APPENDIX D1: Detailed Design Report
DESIGN OF THREE CHANNELS IN THE WITWATERSRAND MINING BASIN

DETAIL DESIGN REPORT

REPORT NO. 12792-Rep-003-Detail Des Rep Rev A

Submitted to:

COUNCIL FOR GEOSCIENCE
Silverton
Pretoria
0184

JANUARY 2014
EXECUTIVE SUMMARY

The Department of Mineral Resources (through the Council for Geoscience) intends implementing measures for the prevention of water ingress into mined out areas in the Witwatersrand Goldfields. Three channels have been identified previously, within natural watercourses, for lining along streams traversing shallow undermined areas in the Witwatersrand Goldfields.

The channels identified under this project are:

- Durban Roodepoort Deep (DRD) West Rand 2,400 metre section
- New Canada Dam (NCD) Central 600 metre section
- Elburgsrpuit (ELB) East Rand 590 metre section

The Design Development and Documentation and Procurement Phases are now complete. This report documents what has been undertaken during the Design Development and Documentation and Procurement Phases. Previously, the Preliminary Design Report captured what was done during the Concept and Viability Phase of the project.

The 1 in 5 year storm events that had been determined during the Concept and Viability Phase were verified using a different method as a precursor to the Design Development Phase.

The geometry of each channel was designed and the stormwater flow hydraulics were modelled on computer. The range of hydraulic roughnesses of gabions and Reno mattresses were researched for the clean and vegetated conditions and modelled for all scenarios.

The shear forces acting on the gabions and stone mattresses were calculated. The stability of gabions and stone mattresses was checked for different longitudinal slopes and channel dimensions.

The upgrades of the culverts under two provincial roads were designed and modelled on computer. The structural integrity of the new culvert bridges was checked. Steel reinforcing was designed for all concrete members. Contact was made with the Gauteng Department of Transport, Roads and Works, municipalities and other role players to obtain their authorisation to upgrade the culverts.

Layouts, longitudinal sections and details of the channels, culvert upgrades and ancillary works were produced.

Quantities were calculated and a Bill of Quantities was prepared for each channel. Previous cost estimates were updated. One tender document, including all procurement documentations was prepared for each of the three channels.

It is recommended that environmental authorisations be obtained from the Department of Water Affairs and Environmental Affairs to implement some or all of the channels.
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1 INTRODUCTION

The Department of Mineral Resources (through the Council for Geoscience) intends implementing measures for the prevention of water ingress into mined out areas in the Witwatersrand Goldfields. Three channels have been identified, within natural watercourses, for lining along and across streams traversing shallow undermined areas in the Witwatersrand Goldfields.

Zitholele Consulting was appointed to provide professional engineering services to the Council for Geoscience (CGS) to undertake the design of the lining of these channels in order to render them significantly impermeable to water ingress.

The channels identified under this project are:

- Durban Roodepoort Deep (DRD) West Rand 2,400 metre section
- New Canada Dam (NCD) Central 600 metre section
- Elburgsrpuit (ELB) East Rand 590 metre section

2 PROJECT LOCALITY

Three sites were chosen by the CGS within the Witwatersrand mining basin as part of this project and are shown on Figure 1. Each of the specific sites is shown in more detail in Figure 2 to Figure 4.

3 PROJECT MOTIVATION AND OBJECTIVE

Ingress of surface water into underground mines, and the subsequent decant of the impacted water, is a major concern in the Witwatersrand mining basin. The objective of this project is to alleviate the ingress of surface water into underground mines in identified areas, by lining the channels to render them significantly impermeable.
Figure 1: Study Area within the Witwatersrand Basin
Figure 2: Site Locality of DRD Channel
Figure 3: Site Locality of New Canada Dam Channel
Figure 4: Site Locality of Elburgspruit Channel
4 PROJECT STAGES

The following stages typically make up the project life cycle.

The Concept and Viability stage is complete and was captured in the Preliminary Design Report. The Preliminary Design Report was approved by CGS before commencing with the Design Development Phase. This report documents what has been undertaken during the Design Development and Documentation and Procurement Phases.

5 COMPLETED PHASES

5.1 Inception

A topographical survey and geotechnical investigation was done. The areas of water ingress was confirmed by undertaking a desktop study as well as site measurements. The Inception Phase was described in detail in the Project Implementation Report.

5.2 Concept and Viability (Preliminary Design)

The 1 in 2 year and 1 in 5 year flood events were determined for each channel. A preliminary design of the channel geometry was done. The channel liner layers were designed. The advantages and disadvantages of Reno mattresses and concrete liners were compared. Entrance and exit concrete headwalls were designed. Safety, access and maintenance aspects of the channel designs were considered.

