CASE STUDY ON THE REMEDIATION OF WATER INGRESS TO OLD GOLD WORKINGS LINKED TO ACTIVE MINING AREAS IN SOUTH AFRICA[1]

Mike Palmer[2], Chris Waygood, and Irene Lea

Abstract. Grootvlei Mine is located in the Far East Rand Basin, part of the Witwatersrand Basin, which has been actively mined for over 100 years. In order to maintain access to its reserves, Grootvlei dewaters approximately 75 Ml/day from its workings. The water is treated and discharged to the Blesbokspruit.

A portion of the water pumped from underground is believed to originate from surface water. Technical assessments to identify the areas of ingress, quantities of ingress and possible measures to reduce the ingress are the subject of this paper. In addition, progress made with remediation works on one identified ingress area is discussed. The remedial works are being carried out by Grootvlei Mine, with partial funding provided by the Council for Geoscience.

The site represents a difficult working environment due to the very wet conditions resulting from historical roadway construction and tailings spills.

[1] Paper presented at the 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, 2006, St. Louis MO. R.I. Barnhisel (ed.) Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502

[2] Mike Palmer is an associate at Jones & Wagener (Pty) Ltd, Consulting Civil Engineers, Gauteng, South Africa. Chris Waygood is a director of Jones & Wagener. Irene Lea is a geohydrologist, and is Environmental Officer for the Petrex operations in South Africa.

7th International Conference on Acid Rock Drainage, 2006 pp 1483-1494

DOI: 10.21000/JASMR06021483

https://doi.org/10.21000/JASMR06021483

Introduction

Grootvlei Proprietary Mines (Pty) Ltd is a subsidiary of Petrex (Pty) Ltd and is the last remaining operational gold mine in the East Rand Basin of the Witwatersrand gold fields. Mining in the East Rand Basin has been ongoing over the last 80 years, and the basin is now largely mined out. The Mine is located in South Africa's Gauteng province, approximately 25 km east of Johannesburg. The mining area is shown in Fig. 1.

Grootvlei Mine currently dewaters approximately 75 Ml/day from its workings in order to maintain access to the underground reserves. Water is pumped from the No. 3 shaft, with the pump station located at a depth of approximately 740 m below surface. The water is treated via a High Density Separation (HDS) process including aeration and addition of lime to remove primarily iron, where after it is discharged to a river known as the Blesbokspruit, which flows over the East Rand Basin. This discharge is in line with the conditions of the existing water use license, issued by the Department of Water Affairs and Forestry (DWAF).

A proportion of the water pumped from underground is believed to originate from surface water. A high proportion of the flow in the Blesbokspruit is the result of industrial discharges, primarily from four sewage treatment plants and a paper mill. An investigation was carried out to identify methods by which to reduce the volumes of water required to be pumped from underground (Jones & Wagener, 2003). The first phase of remediation works recommended by the investigation is currently being carried out.

Ingress Investigation

Numerous previous studies (most notably Scott (1995) Barradas and Loggenberg (1996), Petmin (2000) and Wates Meiring & Barnard (2002), all cited in Jones & Wagener (2003)) had been carried out on the ingress of water at Grootvlei, indicating a strong possibility that a significant proportion of the water originated from surface water. In addition, a large proportion of the flow in the Blesbokspruit comprises industrial flows (some 205 Ml/day, compared with 68 Ml/day natural flows). It is therefore not unreasonable to assume that reducing the flow in the Blesbokspruit would significantly reduce the recharge to the East Rand Basin.

Based on this, a previous investigation suggested the construction of a canal, 35 km long, to remove the industrial flows from the river, with an estimated 50% reduction in ingress volumes.

However, the ingress volumes show strong seasonality, with summer inflow rates being almost double those in winter, with a lag of 1 to 2 months. The industrial flows, on the other hand, are largely constant. Field studies showed the presence of significant clay alluvium along the Blesbokspruit, which would be expected to limit recharge volumes from surface and result in a lag of longer than 1 to 2 months. In addition, mining personnel indicated that inflows appear to be significantly higher in areas of shallow undermining than deeper areas. Removal of the industrial flows would also not reduce ponding over much of the catchment, since the ponding is attributed to existing dams and areas where culverts and road structures have resulted in silting and damming of flows, as illustrated in Fig. 2 and 3.

