for proper performance and cost auditing.

Time is of the essence. The water level will reach the 300m mark in 20 months from now so it is essential that steps be taken immediately to start preparing the pumping and treatment infrastructure.

Pumping is not a once-off activity, and will have to continue indefinitely. Initially, this will involve considerable financial outlay to establish the pumping and treatment facilities, and an ongoing cost to maintain the pumping and water treatment. The cost will have to be borne by the state. It should be noted that much of this expense will not be new, as the government has for decades been paying pumping subsidies

[10] Note that detailed hydrological modelling calculations still need to be carried out to define the optimum depth more precisely.

to mines to cover the cost of pumping inflow from defunct, adjacent mines. These so-called pumping subsidies are derived from taxation. The cost of not preventing decant may ultimately be greater than the cost of pumping: the degree of damage to infrastructure may be such that pumping will become an absolute necessity after decant commences, and will then have to be done under extremely unfavourable conditions.

Pumping will not necessarily be a perpetual cost. In the long-term, the quality of the pumped water will improve to the point where the water will become saleable. Treatment costs will then be substantially lower and the pumping operations will probably generate a profit.[11]

The complaint is often made that current taxpayers should not be held liable for costs incurred by previous generations. But government is invariably the largest single beneficiary of mining ventures through the state share of profits formulae, taxation of company profits and taxation of salaries paid to workers. The revenue thus obtained is ploughed back in the form of infrastructure and services, which citizens enjoy. Those who complain that they are paying for a liability that was not of their making need to be aware that the infrastructure such as road networks, schools, hospitals and the like from which they benefit were partly paid for by taxation of now defunct mining companies.

CONCLUSION

Mining invariably creates environmental problems. Some are immediate; others appear years or even decades after mining ceases. Amongst the latter category is the leakage of acidic water contaminated with heavy metals from closed and abandoned mines. The problem is well known and affects mining districts around the world, but very seldom does it occur within a major metropolitan area. The Witwatersrand conurbation is now faced with the prospect of such uncontrolled leakage of polluted water from old mines that lie within the city limits.

[11] It is cheaper to pump water from 300m below surface in Johannesburg than to pump it to the city from Vaal Dam 80 km away, which also involves lifting the water about 250m.

There is currently a window of opportunity during which steps can be taken to prevent the situation getting out of control. The technology required to control the problem is well established and there are many companies in the private sector that have the necessary expertise to implement the solution. It is essential that we act immediately and decisively if we are to avoid catastrophe.









GLOSSARY

- **Aquifer** Zone below the surface capable of holding groundwater.
- **Cocopan** Small wagon running on rails used to transport broken rock on a mine.
- **Conglomerate** Sedimentary rock consisting of pebbles and sand fused together.
- **Cross-cut drive** Tunnel leading from a shaft to the mining area.
- **Decant** (in mining) Surface discharge of water from an abandoned mine.
- **Discharge** Seepage of groundwater at the surface.
- **Dyke** Vertical, planar body of igneous rock formed by the solidification of molten rock in a crack.
- **Evapotranspiration** The process of transfer of water to the atmosphere by evaporation and transpiration by plants.
- **Fault** Crack in the Earth along which differential movement of the rock mass has occurred.
- **Fool's gold** The common name for the mineral pyrite (iron sulphide).
- **Fractured rock aquifier:** a water-bearing rock mass (aquifer) in which the open spaces that accommodate the water are the result of cracks in the rock
- **Groundwater** Water occupying openings below ground.
- **Grouting**: the pumping of concrete into open spaces underground in order to seal them
- **Incline shaft** An inclined tunnel on a mine.
- **Joint** A planar crack in the rock mass.

- **Level (in a mine)** A near horizontal surface on which mine tunnels are opened.
- **Mine plan** Accurate drawing showing the positions of mine excavations. **Mine void:** the underground cavity created by mining
- **Pack (in a mine)** Stack of wooden logs used to support the rock mass above an underground excavation.
- **Pillar (in a mine)** Rock column left in place to support the rock mass above an underground excavation.
- **Pyrite (also pyrites)** A mineral consisting of iron and sulphur.
- **Quartzite** A hard sedimentary rock made of grains of the mineral quartz that have been strongly bonded together.
- **Raise (in a mine)** An inclined tunnel excavated upwards from a lower to a higher level.
- **Recharge** The inflow of water from the surface to the groundwater.
- **Reef** Term used on the Witwatersrand mines for conglomerate.
- **Reef drive** Horizontal tunnel excavated along a reef.
- **Regolith** Soil and partly decomposed rock lying above the bedrock.
- **Shale** Sedimentary rock composed of mud and silt particles.
- **Spring** A point where groundwater seeps out at the surface.
- **Stope** Open space left after mineral-bearing (e.g. gold) rock has been extracted.
- **Sub-vertical shaft** A mine-shaft that commences far below the surface.
- **Sump (in mining)** A depression excavated to collect water in a mine.

- **Surface subsidence (in mining):** sinking of the land surface due to collapse of underground mine workings
- **Uraninite** A mineral consisting of uranium and oxygen.
- **Water table** The surface in an aquifer below which all voids are filled with water.



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