Environmental and Health and Safety legislative requirements for the project were considered.

Preliminary cost estimates were prepared and the following recommendations were made:

- That reno mattresses be specified as the top liner layer of the canals which would allow vegetation growth in the channels
- That the design should accommodate the 1 in 5 year flood instead of the 1 in 2 year flood, because the estimated cost is only marginally higher for the 1 in 5 year flood event

The Concept and Viability Phase was captured in detail in the Preliminary Design Report.
6 DESIGN DEVELOPMENT PHASE (DETAIL DESIGN)

6.1 Hydrology

The hydrology of the three sites were modelled during the preliminary design using *Hydrosim (Version 5.2)*. The resulting flood peaks for 2 year and 5 year recurrence intervals are presented in the table below:

**Table 1: Flood Peaks for 1 in 2 and 1 in 5 year recurrence intervals**

<table>
<thead>
<tr>
<th>Channel</th>
<th>1 in 2 Year Flood Peak (m³/s)</th>
<th>1 in 5 Year Flood Peak (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRD</td>
<td>94</td>
<td>144</td>
</tr>
<tr>
<td>NCD</td>
<td>81</td>
<td>120</td>
</tr>
<tr>
<td>ELB</td>
<td>81</td>
<td>118</td>
</tr>
</tbody>
</table>

These values were verified using a less complex method, namely the *Rational Method* for quality purposes. The *Hydrosim* model is however a more detailed approach which produces more accurate results. The results of the two methods are compared in the table below:

**Table 2: Comparison of Calculated Flood Peaks**

<table>
<thead>
<tr>
<th>Channel</th>
<th><em>Hydrosim</em> 1 in 5 Year Flood Peak (m³/s)</th>
<th><em>Rational Method</em> 1 in 5 Year Flood Peak (m³/s)</th>
<th>Percentage Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRD</td>
<td>144</td>
<td>146</td>
<td>+1.2%</td>
</tr>
<tr>
<td>NCD</td>
<td>120</td>
<td>129</td>
<td>+7.8%</td>
</tr>
<tr>
<td>ELB</td>
<td>118</td>
<td>103</td>
<td>-13.0%</td>
</tr>
</tbody>
</table>

The results are within the same order of magnitude and the *Hydrosim* results were therefore accepted.

6.2 Hydraulic Design

6.2.1 Hydraulic Roughness (Manning n Value)

The surface roughness of a channel or a pipeline has a major influence on the friction between the flowing water and the conduit surface. The rougher the surface is, the higher the friction. In the Manning equation, which is extensively used for the design of channels, the roughness is presented by the value of *n*:

\[
\frac{hf}{v^2} = 
\]

Where

- \( hf \) = friction energy loss (m)
- \( n \) = Manning n value
- \( v \) = Flow velocity (m/s)
- \( L \) = Length (m)
- \( R \) = Hydraulic radius (m) = A/P

Where

- \( A \) = Cross sectional flow area (m²)
- \( P \) = Wetted perimeter length (m)
Immediately after completion the stone surfaces of the gabions and mattresses will be bare, after which grass and vegetation will start growing. This would increase the hydraulic roughness of the channels. Figure 4.8 to Figure 4.10 in the South African Roads Drainage Manual was used to predict the range of n values for the gabion and stone mattress channels over a time period and is presented in the table below:

<table>
<thead>
<tr>
<th>Description</th>
<th>Manning n Value ( )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed gabions and stone mattresses without vegetation – minimum of range</td>
<td>n = 0.025</td>
</tr>
<tr>
<td>Channel vegetated with grass – maximum of range</td>
<td>n = 0.030</td>
</tr>
</tbody>
</table>

### 6.2.2 Hydraulic Design Method

#### Geometry

The natural longitudinal and cross sections of each channel, from the topographical survey, were imported into the software Hec-Ras. Standard geometric cross sections were designed for each channel as indicated in the figure below:

The side slopes were set at a value of 1 in 2 to, for slope stability in accordance with geotechnical principles.

**Figure 5: Typical Channel Geometric Cross Section**

The channels were designed to follow the centre line of the natural stream. The longitudinal slope of the channels were designed to approximately follow the natural slope in order to minimize earthworks excavation and fill volumes.