This was seen as a major drawback of the canal proposal, in that after construction, significant problem areas would still remain in terms of surface recharge, and the estimated 50% reduction in ingress appeared highly optimistic.

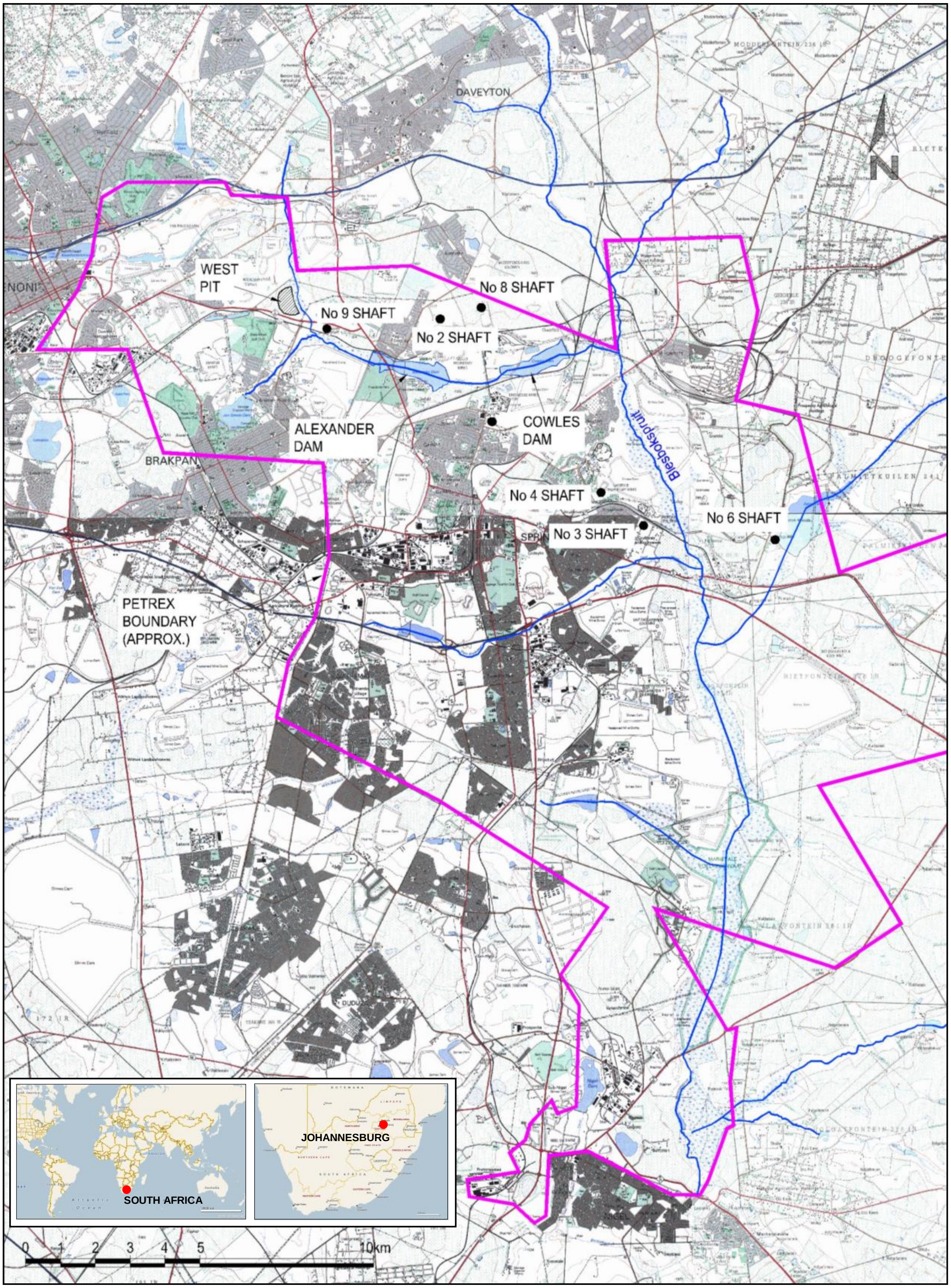

Figure 1. Grootvlei Mine locality plan

Figure 2. Ponding at West Pit

Figure 3. Ponding in the southern Blesbokspruit

It was therefore decided to focus on identifying all potential recharge mechanisms for the East Rand Basin and to quantify as far as possible the contribution of each mechanism to the surface water ingress into the basin. From this it would be possible to identify, evaluate and cost a range of remedial options for reducing the volume of surface water recharge.

Investigational Work

A conceptual groundwater model was required to gain an understanding of the primary mechanisms of ingress into the basin. The following assessments were carried out to enable the development of a model:

Basin geology. The geology of the basin and its influence on recharge to the workings was considered.

Seasonality of ingress. Pumping rates do not necessarily correlate with inflows if the water levels underground are not constant and pumping rates vary depending on electricity costs, maintenance and other factors. Historical pumping, water level and rainfall data were obtained. The water level data were used to calculate storage volumes underground using a digital terrain model (dtm) of the reef within the East Rand Basin and shareholders plans of the mined out areas. An average stoping width of 2 m was applied to calculate the mined out volume, although stoping widths do vary significantly, and are often narrower.

Ingress volumes could then be calculated and the seasonality determined. The fluctuation of the calculated ingress in relation to rainfall is illustrated in Fig. 4.

Photo survey. An aerial survey of the catchment was conducted. The Blesbokspruit was also photographed over the length of the Petrex mining area to assess the current status in terms of historical problems identified by Barradas and Loggenberg (cited in Jones & Wagener, 2003) and the impact of other developments such as roads, tailings dams and tailings reclamation activities. The impact of road construction with related silting and ponding was evident from the aerial photographs, as illustrated in Fig. 2 and 3.

Delineation of areas of shallow undermining. Observations by mining personnel indicated that any mining shallower than approximately 300 m from surface is characterised by significantly increased groundwater inflows. These areas were therefore targeted as high risk areas requiring further investigation.

