Acid Mine Drainage in South Africa

Mariette Liefferink
West Wits Pit
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 to the environment of mining waste can result in profound, generally irreversible destruction of ecosystems.”

If this is indeed so then the Witwatersrand gold mining area of South Africa is at serious risk.

Reference:s CSIR. Briefing Note August 2009. Acid Mine Drainage in South Africa. Dr. Pat Manders. Director, Natural Resources and the Environment.
• The potential volume of AMD for the Witwatersrand Goldfield alone amounts to an estimated 350ML/day (1ML = 1000m3).

• This represents 10% of the potable water supplied daily by Rand Water to municipal authorities for urban distribution in Gauteng province and surrounding areas, at a cost of R3000/ML.

• The gold mining industry in South Africa (principally the Witwatersrand Goldfield) is in decline, but the post-closure **decanant of AMD** is an **enormous threat**, and this could become worse if remedial activities are delayed or not implemented.

Reports

- 1960
  Final Report, Interdepartmental Committee on Dolomitic Mine Water: Far West Rand. DWAF.

- 1963

- 1995
  Screening surveys of Radioactivity in the Mooi River Catchment by the Institute of Water Quality Studies of the DWAF.

- 1996
  Scientists predict West Rand Decant in 2002 and suggested a solution in “An Integrated Strategic Water Management Plan for the Gauteng Gold Mines”. The success of the proposed solution is dependent on the mines, water suppliers, water users and Government adopting an integrated approach – with Government taking the lead role. The Western Utility Corporation developed an alleged technical and economical viable solution, but at the time of writing, Government has not given its approval to this initiative. Government alleges that the polluter cannot be allowed to profit from its pollution.

- 1999
  Report, “Radioactivity Monitoring Programme in the Mooi River (Wonderfonteinspruit) Catchment”. Institute for Water Quality Studies. DWAF, April. Mining activities are a major contributor to uranium and uranium series radionuclides within the catchment. Concentrations decrease downstream of the sources, indicating removal from the dissolved fraction by interaction with sediments.
• 2002
Publication of the “Radioactivity study on sediments in a dam on the Wonderfonteinspruit Catchment.” Conducted by the Council for Geoscience and commissioned by the DWAF. Wade et al. (2002) (WRC).

• 2002
Publication of the “Tier 1 Risk Assessment of Selected Radionuclides in Sediments of the Mooi River Catchment.” WRC Report 1095/1/02 by P. Wade. Radionuclides are concentrated in sediments downstream of their sources. Sequential extractions showed that these radionuclides are distributed in multiple phases within the sediments and that they may be remobilized by environmentally plausible chemical processes such as AMD.

• 2002
Coetzee et al. (2002) of the Council for Geoscience reported on “Uranium and heavy metals in sediments in a dam on the farm Blaauwbank”. This study confirmed the findings of Wade et al and used further sequential extractions to characterize the sediments in a dam downstream of mining activities in the Carletonville area.

• 2005
Publication, WRC on “Impacts of gold-mining activities on water availability and quality in the Wonderfonteinspruit Catchment.” Mining-related impacts such as large-scale land degradation associated with DWAttering of karstic aquifers and widespread pollution of surface water and groundwater systems are discussed.

• 2005
Publication Council for Geoscience, “Contamination of wetlands by Witwatersrand gold mines – processes and the economic potential of gold in wetlands” by H Coetzee et al, Report No. 2005-0106. For more than a century, the mines of the Witwatersrand have discharged contaminated water into the streams and rivers of the area, which led to the formation of a system of large wetlands. Concerns have been raised about their ability to cope with the pollutant loads flowing into wetlands.