#### Culverts under Provincial Roads

The geometry and dimensions of the existing culverts under the R41 Randfontein Road in Roodepoort and the R29 Main Reef Road in Germiston were entered into the respective models. The existing culverts under the provincial roads had to be widened in the model to accommodate the 1 in 5 year peak floods.
Computer modelling

*Hec-Ras* calculates the backwater model (which includes water flow depth, the energy grade line, the flow velocities and the energy losses due to friction in the channels) at the given peak flow rates. Some of the most important outputs from the hydraulic computer models are:

- The water depth: This would indicate how deep the final lined channels must be and
- Whether super-critical or sub-critical flow is experienced: super-critical flow is unwanted due to high shear stresses (erosion, liner damage) and high variability in water depth (waves may be experienced on the water surface)

The computer analyses were processed for different scenarios, namely:

- Variations in hydraulic roughness (Manning n value): The roughness of the channels will increase over time as vegetation grows
- Variations in peak flow rate: This was done to check whether higher peak flows than 1 in 5 years (say 1 in 50 years) will damage the channel

Finally optimisation was done of the channel dimensions (bottom width and depth), to minimise the cost.

Shear stresses

The cross sections and the longitudinal slopes from the hydraulic model was entered into the software *Macra1* as provided by the gabion supplier *Maccaferri* to check the shear stresses between the water and the gabions or *Reno* mattresses. The possibility of erosion underneath the gabions or *Reno* mattresses was also checked. (High shear stresses transport and displaces the stones inside a gabion or *Reno* mattress as shown in the figure below):

![Diagram of shear stresses](image)

Figure 6: The Displacement of stones inside gabions and *Reno* mattress under high shear.

If shear stresses were found to be unacceptably high, then the longitudinal slope of the channel was decreased, which decreases the flow velocity (m/s) and the shear stress. A reduction in longitudinal slope however also increases the
water depth, which increases the overall depth of a channel and therefore also increases the cost. This can unfortunately not be avoided, as the surface liner must be stable.

6.2.3 Results

Culverts

The culvert under the R41 Randfontein Road in Roodepoort was found to be grossly undersized for a 1 in 5 year flood. The DRD channel crosses under this road. The existing culvert is approximately 7m wide and 2m high, which gives a cross sectional flow area of 14m². It was found that a culvert with a minimum cross sectional area of 50m² will be sufficient for the 1 in 5 year flood, which has a magnitude of approximately 144m³/s. The effective open width of this culvert (disregarding precast culvert “legs”) will be 18.3m and the effective height will be 2.7m. The upgraded culvert was modelled on computer and found to be sufficient.

A cross section and a longitudinal section of the hydraulic analysis of the DRD culvert are presented below:
The culvert under the R29 Main Reef Road in Germiston was also found to be grossly undersized for a 1 in 5 year flood. The ELB channel crosses under this road. The existing culvert is a circular concrete culvert with a diameter of 1m, which gives a cross sectional flow area of 0.8m$^2$. It was found that a culvert with a minimum cross sectional area of 44m$^2$ will be sufficient for the 1 in 5 year flood, which has a magnitude of approximately 118m$^3$/s. The effective width of this culvert (disregarding precast culvert “legs”) will be 18.3m and the effective height will be 2.4m. The upgraded culvert was modelled on computer and found to be sufficient.

Figure 8: Hydraulic Analysis Longitudinal Section through DRD Channel
A cross section and a longitudinal section of the hydraulic analysis of the ELB culvert are presented below:

Shear Stresses

It was found that the DRD channel must be limited to a longitudinal slope of 1.2% maximum (1.2m vertical drop over a length of 100m). At steeper slopes than 1.2% the velocities and the shear stresses are too high and the Reno mattresses will be damaged.
The longitudinal slope of the newly lined channel must however tie in with the existing slope of the stream, which in places was up to 1.5%. It was therefore necessary to put downward steps in the channel while limiting the longitudinal downward slope of the channel to 1.2% maximum.

This is also shown in the figure below:

Figure 11: Longitudinal Channel Slope and Steps

High velocities and high shear stresses are however expected where the water drops over the channel steps. The channel will therefore be lined with concrete immediately before and immediately after the channel steps. This is shown in the figure below:

Figure 13: Details of step in Channel Bottom
The maximum allowable longitudinal slopes, as governed by the maximum allowable shear stress is presented in the table below:

**Table 3: Maximum Allowable Longitudinal Slopes**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Maximum Longitudinal Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRD Channel</td>
<td>1.2% (1.2m in 100m)</td>
</tr>
<tr>
<td>ELB Channel</td>
<td>1.3% (1.3m in 100m)</td>
</tr>
<tr>
<td>NCD Channel</td>
<td>1.3% (1.3m in 100m)</td>
</tr>
</tbody>
</table>