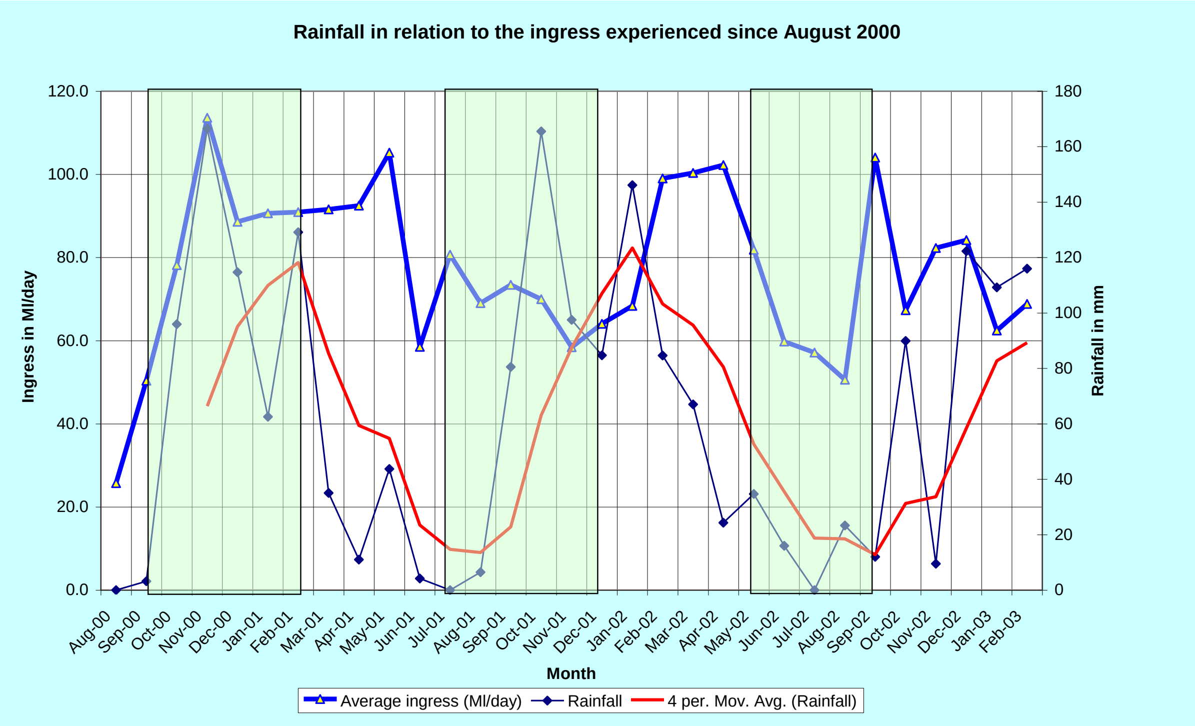

Figure 4. Relationship between rainfall and ingress volume.

Alluvium survey. A survey was undertaken along the Blesbokspruit to assess the depth of alluvial clays, using hand auguring and information from previous investigations. It was found that alluvial clays are present to depths of at least 1.5 m in most instances. In addition, there are extensive silt deposits of up to several metres depth at some culverts and bridges.

Flow measurements. Flow rates were measured underground at areas where inflows could be associated with shallow workings or a particular geological feature. Surface flow measurements were also undertaken upstream and downstream of areas of potential ingress, using in-stream hand held equipment. The surface measurements proved to be problematic given the low flow rates and the wide wetland areas, as well as ad-hoc pumping from and to the streams by industry in the area.

Isotope study. Measurement of nitrogen isotopes was used to assess whether a link exists between the industrial discharge (primarily treated sewage water, thus high in nitrates) and the underground recharge. Although the results are based on a single sampling run only, and are subject to validation by further testing, the study provided strong evidence of a link.

Conceptual Modelling

Ground water modelling usually implies analysis of groundwater flow volumes using two primary concepts, namely Darcy's Law (momentum balance) and conservation of mass. From these simple approaches, a host of mathematical computations can be undertaken to determine inflows or outflows within a particular environment for which the flow characteristics and extent are known.

Where this is not possible due to limited available data, or the complexity of the area, the problem can be simplified by considering broad areas or components for which a particular recharge or flow is either assumed or determined from analysis or interpretation of field data.