• 2006
Publication of “An Assessment of Sources, Pathways, Mechanisms and Risks of Current and Potential Future Pollution of Water and Sediments in Gold-Mining Areas of the Wonderfonteinspruit Catchment.” Report, WRC, H Coetzee et al, Council for Geosience. 2004. Report No 1214/1/06. This report eventually became the most important reason for POEA to be established.
• 2006
Publication of “Impact of the discharge of Treated Mine Water, via the Tweelopies Spruit, on the receiving water body Crocodile River system, Mogale City, Gauteng Province”. DWAF, Report, 16/2/7/C221/C/24. 15.12.2006 by J Fourie et al.

• 2006

• 2006
“Archaeological Assessment: The Proposed Wonderfontein Spruit Treated Water Discharge Project.” Matakoma Heritage Consultants. 25 April.

• 2006

• 2006

• 2006

• 2007
• 2007

• 2007

• 2007
  Publication of the “Status Report on the Actions Arising from the Study of Radiological Contamination of the Wonderfonteinspruit Catchment Area (WCA)”. 29 October.

• 2008

• 2009
  Publication of Draft Regional Mine Closure strategies for the West, Far West, Central and Eastern Rand Basins.
GOLD-MINING AREAS OF WEST RAND AND FAR WEST RAND

RADIOACTIVITY MONITORING PROGRAMME (01/97-12/97)

Mooi River Catchment

Extent of Study Area
International Boundaries
Provincial Boundaries
Mining Area

Witwatersrand Goldfields:

- Kosh Basin
- Free State Goldfields
- Far West Rand
- West Rand
- Central Rand
- Eastern Rand

Key Issues

- Interconnection of mining basins
- Acid Rock Drainage and Mine Drainage
- Large Salt Loads
- Decanting of Flooded Mines
- Physical Instability
- Dust Pollution
- Land Use Conflicts with Growing Urban Centres
- Radioactivity (Contamination) and Uranium
The Witwatersrand has been mined for more than a century. It is the world’s largest gold and uranium mining basin with the extraction, from more than 120 mines, of 43 500 tons of gold in one century and 73 000 tons of uranium between 1953 and 1995. The basin covers an area of 1600 km², and led to a legacy of some 400 km² of mine tailings dams and 6 billion tons of pyrite tailings containing low-grade uranium.

*The Witwatersrand Mining Basin is composed of the Far East Basin, Central Rand Basin, Western Basin, Far Western Basin, KOSH and the Free State gold mines.*
• Tailings Dams contain 100,000 tons of U
• 50 Tons of U discharged annually
• Seepage/Percolation: 24 tons U (1,000 to 1 million higher than the background U concentrations)

Technologically Enhanced Naturally Occurring Radioactive Material

• Point Discharges: 12 tons of U
• Stormwater: 10 tons of U
• Sinkholes: Secondary Sources of U contamination
• Waste from gold mines constitutes the largest single source of waste and pollution in South Africa and there is wide acceptance that Acid Mine Drainage (AMD) is responsible for the most costly environmental and socio-economic impacts.

• As at 1997, South Africa produced an estimated 468 million tons of mineral waste per annum (DWAF, 2001).

• Gold mining waste was estimated to account for 221 million tons or 47% of all mineral waste produced in South Africa, making it the largest, single source of waste and pollution (DWAF, 2001).

• There are more than 270 tailings dams in the Witwatersrand Basin, covering approximately 400 km² in surface area (AngloGold Ashanti, 2004).

• These dams are mostly unlined and many are not vegetated, providing a source of extensive dust, as well as soil and water (surface and groundwater) pollution (AngloGold Ashanti 2004).
Sinkholes caused by dewatering and rewatering of aquifers
Air Pollution
The health effects of uranium particles inhaled:

- **Small particles** are carried by the inhaled air stream all the way into the alveoli. Here the particles can remain for periods from **weeks up to years** depending on their solubility.

- Highly insoluble uranium compounds may remain in the alveoli, whereas soluble uranium compounds may dissolve and pass across the alveolar membranes into the bloodstream, where they may exert **systemic toxic effects**.

- In some cases, insoluble particles are absorbed into the body from the alveoli by **phagocytosis into the associated lymph nodes**.