Computer Modelling

Roughness

It was found that an increase in hydraulic roughness increases the water flow depth and decreases the flow velocity. The higher roughness value is therefore the more critical value, which would lead to the design of a deeper channel. The resulting flow depths are presented in the table below:

**Table 4: Flow Depths for Varying Values of Manning n Roughness**

<table>
<thead>
<tr>
<th>Manning n Value ( )</th>
<th>Water Flow Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.025</td>
<td>2.0*</td>
</tr>
<tr>
<td>0.030</td>
<td>2.2*</td>
</tr>
</tbody>
</table>

* Based on a longitudinal slope of 0.8%, a bottom width of 11m and side slopes of 1 in 2

All channels were therefore analysed for a roughness of 0.030, which is the more critical value.

Critical flow depth

The critical flow depth is the depth at which the water has the minimum specific energy, which is sum of the flow depth and the velocity energy. Any flow depth deeper than the critical flow depth is classified as sub-critical flow and shallower than the critical flow depth is supercritical flow. The equation for specific energy is given below:

\[
E = y + \frac{v^2}{2g}
\]

Where

- \( E \) = specific energy (m)
- \( y \) = flow depth (m)
- \( v \) = average velocity (m/s)
- \( g \) = gravitational acceleration (m/s\(^2\)), a constant

Critical flow occurs when \( E \) has a minimum value. The relationship between \( E \) and \( y \) is presented in the figure below:
Supercritical flow occurs when the kinematic energy of the water is relatively high while the flow depth is relatively low. Supercritical flow is unwanted due to the following reasons:

- High velocities may damage the reno mattresses
- The flow depth is unstable and unpredictable and waves may form on the surface. This may lead to overtopping of the channel walls.

The critical flow depth was calculated for each channel and is presented in the table below:

**Table 5: Calculated Critical Flow Depths**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Critical Flow Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRD Channel</td>
<td>2.25</td>
</tr>
<tr>
<td>ELB Channel</td>
<td>2.00</td>
</tr>
<tr>
<td>NCD Channel</td>
<td>2.00</td>
</tr>
</tbody>
</table>

The channels were therefore designed to have normal flow depths that are higher than the critical flow depths indicated in the table above to ensure that the flow is sub-critical.
Greater Flood Events

Larger flood events, namely the 1 in 50 year flood events were modelled to check whether it would damage the channel liners. It was found that although the overall flow depth was much deeper than the channel depth (and that the channel walls will be overtopped), that no damage was expected to the gabions or Reno mattresses due to high shear stresses.

6.3 Technical Challenges Associated with the NCD Channel

The NCD channel is located in a relatively wide wetland with very little fall in the downstream direction. The longitudinal fall was found to be approximately 0.09% (or less than 1m vertical drop over a distance of 1000m). The lined channel must tie in with the natural stream level where it starts and where it stops. The designer is bound to these entry and exit levels and no simple method exists to avoid these limitations. The result of this limitation (small downward slope) is that the channel must have a base width of 21m wide to keep the overall depth of the channel to below 2.13m deep.

A second problem is that the portions next to the new channel must be backfilled to ensure that surface water will flow in the new channel and not next to the new channel. The wetland is a very wide and relatively flat area. This backfill volume next to the channel is relatively large (in the order of 110 000 m³). This is also shown in the figure below:

![Figure 14: Backfill required next to the NCD Channel in the Wetland Area](image)

The backfill material will have to be imported from a registered borrow pit or quarry, which would be relatively expensive.

A third issue is that the wetland is a difficult area to work in, because of the wet conditions.

It is not impossible to construct the new lined NCD Channel, but it will be relatively expensive.

6.4 Structural Design

6.4.1 Culvert Bridges

Structural inputs were required to design the foundation, the surface slab and the wing walls of the 2 new culvert bridges.
The maximum permissible mass of vehicles and wheel loads were obtained from Regulations 240 of the Road Traffic Act (1996), as published by SANRAL. In terms of this regulation the maximum permissible mass load of a two axle unit, with four wheels fitted per axle is 20 400 kg on a refuse removal vehicle or a breakdown vehicle and 18 000 kg on any other vehicles. The minimum spacing between such two axles (which gives the highest loading) is 1.37m centre to centre.