To a large degree, the second approach was followed in this study, based on the extent to which information was available to allow a meaningful assessment. As with any multi-parameter model, it is possible to simulate the observed ingress by assigning incorrect recharge rates to the various components. However, within the bounds of accepted or substantiated possible recharge values, the conceptual model provides an indication of the likely contributions and the extent to which mitigation measures may be successful in reducing the inflows.

Each area of ingress was assessed, and the components of the conceptual groundwater balance are summarised below.

Main Reef outcrop where mining has extended to surface. Where the Main Reef outcrops on surface, surface and shallow mining has caused subsidence along the outcrop area (Fig. 5 and 6). There are two main ingress mechanisms associated with this component of the water balance. The first is ingress via direct rainfall, and its contribution was calculated by taking average rainfall over an assumed 10 m wide zone along the exposed outcrop. The second mechanism is surface runoff, where surface outcrop areas intersect stream beds. The contribution of surface runoff was determined by estimating runoff volumes and measuring the catchment area of each exposed outcrop zone.

Figure 5. Old access shafts on outcrop

Figure 6. Stoping on Main Reef outcrop

Sub-outcrop where shallow undermining has taken place. The ingress to areas of mining shallower than 300 m was quantified using accessible areas where flows could be measured, and extrapolated to the remaining shallow areas.

Structural features. Structural features tend to be the main conduit for recharge from the overlying dolomitic aquifer. One fault in particular, referred to by mine personnel as the “rain forest” is situated below Cowles Dam (refer to Fig. 1). The flow along this fault has been measured and is estimated to potentially contribute as much as 10 Ml/day.

Recharge from the southern Blesbokspruit wetland area. Apart from one potential area of shallow undermining and the possibility of the Cowles Dam fault extending south into the Blesbokspruit wetlands, the risk of high surface water recharge in this area was considered low, given the depth of mining and the presence of Karoo geology overlying the dolomitic aquifer.