- “Insoluble” particles may reside in the lungs for years,
Housing Development (Retirement Village) on Mined Land, within 500m buffer zone of tailings dam

AMBERFIELD LIFESTYLE ESTATE
Congratulations! You have just invested in the West Rand's premier Lifestyle Estate.
Every effort has been made to provide you with the services, facilities and care expected of such a prestige development, and as such due diligence has gone into…
Uraniferous Tailings Spillages
GROUNDWATER POLLUTION
“The mean values for the Wonderfonteinspruit samples were found to exceed not only natural background concentrations, but also levels of regulatory concern for cobalt, zinc, arsenic, cadmium and uranium, with uranium and cadmium exhibiting the highest risk coefficients.”
<table>
<thead>
<tr>
<th>Risk quotient</th>
<th>Colour</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5</td>
<td><img src="Green.png" alt="Green" /></td>
<td>Quotients in this range are unlikely to represent any environmental risk.</td>
</tr>
<tr>
<td>0.5-2</td>
<td><img src="Yellow.png" alt="Yellow" /></td>
<td>Quotients in this range may represent a risk, allowing for analytical and other uncertainties.</td>
</tr>
<tr>
<td>&gt;2</td>
<td><img src="Red.png" alt="Red" /></td>
<td>Quotients in this range will represent an environmental risk</td>
</tr>
</tbody>
</table>
Nickel Concentration
Arsenic Concentration
The measured uranium content of many of the fluvial sediments in the Wonderfonteinspruit, including those off mine properties and therefore outside the boundaries of licensed sites, exceeds the exclusion limit for regulation by the National Nuclear Regulator.

For approximately 50% of the 47 sampling sites, the calculated incremental doses of the respective critical group are above 1 mSv per annum up to 100 mSv pa (548 mSv pa Blyvooruitzicht Mine/Bridge Carletonville)

The radioactive contamination of surface water bodies in the Wonderfonteinspruit catchment area caused by the long-lasting mine water discharges and diffuse emissions of seepage and runoff from slimes dams poses radiological risks to the public resulting from the usage of polluted environmental media;

The pathway sediment→SPM→cattle→milk/meat→person (“SeCa”) can cause radioactive contamination of livestock products (milk, meat) resulting in effective doses of the public in some orders of magnitude above those resulting via the pathway “WaCa
Andries Coetzee’s Dam
900mg/kg U

Photo: Courtesy Dr. Henk Coetzee
Tudor Dam - Elevated levels of radioactivity

10 000 – 100 000 Bq/kg

Regulatory Limits: 500Bq/kg
Contamination – Tweelopiespruit

Road built with mine waste material

Contamination – Wonderfonteinspruit

Courtesy: DME
Draft Regional Closure Strategy For The Far West Rand Goldfield

• An airborne radiometric survey of the WR and FWR was done for DWAF

• Interpretation of the data show many of the residential areas (Carletonville, Westonarea, Khutsong, Kagiso, Randfontein) fall within areas of high risk of radioactivity contamination.
Randfontein

Wetlands contaminated with radioactive material
The study undertaken by the NNR has confirmed the presence of radioactive contamination in the WCA.

**Preliminary results of analyses conducted on produce grown in the area have indicated that the dose levels are of radiological concern to the regulator.**

The study has also highlighted the need for all the regulators to work closely together since the contamination includes non radiological contaminants such as heavy metals and salts.
“The most important lesson learnt from the studies in the Wonderfonteinspruit is that no short-cuts exist which would allow certain pathways to be ignored in a study of radioactive contamination within these mining areas.”
At present the U and other heavy metals, such as cadmium, copper, zinc, arsenic and cobalt are adsorbed in the sediment. Plausible environmental conditions such:

- Acid mine drainage
- Acid rain
- Drying out of the sediment and influx of water
- Dredging operations
- Tailings spillages
- Turbulence caused by cattle drinking the water or children playing in the water can cause the mobilization or transport of uranium in the Wonderfonteinspruit.
The central basin is currently flooding at 0.9 meter per day (60 ML per day) with no means of intercepting the water prior to reaching surface which will contaminate all ground water and decant on surface in a densely populated area (Boksburg) at three times the rate of the Western Basin.