A side elevation of the reinforced concrete roadway on top of the precast concrete culverts is presented in the figure below:

![Side Elevation of the Reinforced Concrete Roadway on top of the Precast Concrete Culverts](image)

Figure 15: Side Elevation of the Reinforced Concrete Roadway on top of the Precast Concrete Culverts

The maximum moments and shear forces were determined for the reinforced concrete roadway and are presented in the table below:

<table>
<thead>
<tr>
<th>Description</th>
<th>Maximum Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Negative Moment</td>
<td>-99kNm/m width</td>
</tr>
<tr>
<td>Maximum Positive Moment</td>
<td>+137.8kNm/m width</td>
</tr>
<tr>
<td>Maximum Shear Force</td>
<td>167kN/m width</td>
</tr>
</tbody>
</table>

A minimum overall depth of 255mm was selected for the concrete slab and a minimum cover to main reinforcement of 50mm.

The maximum acceptable load on the precast concrete culverts was checked and found to be acceptable.
6.5 Tender drawings

The following drawings were prepared for each channel:

- A locality plan showing where the site is with a 1 in 50 000 map as a backdrop
- A general layout and typical details. This includes the an overall general layout of each channel as well as typical sections through the channel
- Plans of the channels and longitudinal sections. The exact layout coordinates and longitudinal sections are shown.
- Sections and details of new culverts
- Temporary road detours around new culverts
- Layouts, sections and details of pedestrian bridges across the channels
- Fencing and gate layout drawing

The following standard details were prepared:

- Fencing and Pedestrian Gate: Layout, sections and details
- Sliding Gate Details: Layout, sections and details
- Fencing and Gate: Layout, sections and details
- Steel Palisade Fencing Bridges: Layout, sections and details

6.6 Tender Document

A draft tender document was compiled and submitted to the Council for Geosciences on 21 October 2014. The Council for Geosciences reviewed the document and submitted their comments.

Two of the changes required to the tender documents were:

- The tender document had to be split into three documents for the three separate channels
- The evaluation of the functionality and quality of tenderers had to be clarified

The changes were completed on 8 January 2014.

The tender documents were based on the following:

- *SABS 1200: Standardised Specification for Civil Engineering Construction*
- *General Conditions of Contract (2010)*

The tender dates, tender box location and the Contract Numbers must still be finalised.

6.7 Wayleave Applications

In order to upgrade the two culverts under the R41 Randfontein Road in Roodepoort and the R29 Main Reef Road in Germiston permissions must be obtained from the following organisations. This is to ensure that existing infrastructure is not damaged and for the integration of the services along the different servitudes:

- Gauteng Roads (GauTrans)
- Ekurhuleni Municipality
- Telkom
Initial contact was made and drawings were forwarded to all these organisations. A meeting was held with Ekurhuleni Municipality and drawings of the proposed upgrade to the culvert under the R29 Main Reef Road in Germiston were presented to the roads engineer and the wayleave coordinator. The Ekurhuleni Municipality were positive about the proposed upgrades, but no formal approval has been obtained as yet.

More interaction with these organisations is required to finalise all approvals. These wayleaves were not part of Zitholele’s original Scope of Work and should be advanced by the Council for Geoscience.

7 ENVIRONMENTAL AUTHORISATIONS
Three Basic Assessment Reports were compiled and submitted to CGS for review.

The reviewed Basic Assessment Reports were released for public and authority review.

The review period ends on 11 March 2014 after which the reports will be submitted to DEA for authorisation.

Environmental authorisations are required for the culverts, which were not part of the original scope.

8 UPDATED COST ESTIMATE
Rates were estimated for all the payment items listed in the three bills of quantities of the three channels to obtain an updated cost estimate. The updated cost estimate totals are presented in the table below. These totals include a 10% allowance for contingencies:

Table 6: Estimated Construction Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>Estimated Construction Cost*</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRD Channel</td>
<td>R 90 040 000.00</td>
</tr>
<tr>
<td>ELB Channel</td>
<td>R 30 120 000.00</td>
</tr>
<tr>
<td>NCD Channel</td>
<td>R 56 300 000.00</td>
</tr>
</tbody>
</table>

*Amounts include P&G and 10% Contingency, but exclude VAT

The cost estimates above are for construction only and exclude professional engineering, environmental or health and safety agent fees.

The priced bills of quantities are submitted with the tender documents in electronic format.
9 RECOMMENDATIONS AND CONCLUDING REMARKS

Environmental and Department of Water Affairs authorisations must be finalised before the channels can go out for procurement.

D Jansen van Rensburg PrEng
for Zitholele Consulting (Pty) Ltd

N Rajasakran PrEng

ZITHOLELE CONSULTING