Overlying dolomitic aquifer. Experience has shown that the base of the dolomites is generally very impermeable and inflow to the mine workings from the dolomitic aquifer is restricted to geological features linking the two. The inflow from the dolomites is, however, significant and is expected to be relatively constant, particularly where karstification has been accelerated in the exposed areas of dolomite around the Blesbokspruit.

The inflow from this source was calculated by measuring the area of exposed dolomite and applying a recharge rate of 15% of mean annual precipitation. This is considered to be within an acceptable range, based on past experience and previous studies.

Flooded defunct coal mine. The Largo Mine is a defunct, flooded coal mine situated to the east of Grootvlei and adjacent to the Blesbokspruit. The area is characterised by surface subsidence. The extent to which this mine interacts with the dolomitic aquifer and influences the recharge to Grootvlei is the subject of further investigation.

Modelling results

The estimated recharge for each component is indicated in Table 1.

Table 1. Groundwater recharge components.

Recharge Component	----------Average flow rate (Ml/day)----------	
	Wet Season	Dry Season
Catchment recharge into outcrop	42.00	7.00
Direct recharge via outcrop	2.53	0.00
Shallow undermining	24.29	24.29
Preferential recharge (geological structures)	10.38	10.38
Recharge via dolomitic aquifer	29.34	29.34
Total	108.54	71.01

A sensitivity analysis was conducted to indicate the parameters having the greatest influence on the water balance. The analysis indicated that the model is most sensitive to the dolomite ingress, this being the dominant source of ingress. During the wet season, the model is also sensitive to the runoff volume and subsequent surface water influx through direct inflows via the outcrop into shallow mining areas.

The model indicated that the primary sources of surface water ingress are related to the outcrop and shallow undermining areas.

Further modelling work was commissioned by the Council for Geoscience (CGS), also to assess the surface water contribution to the ingress in the East Rand Basin. The work was carried out by Africa Geo-Environmental Services (AGES) and involved the compilation of a finite element model of the East Rand Basin, accounting for all possible sources of inflow to the underground workings. This work indicated that 65% (or 48 Ml/day) of the ingress to the East Rand Basin originates from surface water.

The modelling also calculated the ingress at West Pit (identified as an area of shallow undermining with high potential ingress, discussed later) to be in the order of 5,5 Ml/day, or 12% of the average ingress from surface water. Should remedial works prevent all ingress at West Pit, the overall dewatering rate could be reduced by approximately 7% (AGES, 2005).

Proposed remediation options

Based on the outcome of the modelling, it was decided to focus the initial remediation measures on the outcrop areas and the areas of shallow undermining.

In the dry outcrop areas, situated to the north (refer to Fig. 7), the extent of faulting makes it difficult to plug the holings. However, much of this area is currently being re-mined opencast, and will be rehabilitated as part of the mining process. Rehabilitation of the remaining areas will be considered once mining has ceased.

There are a number of areas of shallow undermining, most notably adjacent to Grootvlei's West Pit, an opencast pit adjacent to the stream (Fig. 2 and 7). The flow in the stream constitutes largely surface runoff, with the industrial flows amounting to some 22 Ml/day. Underground mining in this area is extremely shallow, being only 7 m below surface in places. Significant underground seepage is experienced in this area, estimated to be up to 10 Ml/day.

A large quantity of silt (mostly in the form of gold tailings) has been deposited upstream of the road culvert, and appears to cover most of the footprint of the wetland. It is considered important to improve the drainage in this area to minimise the extent of ponded water, as simply diverting the industrial flows around the area is not expected to significantly reduce the ponding.

The strategy proposed for this area is to divert low flows around the wetland and to improve the drainage by opening up the downstream road and railway culverts, allowing the area to dry. This would be followed by removal of the tailings, and revegetation of the area.

Further areas of shallow undermining have been indicated in the south eastern parts of the East Rand Basin, where the Blesbokspruit forms a wide wetland area. However, these areas have not been noted by mine personnel as areas of significant recharge, and have still to be investigated further.