Photo: Courtesy Prof. McCarthy
Photo: Courtesy Prof. Terence McCarthy
Eastern Basin
108 ML

Photo: Courtesy Elise Tempelhoff
West Rand goldfields

Decanting Volumes: Currently between 18 and 36 ML/per day

An unqualified volume still escapes downstream
North and south (intercontinental water divide)

Environmental critical level not absolute decant management solution

Dolomitic Outlier not a low permeability barrier: faults and fractures

Photo: Courtesy Henk Coetzee
Chronological Analysis of AMD: West Rand

- 1996: SWaMP Report
- 2002: Decant
- 2002 - 2005: Uncontrolled Decant
- 2005 – 2009: Partial Treatment
- 2009 – Western Utility Corporation (WUC) Proposal
- 21 January 2010 – Uncontrolled Decant
- 18 March 2010 - R6.9 (lime treatment)
- May 2010 – Revised Directive
- 1 July 2010 – Discharge Untreated AMD
In 2002 in the Krugersdorp-Randfontein area water has started to decant from a number of shafts into the Tweelopiespruit and the Wonderfonteinspruit. The water has a pH of 2.2 (the normal pH is 7.3).

The combination of the pH and redox driven reactions resulted in a measured uranium concentration of 16mg/l of the Robinson Lake, and resulted in the NNR declaring the lake a radiation area.

The background U concentration in water is 0.0004mg/l.

In terms of the DWAF regulations for drinking water, the U concentration should not exceed 0.07mg/l and for irrigation, 0.01mg/l.
DISTILLED WATER
ORANGE JUICE
VINEGAR
LEMON JUICE
BAKING SODA
AMMONIA
BLEACH
BATTERY ACID

14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

Alkaline

Acid

pH (Logarithmic)

DWAF Guidelines

Drinking Water

Irrigation

Aquatic Ecosystem

(Site Specific)

Typical Wits Acid Mine Drainage

6.0-9.0
6.5-8.4
7.0-8.0
2.5-4

Alkaline

Acid

pH (Logarithmic)

DWAF Guidelines

Drinking Water

Irrigation

Aquatic Ecosystem

(Site Specific)

Typical Wits Acid Mine Drainage

6.0-9.0
6.5-8.4
7.0-8.0
2.5-4
Robinson Lake
pH 2.6
U concentration of 16 mg/l; resulted in the NNR declaring the lake a radiation area
Volumes and loads
2005 - Jan. 2010

• Polluted water is discharged into a receiving environment
  – Volume = ~25Ml/d
  – Salt content = ~4g/l
  – Salt load = ~100 tons per da

Photo: Courtesy Dr. Henk Coetzee
Cradle of Human Kind World Heritage Site
In April 2009 the mine void water, containing sulfuric acid will have been flowing into the Zwartkrans compartment for 8 years – the corresponding void in the dolomite that has formed so far amounts to a staggering 16,700 m³
January 21, 2010
Uncontrolled decant of AMD
18 Winze
Water Treatment Plant
Precipitated Heavy Metals
Radioactive Sludge
CPS Pit
Acid Mine Drainage

• Waste from gold mines constitutes the largest single source of waste and pollution in South Africa.
• Acid Mine Drainage (AMD) is responsible for the most costly environmental and socio-economic impacts.
• Production of AMD may continue for many years after mines are closed and tailings dams decommissioned.
• AMD is not only associated with surface and groundwater pollution, degradation of soil quality, for harming aquatic sediments and fauna, and for allowing heavy metals to seep into the environment.
Acid Mine Drainage

• Long-term exposure to AMD polluted drinking water may lead to increased rates of cancer, decreased cognitive function and appearance of skin lesions.