The rehabilitation of the West Pit area was therefore selected as the first phase of the remedial works.

Remediation at West Pit

The shallow mining adjacent to West Pit is covered by a wide wetland area that has been created by a combination of environmentally poor road and railway construction, flat slopes and tailings washing from old tailings dams into the stream.

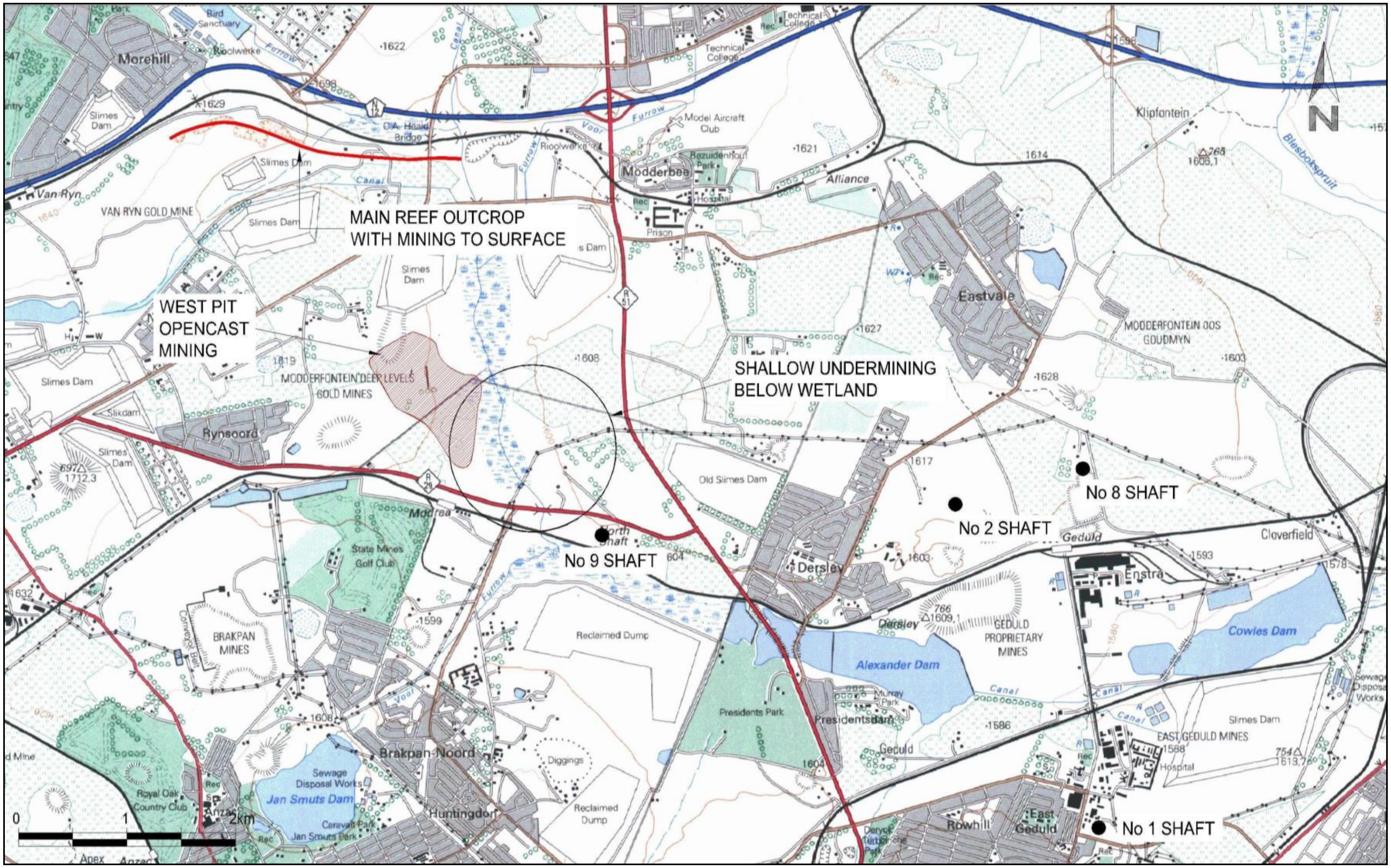

Figure 7. Location of Main Reef outcrop and West Pit

Scope of work

At the time of writing, construction was underway on the remedial works adjacent to West Pit. The works involve the following (refer to Fig. 8):