• Heavy metals in drinking water could compromise the neural development of the fetus which can result in mental retardation.

• If indeed the extent of “… problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk” (EEB, 2000), then the Witwatersrand gold mining area of South Africa is at serious risk.
Uranium Pollution of Water resources in Mined-Out and Active Goldfields of South Africa – A Case Study in the Wonderfonteinspruit Catchment on Extent and Sources of U- Contamination and Associated Health Risks

Prof.Dr. Frank Winde

“Results indicate that U-levels in water resources of the whole catchment increased markedly since 1997 even though U-loads emitted by some large gold mines in the Far West Rand were reduced. This apparent contradiction is explained by the contribution of highly polluted water decanting from the flooded mine void in the West Rand.

“800kg of U per year flowing into Boskop Dam as Potchefstroom’s main water reservoir

“Of particular concern is the fact that U-levels in the WFS are comparable to those detected in the Northern Cape which had been geostatistically linked to abnormal haematological values related to increased incidences of leukaemia observed in residents of the area”.
– Even though a large number of the world’s rivers are contaminated by heavy metals released from present day and historic mining operations, relatively little is known about the effects on communities that live beside and rely on these rivers for food and livelihood. One of the complications is that the toxicity of many metals is a function of such conditions as redox, pH and water hardness.

– Elevated salts and metals can also negatively affect the health of animals in many different ways, depending on the species, age, sensitivity, general health and diet of the consumer, among other factors.

– Some metals, when consumed in excess, can affect organs and the central nervous system, cause reproductive failure or birth defects, and act as cofactors in many other diseases.

– Certain receptors may be more sensitive than others, depending upon species, age, sex, season, body mass, metabolic rate, general health, diet, behaviour, etc, with younger animals and children being generally more at risk than adults under the same conditions of exposure (WHO).

– The potential for trans-generational (genetic) impacts of bioaccumulated metals and NORMs (Naturally Occurring Radiactive Materials) on biota exposed above certain thresh-holds.

– The probability that such latent impacts will only be identified and assessed over the next 100 to 500 years.
Tweelopiespruit Inlet
Inflow into Game Reserve
Flow Rate ML/DAY
2006 - 2010

Inflow into Game Reserve V1C
Aviary

No Flow
Aviary Dam Game Reserve Outlet
Weekly Oct 2007-May 2010
pH Units
Aviary Dam Game Reserve Outlet
Weekly Oct 2007-May 2010
Conductivity mS/m

Conductivity mS/m@ 25ºC

Directive
Aviary Dam
Weekly Oct 2007 – Apr 2010
Uranium ppb

Uranium ppb
Domestic Guideline 70 ppb
Directive
Mine Water Dissolved Iron Concentrations vs. pH into Tweelopies
Weekly mg/L
Feb 09 – May 10
V 1
Entry into Game Reserve-Manganese
Monthly Oct 2007- Apr 2010

Mn (Dissolved) mg/l

Directive
Directive – May 2010

Suitable for:
Conductivity - Unacceptable Domestic
Sulphate (SO42−) (mg/L) - Nothing
Manganese (Mn) (mg/L) - Nothing
Iron (Fe) (mg/L) - Unacceptable Domestic + Livestock watering
CLOSURE RISKS AND LIABILITIES

- Latent impacts may take decades, or even centuries, to manifest themselves.
- Inherent water quality risks
- Gold mine ore bodies – associated with radionuclides
- Hydrological interconnections between mines – cannot be considered in isolation
- Tailings dams and waste rock dumps can never be maintained in completely reducing environment - water risk ad infinitum
- Long term risk re formation of sinkholes
“It is as unacceptable for companies, when they move on, to leave great holes in the earth and polluted rivers as it is to leave disrupted or unenriched communities....” (quoted in Anglo America 2002b:3)