- Construction of a weir across the wetland to direct the industrial flows and runoff up to the 1:5 year event into a low flow canal around the western side of the wetland.
- The low flow canal will be separated from the floodplain area by a berm, and will direct these flows under the roadway via a new culvert.
- The existing culvert will be opened up and the original stream will be reinstated, while the area of ponding will be allowed to dry out.
- Once the area has drained, the exposed tailings will be removed.
- The area will then be revegetated and maintained to prevent the growth of large stands of reeds.
- Over the area with the highest risk of ingress, the length of low flow canal will be lined with concrete to minimise seepage.

The end result is expected to be an open, grassed area which is only inundated during extreme events, with the low flows restricted to a dedicated canal, where the width over which possible ingress can occur is significantly reduced. The expected cost of the work is US$ 1.55 million (2005).

Challenges encountered

Difficult working conditions on site have presented both the consultant and the contractor with a number of challenges since construction began.

Access to waterlogged areas. Very soft ground conditions have made access to the waterlogged areas difficult. In order to gain access it is necessary to construct rockfill platforms into the wetland area. A woven geotextile has been used as a support layer beneath the rockfill material. This measure has proved highly successful, with minimal loss of material.

Depth of tailings. Initially, the depth of the tailings in the area was determined by hand augering, and estimated to be up to 1,5 m thick. During construction the tailings thickness was found to be significantly greater, causing concerns about invert levels, and the ability to effectively drain the area, given the extremely flat longitudinal slope on this portion of the stream.

Flat slopes. The flat longitudinal slope (in the region of 1:1000) has resulted in large scale silting, not only in the area of concern, but also downstream of the road and railway. It was therefore necessary to excavate a canal downstream of the area to provide a direct drainage route to the main watercourse, thus facilitating drainage of the West Pit area. The entire downstream canal is located within a wetland area, with soft, wet conditions underfoot, requiring the construction of a rockfill access road on woven geotextile.

The flat slopes mean that this canal will always be prone to silting, and maintenance will be required to keep it open and to prevent excessive reed growth.

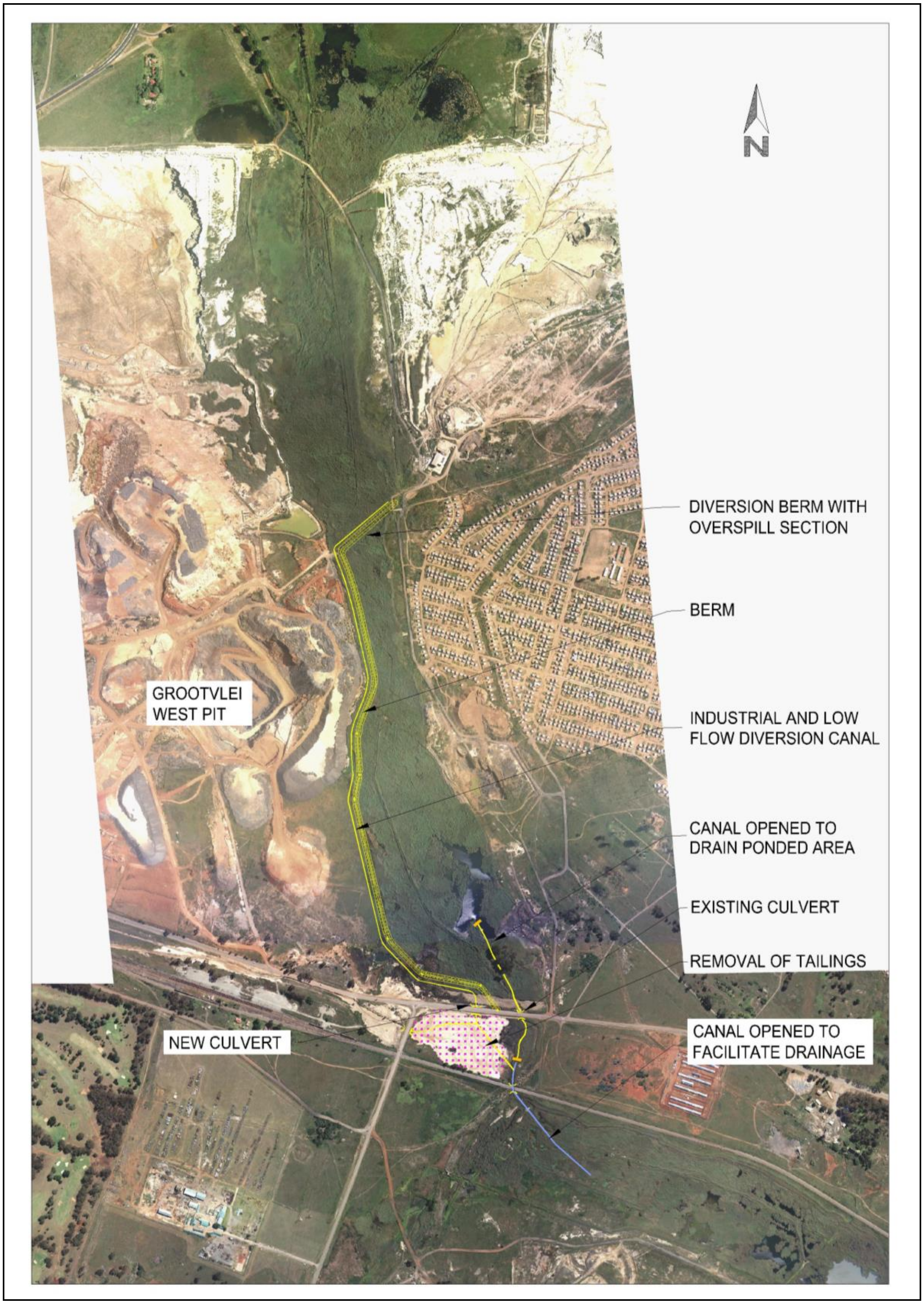

Figure 8. Remedial works at West Pit

Conclusions

From the investigations it was concluded that a significant portion (up to 65%) of the ingress to the East Rand Basin originates from surface water. The majority of this water appears to originate from ingress at the open holings and subsidence areas at the Main Reef outcrop, as well as from areas of shallow undermining.

The current rehabilitation will only address one area of shallow undermining. Modelling has shown that this could reduce the required pumping rate by up to 7%. This will be evaluated once the rehabilitation work is completed.

While the works will improve the flow past West Pit, the reduction in ponding is also partially dependent on the downstream areas being able to drain effectively. Regular maintenance on the downstream canal will be required to keep it clear and maintain the flow.

Further investigation is required at all the remaining identified areas to confirm both the ingress volumes and the mechanisms of ingress.

References

Africa Geo-Environmental Services (Pty) Ltd 2005. Conceptual groundwater flow model of the Far East Rand Basin – Grootvlei sub-catchment. Phase 1. AGES Technical Report No. AS/R/05/01/24. Prepared for Council for Geoscience and Ferret Mining (Pty) Ltd.

Barradas & Loggenberg 1996. Investigation of Surface Water Ingress to the East Rand Basin.

Jones & Wagener (Pty) Ltd 2003. Grootvlei Proprietary Mines (Pty) Ltd, a subsidiary of Petrex (Pty) Ltd: Feasibility study on the reduction of surface water inflows to the underground workings. Jones & Wagener Report No. JW101/03/8894.

Petmin 2000. Strategic Water Management Plan – Integration with the Entire Basin.

Scott 1995. Flooding of Central and East Rand Gold Mines. An Investigation into Controls over the Inflow Rate, Water Quality and Predicted Impacts of Flooded Mines. WRC Report No. 486/1/95.

Wates, Meiring & Barnard 2002. Integrated Water Management Plan, Geohydrological Investigation. Prepared for Sappi Enstra.